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UNIVERSIDAD PONTIFICIA

ICAI
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Trabajo de Fin de Grado
Modelling the natural gas market

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MODELLING THE NATURAL GAS MARKET

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EXECUTIVE SUMMARY

1. INTRODUCTION

Natural gas is a fossil energy fuel formed deep beneath the surface millions to hundreds of millions of years ago from the remains of plants and animals that built up in thick layers on the earth's surface and ocean floors [1]. This fossil fuel has become an essential source of energy in today's world. It is used principally to generate electricity, for heating, for transportation, and for industrial production.

Although natural gas is not renewable, and, according to Worldometers, only 52 years of natural gas reserves are left to extract [17], it has become an essential energy fossil fuel due to its cleaner burning capacities and a more even distribution of reserves across the globe. It constitutes a chance for many countries to become more energy independent and to produce energy in a cleaner way than with other fossil fuels such as petroleum and carbon, until the technology to generate all the energy the world consumes from renewable sources is sufficiently developed. Therefore, it is important to understand how the market for this commodity works.

Demand for this commodity is increasing due to its price-calorific value ratio. According to the U.S. Energy Information Association (EIA), the United

States used about 31.5 quadrillion British thermal units (Btu) in 2020 which makes 34% of U.S. total energy consumption [26].

During the spring of 2022, many events surrounding the Russia-Ukraine conflict and some other incidents caused the natural gas price to rocket, increasing by 157% in March 2022 compared to the price before the outburst of the conflict.

The main objectives of this study are to determine which factors affect the demand and supply of natural gas, and therefore the price of natural gas, and to model the market of this commodity as a function of these factors.

2. METHODOLOGY

In order to achieve the objectives described above, a thorough research is first carried out to gather all the information about natural gas needed to develop the model. Official sources, such as the websites of the U.S. Energy Information Administration (EIA) or the World Bank, and official reports were used throughout this study to collect all this information.

Once all this information is studied, the factors that affect most the supply and demand levels of natural gas, and therefore to its price, are selected and transformed to use it in the model in the form of indicators. Eight variables are selected: natural gas production (U.S. Gross Withdrawals), inventory levels (U.S. Storage Volume), drilling activity (U.S. Rotary Rigs in Operation), price (Henry Hub), world industrial production (OECD Index), monetary policy (Wu-Xia shadow rate), and residential heating and cooling demand (REDTI).

A model to simulate what would happen to this price in the case of a variation in each of these eight variables described above is needed. The model used in this study is a Vector Autoregressive model (VAR), in particular, the approach of the dynamic model of the global oil market proposed by Alquist et al. (2013) and Baumeister and Kilian (2012) [55]. Their analysis is based on the following reduced-form vector autoregression (VAR),

$$y_t = c + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + u_t$$

where, applied to our study, y_t is a vector of 8x1 monthly data, c is a 8x1 vector of intercepts, ϕ_i, i=1,...p, are 8x8 coefficient matrices with p indicating the number of lags (twelve in this case), and u_t are white-noise innovations. The variable y_t in our model is the price of natural gas, and the eight variables are the ones mentioned above.

The model was constructed using MATLAB. Firstly, a 384x8 matrix was built, containing the percent changes with some corrections of all eight variables. With this matrix, we estimated the VAR model using the functions in MATLAB *varm* and *estimate* (see Annex I: MATLAB Code). This way, we created the VAR model described above in MATLAB.

Once we have the model constructed, the goal is to determine the dynamic response of natural gas prices to a one-standard-deviation shock to each of our eight variables in our VAR model. For this matter, we use the *irf* function in MATLAB (see Annex I: MATLAB Code). This function returns the dynamic response of each of the eight variables when a one-standard-deviation shock occurs in all eight variables, from where the response of the price of natural gas when a shock or sudden rise occurs in each of the eight variables, is extracted.

Finally, a historical decomposition is performed for the price of natural gas to determine the contribution of each of the eight shocks to the deviation of the price of natural gas throughout history (1991-2020).

3. RESULTS AND CONCLUSIONS

After analyzing the effects on the price of natural gas of a shock of each of the eight variables using this VAR model, it was observed that the variables that decrease natural gas prices are an increase in its production and inventory levels. The ones that can determine the increase in natural gas prices are the increase in residential cooling and heating demand, a higher demand for electricity, and, to a lesser extent, an increased industrial activity.

The monetary policy did not seem to have a great impact on the price of natural gas in this first analysis. Regarding the drilling activity, a sudden growth of this variable does not have nor an immediate nor a as significant impact on natural gas prices and this impact does not last very long in time. As expected, a shock in the variable "natural gas price" has a very significant and immediate impact on itself (see *Figure 1* below).

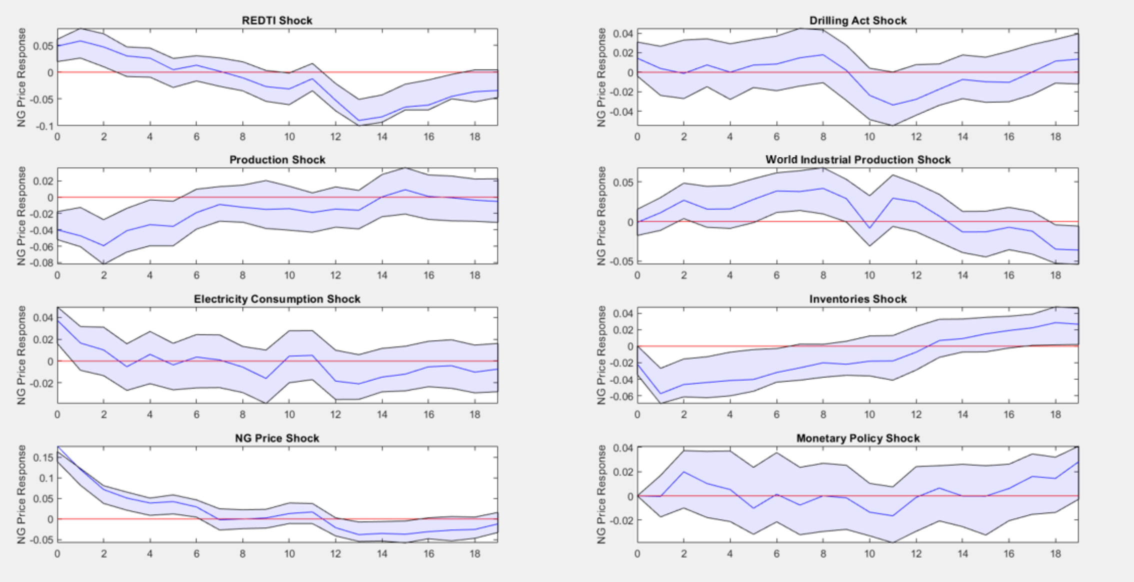

Figure 1. Results of the model. Source: own elaboration

The historical decomposition showed that the indicator REDTI, which represents the residential demand due to changes in temperature, is the variable that seems to have been the most determinant throughout history to explain the fluctuations of the price of natural gas. Industrial demand, on the other hand, was not as important as the residential demand, accounts for most of the demand for natural gas in the U.S.

Production levels were only relevant when there were supply bottlenecks throughout history, as well as the inventories held, which increased before supply shortages and decreased after those events, causing fluctuations in the price of natural gas.

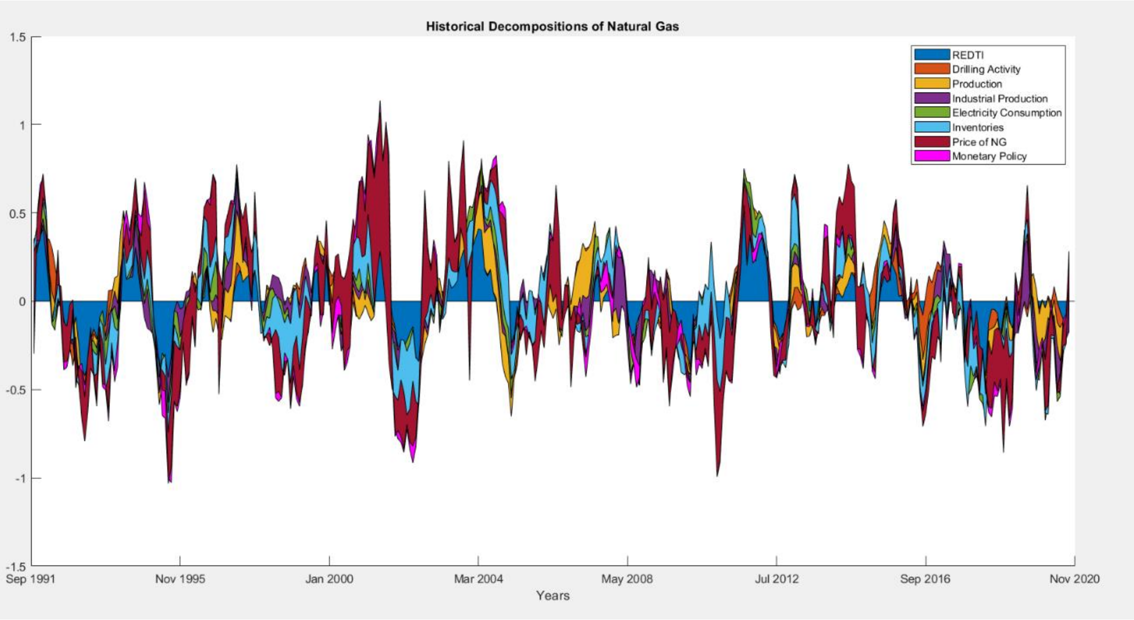

Figure 2. Historical decomposition of price of natural gas 1991-2020. *Source: own elaboration.*

During periods of financial instability, the model could not explain the speculation in the markets, which is reflected by the fact that during those periods the variable “price of natural gas” plays a more important role in the model. Neither the changes in monetary policy nor in the amount of drilling activity explained much of the fluctuations in the price of natural gas throughout the years studied.

Surprisingly, the variable “electricity consumption” was not very significant in determining natural gas price changes throughout history, according to the results of the historical decomposition. In the U.S.A., natural gas accounts for 38% of the electricity generated, while in Europe only 18% of the electricity is generated with this fossil fuel [64]. Therefore, it would have been expected that, since the data used in the model is the electricity consumed in the U.S, this variable would be more significant than it is.

Results for both analyses, the individual analysis of each of the eight shocks and how they affect the price of natural gas, and the historical decomposition analysis, agree on the most relevant variables that explain gas price movements, the residential demand due to temperature changes, the production, and the inventory levels. The only exception is the variable “electricity consumption”, which does not seem as significant when the historical decomposition is performed as it seems with the analysis of the impulse response function of a shock of this variable.

MODELO DEL MERCADO DEL GAS NATURAL

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RESUMEN DEL PROYECTO

1. INTRODUCCIÓN

El gas natural es un combustible energético fósil que se formó en las profundidades de la superficie hace millones o cientos de millones de años a partir de los restos de plantas y animales que se acumularon en gruesas capas en la superficie de la tierra y en los fondos oceánicos [1]. Este combustible fósil se ha convertido en un medio esencial de obtención de energía en nuestro mundo actual. Se utiliza principalmente para generar electricidad, para la calefacción, para el transporte y para la producción industrial.

Aunque el gas natural no es renovable y, según Worldometers, sólo quedan 52 años de reservas de gas natural por extraer [17], se ha convertido en un combustible fósil esencial debido a su capacidad de combustión más limpia y a una distribución más uniforme de las reservas por todo el mundo. El gas es una oportunidad para que muchos países sean más independientes energéticamente y produzcan energía de forma más limpia que con otros combustibles fósiles como el petróleo o el carbón, hasta que la tecnología para generar toda la energía que consumimos a partir de fuentes renovables esté suficientemente desarrollada. Por ello, es importante entender cómo funciona el mercado de esta materia prima.

La demanda de esta materia prima está aumentando debido a su relación precio-valor calorífico. Según la Asociación de Información Energética de Estados

Unidos (EIA), este país utilizó unos 31,5 cuatrillones de unidades térmicas británicas (Btu) en 2020, lo que supone el 34% del consumo total de energía de Estados Unidos [26].

Durante la primavera de 2022, muchos acontecimientos en torno al conflicto entre Rusia y Ucrania y algunos otros incidentes hicieron que el precio del gas natural se disparara, aumentando un 157% en marzo de 2022 en comparación con el precio registrado antes del estallido del conflicto.

Los principales objetivos de este estudio son determinar qué factores afectan a la demanda y a la oferta del gas natural y, por tanto, al precio del gas natural, y modelizar el mercado de esta materia prima en función de estos factores.

2. METODOLOGÍA

Para alcanzar los objetivos descritos anteriormente, primero se lleva a cabo una investigación exhaustiva para recopilar toda la información sobre el gas natural necesaria para desarrollar el modelo. Para ello, se han utilizado fuentes oficiales, como las páginas web de la Administración de Información Energética de Estados Unidos (EIA) o del Banco Mundial, e informes oficiales.

Una vez estudiada toda esta información, se seleccionan los factores que más afectan a los niveles de oferta y demanda de gas natural, y por tanto a su precio, y se transforman para utilizarlos en el modelo en forma de indicadores. Se seleccionan ocho variables: la producción de gas natural (extracciones brutas de EE.UU.), los niveles de inventario (volumen de almacenamiento de EE.UU.), la actividad de perforación (equipos de perforación rotativos en funcionamiento de EE.UU.), el precio (Henry Hub), la producción industrial mundial (índice de la OCDE), la política monetaria (tasa Wu-Xia) y la demanda de calefacción y refrigeración residencial (REDTI).

Se necesita un modelo que simule lo que ocurriría con este precio en caso de variación de cada una de estas ocho variables descritas anteriormente. El modelo utilizado en este estudio es un modelo vectorial autorregresivo (VAR), en concreto, el enfoque del modelo dinámico del mercado mundial del petróleo propuesto por Alquist et al. (2013) y Baumeister y Kilian (2012) [55]. Su análisis se basa en la siguiente autorregresión vectorial (VAR) de forma reducida,

$$y_t = c + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + u_t$$

donde, aplicado a nuestro estudio, y_t es un vector de datos mensuales de 8x1, c es un vector de interceptas de 8x1, ϕ_i, i=1, ...p, son matrices de coeficientes de 8x8 con p indicando el número de rezagos (doce en este caso), y u_t es ruido. La variable y_t en nuestro modelo es el precio del gas natural, y las ocho variables son las mencionadas anteriormente.

El modelo se construyó con MATLAB. En primer lugar, se construyó una matriz de 384x8 que contiene los cambios porcentuales con ciertas correcciones de las ocho variables. Con esta matriz, estimamos el modelo VAR utilizando las funciones en MATLAB *varm* y *estimate* (ver *Anexo I: Código MATLAB*). De esta manera, creamos el modelo VAR descrito anteriormente en MATLAB.

Una vez que tenemos el modelo construido, el objetivo es determinar la respuesta dinámica de los precios del gas natural a una perturbación de una desviación estándar en cada una de las ocho variables de nuestro modelo VAR. Para ello, utilizamos la función *irf* de MATLAB (véase el *Anexo I: Código de MATLAB*). Esta función devuelve la respuesta dinámica de cada una de las ocho variables cuando se produce un impulso de una desviación estándar en las ocho variables, de donde se extrae la respuesta del precio del gas natural cuando se produce un impulso o subida brusca en cada una de las ocho variables.

Por último, se realiza una descomposición histórica del precio del gas natural para determinar la contribución de cada uno de los ocho impulsos a la desviación del precio del gas natural a lo largo de la historia (1991-2020).

3. RESULTADOS Y CONCLUSIONES

Tras analizar los efectos sobre el precio del gas natural de una perturbación de cada una de las ocho variables utilizando este modelo VAR, se observó que las variables que más generan una disminución de los precios del gas natural son un aumento de su producción y de los niveles de inventario. Las que generan un aumento de los precios del gas natural son el aumento de la demanda residencial de refrigeración y calefacción, una mayor demanda de electricidad y, en menor medida, una mayor actividad industrial.

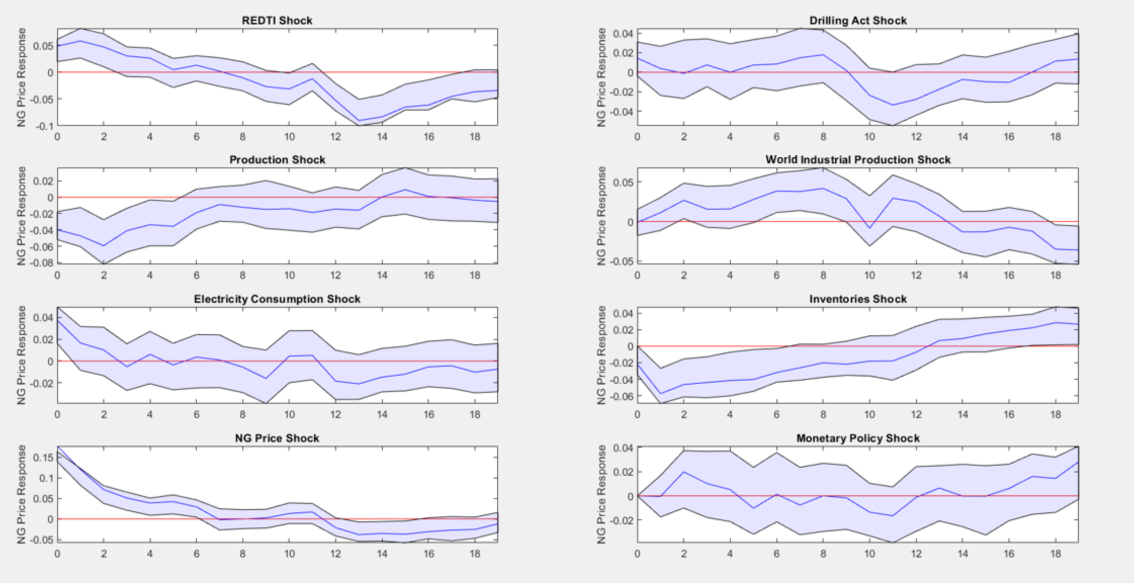

Figura 1. Resultados del modelo. *Fuente: elaboración propia*

La política monetaria no parece tener un gran impacto en el precio del gas natural en este primer análisis. En cuanto a la actividad de perforación, un crecimiento repentino de esta variable no tiene un impacto inmediato ni tan significativo en los precios del gas natural y este impacto no dura mucho en el tiempo. Como era de esperar, una perturbación en la variable “precio del gas natural” tiene un impacto muy significativo e inmediato en sí misma (véase la Figura 1 a continuación).

La descomposición histórica mostró que el indicador REDTI, que representa la demanda residencial debido a los cambios de temperatura, es la variable más determinante a lo largo de la historia para explicar las fluctuaciones del precio del gas natural. La demanda industrial, en cambio, no fue tan importante como la demanda residencial, que representa la mayor parte de la demanda de gas natural en EE.UU.

Los niveles de producción sólo fueron relevantes cuando se produjeron cuellos de botella en el suministro, así como los inventarios, que aumentaron antes de la escasez de suministro y disminuyeron después de los mismos, provocando fluctuaciones en el precio del gas natural.

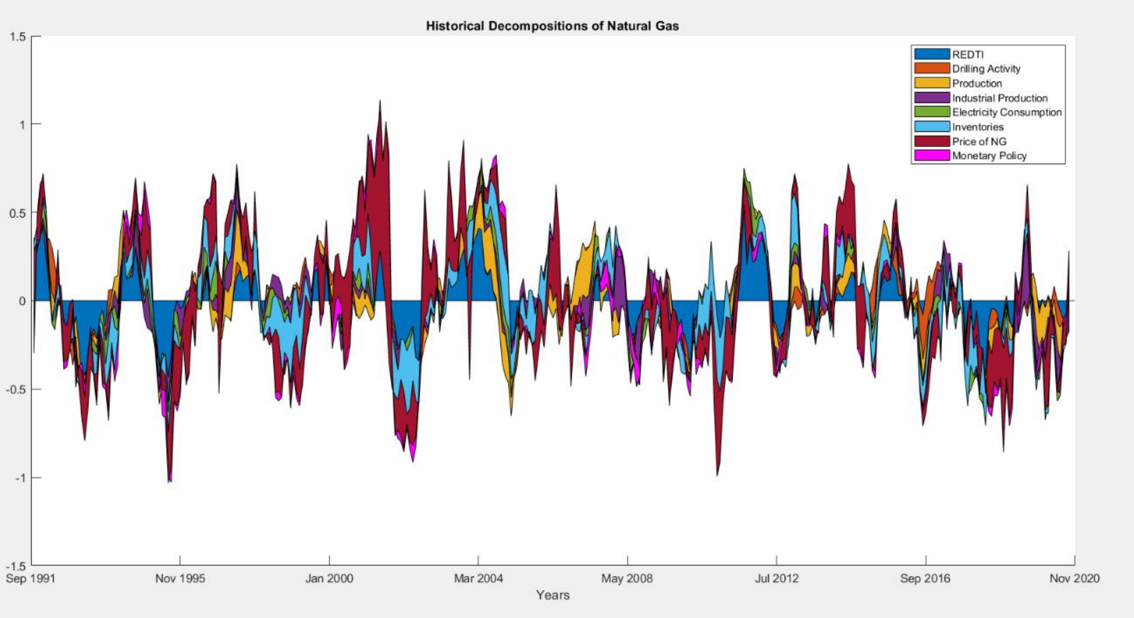

Figura 2. Descomposición histórica del precio del gas natural 1991-2020. *Fuente: elaboración propia.*

Durante los períodos de inestabilidad financiera, el modelo no pudo explicar la especulación en los mercados, lo que se refleja en el hecho de que durante esos períodos la variable "precio del gas natural" desempeña un papel más importante en el modelo. Ni los cambios en la política monetaria ni en la cantidad de actividad de perforación explican gran parte de las fluctuaciones del precio del gas natural a lo largo de los años estudiados.

Sorprendentemente, la variable "consumo de electricidad" no es muy significativa en determinar los cambios del precio del gas natural a lo largo de la historia, según los resultados de la descomposición histórica. En EE.UU., el gas natural representa el 38% de la electricidad generada, mientras que en Europa sólo el 18% de la electricidad se genera con este combustible fósil [64]. Por lo tanto, cabría esperar que, dado que los datos utilizados en el modelo son la electricidad consumida en EE.UU., esta variable fuera más significativa de lo que es.

Los resultados de ambos análisis, el individual de cada uno de los ocho shocks y cómo afectan al precio del gas natural, y el de la descomposición histórica, coinciden en que las variables más relevantes para explicar los movimientos del precio del gas son la demanda residencial por cambios de temperatura, la producción y los niveles de inventario. La única excepción es la variable "consumo de electricidad", que no parece igual de significativa cuando se realiza la descomposición histórica como lo es con el análisis del cambio en el precio del gas natural cuando ocurre una subida repentina del consumo eléctrico.

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To my project director, Elena María Díaz Aguiluz, for her dedication and closeness and for letting me work at my own pace while helping me in all I needed. I will always be grateful for her advice, patience and help in this project.

To my friends and partner, for always supporting me through the most difficult times and for always pushing me to continue.

To all the professors who, throughout my studies, have taught me everything I know today.

To my family, for the support they have always given me and the patience they have. Especially to my parents for all the efforts they make to always give me the best.

THANK YOU

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Chapter 1

Introduction

1.1. Motivation

Natural gas is a fossil energy fuel formed deep beneath the surface millions to hundreds of millions of years ago from the remains of plants and animals that built up in thick layers on the earth's surface and ocean floors [1].

This fossil fuel has become an essential mean of energy in our today's world. It is used principally to generate electricity, for heating, for transportation, and for industrial production. The sectors that use gas the most are the electric power sector, the industrial sector, the residential sector, the commercial sector, and the transportation sector [26].

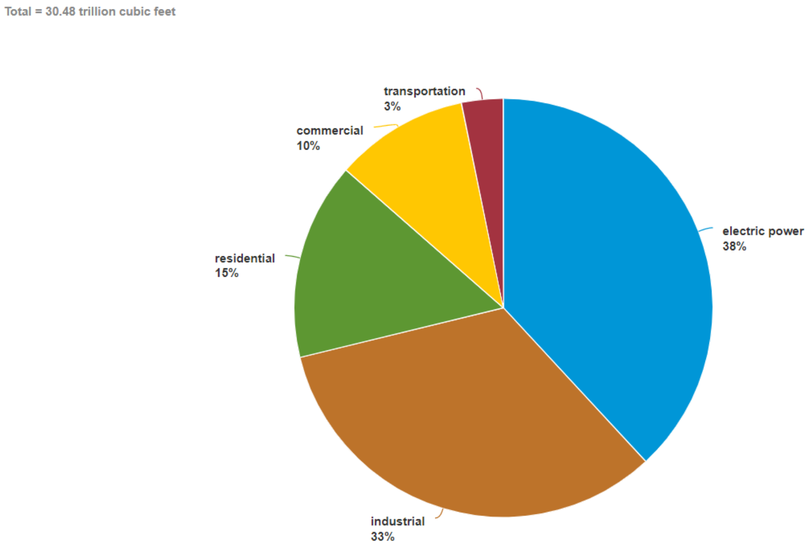


Figure 1.1. US 2020 Natural Gas Consumption by sector [26].

Demand for natural gas is increasing due to its price-calorific value ratio. According to the U.S. Energy Information Association (EIA), the United States used about 31.5 quadrillion British thermal units (Btu) in 2020 which makes 34% of U.S. total energy consumption [26].

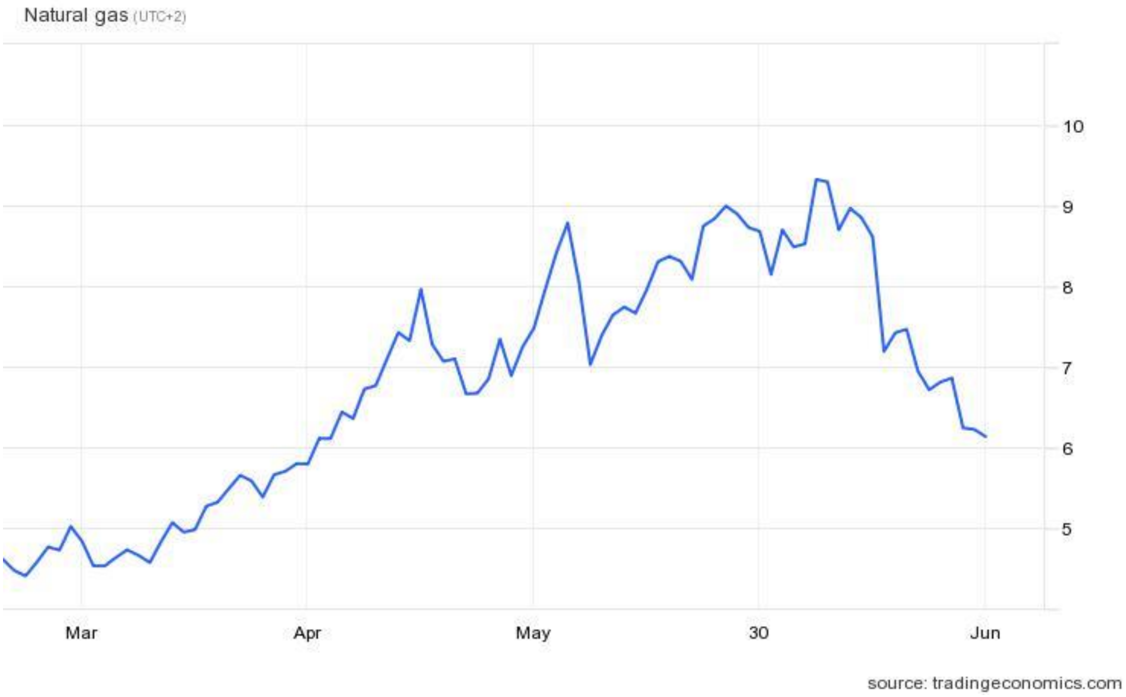
After a 4% drop in 2020 due to COVID-19 crisis, natural gas demand progressively recovered in 2021 as consumption returned close to its pre-crisis level in mature markets. The forecast for 2019 to 2025 expects an average growth rate of 1.5% of demand per year during this period. The Asia Pacific region accounts for over half of incremental global gas consumption in the coming years, due mainly by the development of gas in China and India. Despite the current economic uncertainty, both countries still support natural gas with reforms to increase the role of gas in the energy mix [59].

Although many regions are expected to contribute to the growth in natural gas production in the next five years, North America and Middle East are expected to contribute to half of the net increase in supply. However, the U.S. spending on shale tight oil and gas declined almost by 50% in 2020 due to the crisis. In the Middle East, production growth is driven by the ramping up of large conventional projects in Saudi Arabia, Iran, Israel, Iraq and Qatar [59].

Russia is the other big producer and exporter of natural gas. On February 24th, 2022, Russia decided to attack Ukraine after a long escalation of tension between the two countries. The sanctions imposed on Russia by the European Union and the United States, caused a rise in gas prices due to a decrease in Russian gas exports [60].

One of the first sanctions against Russia has been the suspension of the use of the Nord Stream 2 gas pipeline by Germany. This pipeline runs along the bottom of the Baltic Sea to link Russia with Germany and supply gas to the whole of Europe. However, Putin's decision to recognize the territories of Donetsk and Lugansk as independent led German Chancellor Olaf Scholz to announce that the delivery of the certification that would give the green light to the project would be halted [60].

This halt was accompanied by the announcement by U.S. President Joe Biden to sanction the companies involved in the project, including the Russian state-owned Gazprom, Shell and Engie. This decision leaves Germany and other EU countries, where almost 40% of the gas supply comes from Russia, in a complicated situation, causing a rise of the price of gas in these territories [60].



source: tradingeconomics.com

Figure 1.2. Natural gas prices in USD/MMBtu since February 24th 2022 to June 27th 2022 [61].

Russian energy company Gazprom announced on June 16 that daily gas shipments to Europe via the Nord Stream line will be reduced from 167 million cubic meters to 67 million cubic meters. Shipments through the Yamal-Europe line stopped, and shipments through Ukraine were cut by about half.

In addition to reducing the amount of gas supplied to Europe, Russia also suspended shipments to Poland, Bulgaria, Denmark, Finland and the Netherlands, citing breaches of contract for not complying with the ruble payment system it insisted on [61].

On top of that, the Freeport LNG terminal in Texas was closed on June 9th, 2022, due to a fire. The shutdown was initially scheduled to last three weeks, but the authorities later announced that it would be extended until the end of 2022 [61].

All these events caused the natural gas price to rocket. Price per megawatt-hour for July contracts in Europe, traded on the Netherlands-based virtual natural gas trading point (TTF), rose to EUR 127.17 (USD 133.49) on June 22nd, 2022, up 60% from EUR 79.40 (USD 83.35) on June 8, which was the lowest closing level in the last four months since the start of the Russia-Ukraine war on February 24th [61].

Figure 1.3. Price in €/MWh for July contracts traded in Dutch TTF Gas Futures (February 21st, 2022 - June 27th, 2022) [62].

Even though natural gas is considered the cleanest option among the fossil fuels, there are some environmental implications attached to its drilling and extraction, transportation, burning and consumption [17]. Even though natural gas is mainly methane, which is a strong greenhouse gas, the process of burning natural gas to obtain energy results in fewer emissions of nearly all types of air pollutants than burning coal or petroleum to produce an equal amount of energy [18].

Nevertheless, drilling the wells from which natural gas is extracted, can affect wildlife and land use, and radioactive materials, methane, and other underground gases can leak into drinking water supplies. Moreover, hydraulic fracturing or fracking, requires large quantities of water, which raises water-availability concerns in some communities.

Natural gas is not renewable, and, according to Worldometers, only 52 years of natural gas reserves are left to extract [17]. Yet, the natural gas resource base is more widely geographically dispersed than oil, which makes it a more reliable source of energy, at least until we have the means to produce all the energy we consume through renewable sources, such as solar or wind power.

1.2. Objectives

The main objectives of this project are to determine which factors affect the demand and supply of natural gas, and therefore the price of natural gas, and to model the market of this commodity as a function of these factors.

As it has been mentioned in the previous subchapter, natural gas has become an essential energy fossil fuel due to its cleaner burning capacities and a more even distribution of reserves across the globe. It constitutes a chance for many countries to become more energy independent and to produce energy in a cleaner way than with other fossil fuels such as petroleum and carbon, until the technology to generate all the energy the world consumes from renewable sources is sufficiently developed. Therefore, it is important to understand how the market for this commodity works.

Before modelling the market for gas, it is fundamental to understand what natural gas is, the different types of natural gas, how it is obtained from the ground, how it is transformed in the fuel we use to obtain energy, how it is transported and distributed, where are the reserves of this fuel located across the globe, what are its environmental implications, and how it is priced in the market. All this information will help to understand what are the factors that affect the price of this commodity.

An increase in supply causes the price of natural gas to lower, and an increase in demand causes it to grow. The main forces affecting supply for natural gas are weather conditions, levels of storage and production, political relations and civil unrest, availability of workers and equipment, capacity of the pipeline system, access to natural gas deposits, and the financial environment. On the demand side, the cyclicality of demand, weather, fuel switching and the economic environment, are the main factors to consider. The impact of each of these factors on the price of natural gas can be quantified using indicators related to each of these factors. The next target, therefore, is selecting and adjusting these indicators to use them in the model, which will be explained below.

Once these indicators have been identified, the goal is to build a model using eight variables that replicates the natural gas market performance. The model is then used to investigate what happens to the price of natural gas in the short and medium term if each of the variables suddenly rise. Therefore, the objective is to determine which of these factors affect the price of natural gas the most and which effects are more persistent.

Finally, an historical decomposition is performed to determine the contribution of each of the eight shocks to the deviation of the price of natural gas throughout history.

1.3. Methodology

In order to achieve the objectives described above, a thorough research is first carried out to gather all the information about natural gas needed to develop the model. Official sources, such as the websites of the U.S. Energy Information Administration (EIA) or the World Bank, and official reports were used throughout this study to collect all this information.

Once all this information is studied, the factors that affect the supply and demand levels of natural gas the most, and therefore to its price, are selected and transformed to use it in the model in the form of indicators. In the supply side, the year-to-year percent change in U.S. natural gas gross withdrawals was used as an indicator for variations in production, the month-to-month percent change in the number of U.S. natural gas rotary rigs in operation as the one for variations in drilling activity, and the year-to-year percent change in U.S. natural gas underground storage volume was used as the indicator for fluctuations in inventory levels. In the demand side, REDTI was the indicator used to determine residential heating and cooling demand variations, the electricity consumption was included in the model measuring the year-to-year percent change of electricity end use measured in millions of kilowatts per hour, industrial activity levels were represented by the World Industrial Production Indicator provided by the OECD, and the Wu-Xia Shadow Federal Funds Rate represented the changes in monetary policy. For the price of natural gas, the Henry Hub spot price since 1990 was the one considered.

A model to simulate what would happen to this price in the case of a variation in each of these eight variables described above is needed. The model used in this study is a Vector Autoregressive model (VAR), which is an extension of univariate autoregression model to multivariate time series data, in which all variables are treated as endogenous. In particular, the present project uses an approach that is widely followed to forecast oil prices, the dynamic model of the global oil market proposed by Alquist et al. (2013) and Baumeister and Kilian (2012) [55]. Their analysis is based on the following reduced-form vector autoregression (VAR),

$$y_t = c + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + u_t$$

where, applied to our study, y_t is a vector of 8x1 monthly data, c is a 8x1 vector of intercepts, ϕ_i, i=1,...p, are 8x8 coefficient matrices with p indicating the number of lags (twelve in this case), and u_t are white-noise innovations. The variable y_t in our model is the price of natural gas, and the eight variables mentioned above.

The model was constructed using MATLAB. Firstly, a 384x8 matrix was built, containing the percent changes with the corrections described above of all eight variables. With this matrix, we estimated the VAR model using the functions in MATLAB *varm* and *estimate* (see Annex I: MATLAB Code). This way, we created the VAR model described above in MATLAB.

Once we have the model constructed, the goal is to determine the dynamic response of natural gas prices to a one-standard-deviation shock to each of our eight variables in our VAR model. For this matter, we use the *irf* function in MATLAB (see Annex I: MATLAB Code). This function returns the dynamic response of each of the eight variables when a one-standard-deviation shock occurs in all eight variables. However, the only response we are interested in, is the response of the price of natural gas when a shock or sudden rise occurs in natural gas production, inventories, drilling activity, price, world industrial production, shadow rate, and REDTI. Therefore, we extract these responses and plot them to analyze them in *Chapter 5.*

Finally, a historical decomposition is performed for the price of natural gas to determine the contribution of each of the eight shocks to the deviation of the price of natural gas throughout history (1991-2020).

This project consists of seven chapters that include the collection of the information obtained on natural gas, an explanation of the process followed to achieve the objectives described above, a description of the results obtained, and a chapter dedicated to conclusions and possible future lines of research (*Chapter 8*). Each chapter includes:

- **Chapter 2**. Definition of natural gas, differentiation between various types of natural gas depending on the transportation and storage method, description of a few indexes to price natural gas, and evaluation of the environmental implications of the use of this fossil fuel.
- **Chapter 3.** Description of the process of extracting, transforming, and transporting natural gas. Identification of the main forces affecting natural gas supply and which countries are the main suppliers of this fuel.
- **Chapter 4.** Description of the main uses of natural gas and the forces affecting the short-term and long-term demand levels. Explanation of how the demand for this commodity is distributed across the world.
- **Chapter 5.** Exposition of the process followed to choose and transform each indicator used in the model and explanation of the VAR model used.

- **Chapter 6.** Presentation of the results of the model and impulse response functions. Analysis of the dynamic response of the price of natural gas when a sudden rise in each of the eight variables studied takes place.
- **Chapter 7.** Interpretation of historical fluctuations in the modelled time series by performing historical decomposition of the data and summary of the history of each endogenous variable in light of the VAR.
- **Chapter 8.** Compilation of the main conclusions of each chapter as well as the presentation of the results and several possible future lines of research. Among them, one of the most interesting is the inclusion of nuclear energy supply in the model.

Chapter 2

Natural Gas

2.1. Definition

Natural gas is a fossil energy source that is formed deep beneath the earth's surface [1]. It is composed mainly by methane (CH4), although it also contains smaller amounts of natural gas liquids (NGL) and nonhydrocarbon gases, such as carbon dioxide and water vapor [1].

The formation of natural gas took place millions to hundreds of millions of years ago when the remains of plants and animals built up in thick layers on the earth's surface and ocean floors, sometimes mixed with sand, silt, and calcium carbonate. When these layers were then buried under sand and rock, pressure and heat transformed some of this carbon and hydrogen-rich material into coal, oil, and natural gas [1].

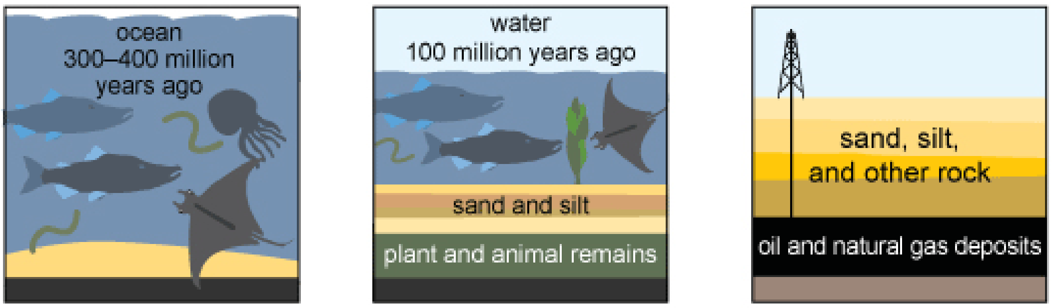


Figure 2.1. Petroleum and natural gas formation [1].

Natural gas is nowadays classified in three different types depending on where it can be found. In some places, natural gas moved into large cracks and spaces between layers of overlying rock. The natural gas found in cracks and spaces between layers of rock is called conventional natural gas. The one that occurs in tiny pores within sedimentary rock is referred to as shale gas or tight gas, and it is sometimes called unconventional natural gas. Finally, the natural gas that occurs with deposits of crude oil is called associated natural gas and the one that is found in coal deposits is called coalbed methane [1].

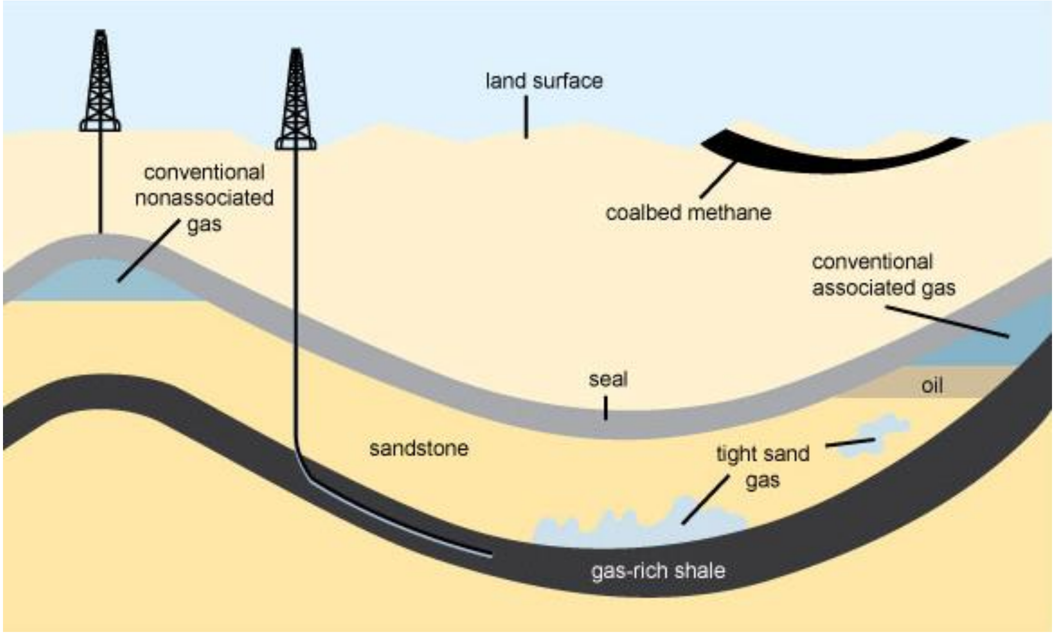


Figure 2.2. Schematic geology of natural gas resources [1].

i) In order to find natural gas, geologists locate the types of geologic formations that are likely to contain natural gas deposits due to its characteristics. This is often done by using seismic surveys on land and in the ocean, which create and measure seismic waves in the earth to get information on the geology of rock formations. Once the seismic survey indicate that a site is likely to contain natural gas, the next step is to test the quality and quantity of natural gas available. For this matter, an exploratory well is drilled and tested. If the test proves that there is enough natural gas to make a profit, production wells are drilled [1].

There are two different ways to extract the natural gas contained in the rock depending on the permeability of the soil. If the permeability is high, the natural gas generally flows easily up through wells to the surface. However, if the permeability is low, natural gas is extracted by drilling both vertically and horizontally and forcing water, chemicals, and sand down the wells under high pressure. This process is known as hydraulic fracturing or fracking and it breaks up the formation, releases the natural gas from the rock, and allows the natural gas to flow to and up wells to the surface [1].

Once the natural gas reaches the surface, it is gathered into pipelines and sent to natural gas processing plants, where water vapor and nonhydrocarbon compounds found in the natural gas extracted from the ground are removed. In order to detect leaks in natural gas pipelines, some chemicals with strong smell called odorants are added to natural gas. Natural gas is then sent through pipelines to underground storage fields or to distribution companies and then to consumers [1].

2.2. Compressed natural gas (CNG) versus liquified natural gas (LNG)

Natural gas can be stored and transported in several forms after being drilled from the wells. The most common ways to reduce natural gas volume and make it safer and easier to transport and store is by compressing the gas to high pressures (compressed natural gas) or by cooling the gas to extremely low temperatures until it becomes liquid (liquified natural gas).

Compressed natural gas (CNG) is the first gaseous product of petroleum that is separated during the distillation process. CNG is odorless, tasteless, and non-toxic, and it is made up of 93.05% methane, nitrogen, carbon dioxide, propane and traces of ethane. It is stored under high pressures (while remaining in its gaseous form), mainly as a means to transport it, or as storage for later use as vehicle fuel. At these high pressures, CNG takes up a smaller volume than ordinary natural gas, but more volume than LNG. It is an environmentally clean alternative fuel, as its combustion process emits a lower percentage of greenhouse gases, such as carbon monoxide, hydrocarbons, and oxides of nitrogen, compared to other fuels. Moreover, while CNG fuel does not offer the same amount of power that diesel fuel would, it has a high-octane rating that provides a high compression ratio and is adaptable to modern engines [2].

Figure 2.3. One of Hexagon's trucks transporting CNG [5].

CNG, travels through pipelines to a distributor, after being extracted from wells and treated. These distributors then send this fuel out to customers in pressurized tanks or to fueling stations. At smaller fueling stations and in vehicles, the compressed gas is stored in thick-walled tanks made of aluminum, steel, or some composite, which adds up weight to the fuel storage system of the vehicles. These high-pressure tanks are kept at pressures around 20-25 MPa, which reduces the volume of the natural gas to less than 1% of its volume at standard atmospheric pressure [3].

Liquified natural gas (LNG), on the other hand, is the liquid form of natural gas. It is produced by purifying natural gas and super-cooling it to temperatures far below zero (-162 ºC), making it easy to store and transport to various destinations. The most common form of transportation of this type of natural gas is using cargo ships. Liquefied natural gas has the highest energy density, which makes it ideal for longer-range vehicles, such as Class 7 and 8 trucks. LNG is non-corrosive and non-toxic, but it is extremely flammable, which makes it important to apply strict safety measures during its transportation [2]. The main difference compared to natural gas transported by pipeline is that at such low temperatures, certain components (water, hydrocarbons, carbon dioxide, mercury) freeze to solid, so they must be extracted almost completely from the liquefied gas. One cubic meter of LNG, after regasification, produces about 600 cubic meters of natural gas in normal condition [4].

Regarding the production process of LNG, this type of natural gas can be produced by several different processes, but each process has the same goal: compressing and cooling the gas. The most common processes are APCI or C3MR method, DMR, Linde, and Cascade procedure. APCI or C3MR is the most common amongst them all. APCI stands for Air Products and Chemicals Inc. the company which first developed this liquefaction process. This procedure is composed of two main cycles. The first cycle consists of a multi-stage propane (C3) precooling system followed by a liquefaction cycle using an MR system consisting of nitrogen, methane, ethane, and propane. In addition to this technology, other large oil and gas companies have developed their own process, such as Shell or Linde. The other commonly used technology is the DMR (dual mixed refrigerant), which uses two mechanically driven compressors instead of a single-component refrigerant [4].

The steel tanks used for storing LNG need to withstand extreme temperatures of -162 ° C and maintain this internal temperature without any external cooling, which requires special insulation. However, LNG has an energy density per unit volume of more than three times that of CNG, which means that LNG can be stored and used more efficiently even with the weight of its tank [4].

Natural gas is transported in the form of LNG when the distance it needs to travel is over 3000-4000 km on land and over 1000-1500 km in the deep sea. Below these distances, it is more economical to deliver the natural gas in its original gaseous state, on the transmission pipeline system [4].

Figure 2.4. LNG tanker used for marine transport [4].

While liquefied natural gas and compressed natural gas are similar in composition, their delivery and storage methods are different. LNG is cooled in order to turn it into liquid form, whereas CNG is pressurized to the point where it is very compact [2].

On one hand, LNG takes up less storage space on a vehicle than CNG, and it also offers a higher energy density that can be compared to diesel fuel. Moreover, using proper procedures, LNG can be converted to CNG [2].

On the other hand, CNG is easier to refuel than LNG, which requires special handling and equipment. CNG is also very light, so if there is a leak, it will dissipate, while LNG will not. It has an unlimited hold time, so even if it goes unused, there is no fuel loss. All of this makes CNG a safer choice over LNG. In addition, CNG has lower production costs than LNG, which makes CNG cheaper for consumers [2].

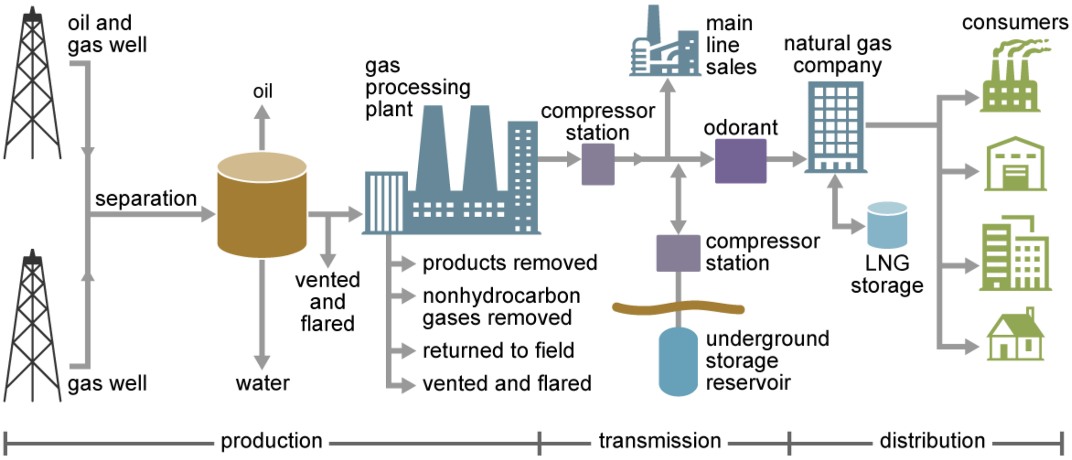


Figure 2.5. Natural gas production and delivery [1].

2.3. Natural Gas Price Indexes

There are three main natural gas trading markets, the European average import border price, the Henry Hub spot price of the US, and the imported liquefied natural gas (LNG) price of Japan [8].

These markets trade based on contracts of various lengths. The majority of production has historically been sold on the basis of long-term supply agreements lasting up to 20 years, due to the high capex costs associated with

LNG production and supply. However, natural gas is also largely sold under spot contracts (up to one year). There are also, short-term (one to four years) and medium-term (four to eight years) natural gas sale contracts [9].

U.S. natural gas prices tend to be set by reference to the price of natural gas at the Henry Hub (HH), European natural gas prices are usually set by reference to the price of natural gas at either the National Balancing Point (NBP) in the UK or the Title Transfer Facility (TTF) in the Netherlands and Asian LNG prices are typically set by reference to the price of the Japan Customs-cleared Crude (known as the 'Japanese Crude Cocktail' or JCC) [9].

Historically, there have been differences between these reference prices, becoming these differences greater with the increase in global spot natural gas trading activity. Market participants buy and sell natural gas on a "spot" basis every day, with the buyer agreeing to pay a negotiated price for the natural gas to be delivered by the seller at a specified delivery point. Natural gas spot prices reflect daily supply and demand balances and can be volatile [9].

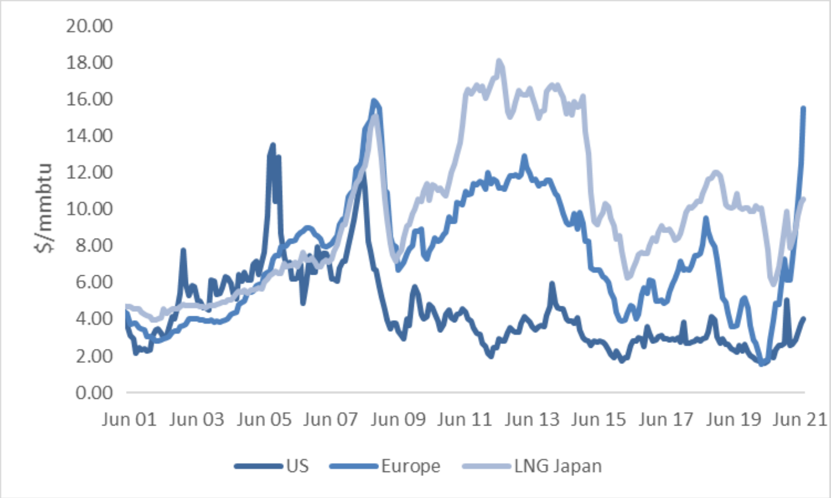


Figure 2.6. Historical nominal prices of natural gas (2001-2021) [6].

Regarding natural gas prices over the past 12 months, sharp fluctuations have occurred, with European prices reaching their lowest level on record, U.S.

prices hitting a multi-decade low in the second quarter of 2020 and imported prices in Japan reaching a 15-year low. The drop in prices was due to the slump in natural gas demand, driven by the global economic recession, as well as abundant supplies of LNG. However, as it can be appreciated in *Figure 2.6* and *Figure 2.7,* all prices recovered when the economic activity resurged [10].

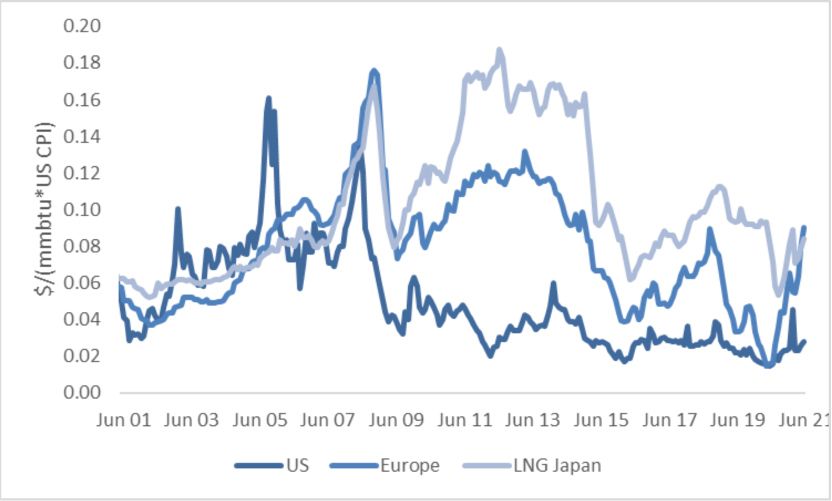


Figure 2.7. Historical real prices of natural gas (2001-2021). Deflated with US CPI [6],[7].

2.3.1. US Henry Hub

Henry Hub is a natural gas pipeline located in Erath, Louisiana, that serves as the official delivery location for futures contracts on the New York Mercantile Exchange (NYMEX), because of its central location and its high degree of interconnectedness. The hub is owned by Sabine Pipeline LLC and has access to many of the major gas markets in the United States. This hub is interconnected with 13 different intra- and interstate pipelines [11].

The NYMEX contract for deliveries at Henry Hub began trading in 1990 and is deliverable 18 months in the future. The settlement prices at Henry Hub are used as benchmarks for the whole North American natural gas market and part of the global liquid natural gas (LNG) market [11].

2.3.2. European average import border price, TTF and NBP

Europe's natural gas price is an average of the different prices for natural gas in all the regions that trade this commodity. The natural gas markets in Europe have been moving away from long-term contracting and have increased the import of natural gas from Russia and Norway. The two main markets in Europe for this commodity are the British NBP and the Dutch TTF [14].

The UK NBP gas market is the longest established spot-traded natural gas market in Europe, having started trading in the late 1990s. NBP stands for National Balancing Point. Under the NBP model, gas from any point in the country within the national transmission system is considered NBP gas. This gas market allows a wide range of participants to buy and sell: oil and gas producers, LNG suppliers, utilities, power utilities, industrial users and financial operators. Gas trading can be carried out through over-the-counter transactions between participants and through brokers, or on stock exchanges [15].

TTF, on the other hand, stands for Title Transfer Facility, and it is an establishment in the Netherlands for virtual trading of futures, physical and exchange trades of natural gas [14]. It was established by Gasunie Transport Services B.V, a subsidiary of Gasunie in 2003 as an alternative to the United Kingdom's National Balancing Point (NBP). The facility allows for gas to be traded within the Dutch Gas Network [14]. The TTF has become so popular due to its high liquidity and the maintenance of a positive natural gas price correlation compared to the other hubs in northwest Europe. The volume of futures traded over the TTF increased by about 24% in 2020 after a 100% growth over the last two years, according to the ICE. The US's Henry Hub Benchmark, on the other hand, started declining from its 2018 peak. For a long time, the US market decided the price of trade but recently, the Dutch Market enabled the shareholders to take a more regional control over the import of billions of euros worth of gas every year. Even Asian markets are using TTF for trading [14].

2.3.3. Japanese imported LNG price and JKM

Japanese LNG price formula is linked to an average crude oil import CIF price. The formula results in a cheaper LNG price than crude oil when the crude oil price is high, and a higher price when the crude oil price is low. These can be put to the following formula.

$$Y = a + bX$$

Where Y is the LNG price and X is the crude oil price. “a” prevents LNG price from falling below a certain level and “b” is a coefficient dependent on the crude oil price and smaller than 1. This formula prevents the LNG price from rising 100% when the crude oil price spikes, for consumers’ interests. The values of “a” and “b” are correlated to suppliers’ and consumers’ interests [12].

The most popular liquified natural gas index in Asia is the JKM. JKM™ is the Liquefied Natural Gas (LNG) benchmark price for spot physical cargoes [13]. It is referenced in spot deals, tenders and short-, medium- and long-term contracts [13]. JKM™ reflects the spot market value of cargoes delivered excluding shipment costs (DES) into Japan, South Korea, China, and Taiwan [13].

Hub pricing, such as the one used in the US and increasingly becoming popular in Europe, is still not available in Asia, although there has been attempts. Until there is the ability to transport gas easily and transparently from the hubs to other regional markets, gas regulations are harmonized, sufficient volumes are traded in the hubs, and the secrecy surrounding gas prices in these regions is lifted, it is unlikely that suppliers and buyers outside the local market will want to trade with these Asian hubs.

2.4. Environmental Implications

Even though natural gas is considered the cleanest option among the fossil fuels, there are some environmental implications attached to its drilling and extraction, transportation, burning and consumption [17].

Drilling the wells from which natural gas is extracted, can affect wildlife and land use, as clearing and leveling of the area is required. When geologists explore for natural gas deposits, they might disturb vegetation and soil with their vehicles. In order to transport natural gas, pipelines are buried in the land, affecting the ecosystem around them, breaking migration patterns, and causing pollution of dirt and pollutants [18].

Moreover, hydraulic fracturing or fracking, requires large quantities of water, which raises water-availability concerns in some communities. The Environmental Protection Agency (EPA) estimates that 70 billion to 140 billion gallons of water were used in the U.S. in 2011 for fracturing 35,000 wells [20]. It has been estimated that a typical well may require 2–10 million gallons of water for fracking completion, although this amount may vary depending on the quality of this water and the shale formation [16]. Most of the water used for this matter is not recoverable, unlike other energy-related water withdrawals, which are commonly returned to rivers and lakes [19].

This water also poses health risks to nearby communities, since radioactive materials, methane, and other underground gases have sometimes leaked into drinking water supplies from improperly cased wells. In Ohio and Pennsylvania, for example, there have been documented cases of groundwater near oil and gas wells being contaminated with fracking fluids as well as with gases. The EPA has identified more than 1,000 chemical additives that are used for fracking, including acids, bactericides, scale removers, and friction-reducing agents. If the wells, transportation and storage of these chemicals are not managed properly, they could leak or spill out of the storage containers or during transport [19]. This technique of obtaining natural gas by injecting water at high pressures has also been associated to some low-magnitude earthquakes.

The use of natural gas for electricity generation and as a transportation fuel for fleet vehicles worldwide has increased over the last years due to its clean burning properties. The process of burning natural gas to obtain energy results in fewer emissions of nearly all types of air pollutants, such as NOx and PM particles, and CO2 than burning coal or petroleum to produce an equal amount of energy. Around 117 pounds of carbon dioxide are produced per MMBtu equivalent of natural gas compared to more than 200 pounds of CO2 per MMBtu of coal and more than 160 pounds per MMBtu of fuel oil [18].

However, natural gas is mainly methane, which is a strong greenhouse gas that leaks to the atmosphere in big amounts. The U.S. EPA estimates that in 2018, methane emissions from natural gas and petroleum systems and from abandoned oil and natural gas wells were the source of about 29% of total U.S. methane emissions and about 3% of total U.S. greenhouse gas emissions [19]. According to National Geographic research *Natural gas is a much 'dirtier' energy source than we thought*, methane is a potent greenhouse gas, whose carbon core and hydrogen arms are arranged in a configuration that absorbs heat exceptionally. A methane molecule is approximately 90 times more effective at trapping heat in the atmosphere than a molecule of carbon dioxide. According to energy experts, CO2 emissions need to be eliminated from the equation because they stay longer in the atmosphere, but to keep air temperatures from raising more than 2 degrees Celsius by 2050 it is also critical to keep any extra methane from leaking into the atmosphere [20].

In areas where natural gas is not economical to transport for sale or contains high concentrations of hydrogen sulfide, it is flared at well sites. Burning natural gas produces CO2, carbon monoxide, sulfur dioxide, nitrogen oxides, and many other compounds, depending on the chemical composition of the natural gas and on how well the natural gas burns in the flare [18].

Some other environmental disadvantages attached to natural gas are the probability of an explosion if not transported or extracted responsibly, and the fact that natural gas is not renewable. According to Worldometers, only 52 years of natural gas reserves are left to extract [17]. Yet, the natural gas resource base is more widely geographically dispersed than oil, which makes it a more reliable source of energy, at least until we have the means to produce all the energy we consume through renewable sources, such as solar or wind power.

Chapter 3

Supply of Natural Gas

3.1. Production Process

The natural gas used by consumers is very different from the one it is extracted from underground. The final product is almost 100% methane, while the raw natural gas contains impurities, such as carbon dioxide, hydrogen sulfide, water vapor, oil, nitrogen, hydrates, and heavier hydrocarbons, consisting mostly of ethane, propane, butane, and pentanes [21]. In order to remove these impurities, the natural gas extracted from the well has to be treated. While part of this treatment is done at the well site, the complete processing takes place at a gas processing plant [21]. The main steps of this treatment process include oil and condensates removal, carbon dioxide and hydrogen sulfide removal, dehydration, and Natural Gas Liquids (NGL) recovery [21].

3.1.1. Oil, water and condensates removal

The first step in processing gas is removing oil, water, and condensates. This step is typically done using equipment installed at or near the wellhead. Although dry pipeline quality natural gas is identical across different geographic areas, raw natural gas from different regions may have different compositions and separation requirements [22].

Sometimes, no special equipment is needed to carry out this separation since the oil and condensates might separate from the gas due to decreased pressures when it is extracted. Some other times the separation is done by easy methods, such as a conventional separator that consists of a closed tank where the force of gravity serves to separate the heavier liquids (oil) from the lighter gases (natural gas) [22].

In certain circumstances, however, specialized equipment is necessary, such as the Low-Temperature Separator (LTX). This separator uses pressure differentials to cool the wet natural gas, extracted from the well at a high pressure, and separate the oil and condensate. The cooled gas travels through a high-pressure liquid 'knockout', which serves to remove any liquids into a low-temperature separator. The gas is then expanded in a temperature separator through a choke mechanism. After the liquid is removed, the dry gas travels back through a heat exchanger and is warmed by the incoming wet gas. The temperature of the gas can be varied by changing the pressure of the gas in various sections of the separator [22].

3.1.2. H2S & CO2 Removal

Once the oil, water, and condensates have been removed, the carbon dioxide and hydrogen sulfide must be removed if present. This step is known as 'sweetening' the gas, due to sulfur's scent, otherwise known as "sour" gas. This step is very important because hydrogen sulfide is extremely harmful, even lethal, and very corrosive [21].

The primary process for sweetening sour natural gas uses amine solutions to remove the hydrogen sulfide. This process is known as the 'amine process', or alternatively as the Girdler process. The sour gas is run through a tower, which contains the amine solution. This solution has an affinity for sulfur and absorbs it. The amine solution used can be regenerated, allowing it to be reused to treat more sour gas. Another option is to use solid desiccants like iron sponges to remove the sulfide and carbon dioxide, instead of the amine solutions [22].

Sulfur can be sold and used if reduced to its elemental form. In order to recover elemental sulfur from the gas processing plant, the hydrogen sulfide solution needs to undergo a process called “The Claus Process”, which includes thermal and catalytic reactions [22].

3.1.3. Natural Gas Dehydration

In addition to separating oil and condensates, it is necessary to remove most of the water contained in the natural gas solution. Natural gas dehydration is imperative to remove the excess water which creates corrosion, freezing issues and does not meet pipeline requirements of 7/MMcf [22]. Some of the liquid contained in the natural gas solution is removed by simple separation methods at or near the wellhead. However, a more complex treatment is needed to remove all the water. This treatment consists of ‘dehydrating’ the natural gas, which usually involves one of two processes: either absorption, or adsorption. Absorption occurs when the water vapor is taken out by a dehydrating agent. Adsorption occurs when the water vapor is condensed and collected on the surface [21].

An example of absorption dehydration is known as Glycol Dehydration. Glycol, has a chemical affinity for water, therefore, when in contact with a stream of natural gas that contains water, glycol absorbs water from the wet gas. The glycol solution used in this process is called ‘contactor’. Once the water has been absorbed, the glycol particles become heavier and sink to the bottom of the contactor where they are removed. The natural gas, free of water, is then transported out of the dehydrator. The glycol and water solution carries with it small amounts of methane and other compounds found in the wet gas. In order to remove these compounds before the glycol solution reaches the boiler a flash tank separator is used, reducing the pressure of the glycol solution stream, allowing the methane and other hydrocarbons to vaporize ('flash'). The glycol and water solution then is put through a specialized boiler, which may also be fitted with air or water cooled condensers, which serve to capture any remaining organic compounds that may remain in the glycol solution. Finally, the water is vaporized out of the solution, allowing the glycol solution to be reused in the dehydration process [22].

The primary form of dehydrating natural gas using adsorption is through solid-desiccant dehydration. In this process, two or more adsorption towers filled with a solid desiccant, such as activated alumina or a granular silica gel material, are used. Wet natural gas is introduced at the top of these towers, and as the wet gas meets the particles of desiccant material, water is retained on the surface of these desiccant particles, leaving the dry gas to exit the bottom of the tower [22]. These types of dehydration systems work the best for large volumes of gas under very high pressure and are usually located on a pipeline downstream of a compressor station. To 'regenerate' the desiccant, after it becomes saturated with water, a high-temperature heater is used to heat gas to a very high temperature. This heated gas passes through the saturated desiccant bed and vaporizes the water in the desiccant tower, leaving it dry and allowing for further natural gas dehydration [22].

3.1.4 NGL Recovery

Natural gas liquids (NGLs) are heavy hydrocarbons including ethane, propane, butane, iso-butane, and natural gasoline. These natural gas liquids have a high BTU and are not pipeline quality, but they are a very valuable by-product when sold separately [21].

The first step of NGL Recovery is to remove all NGL's from natural gas. There are two principal techniques for removing NGLs from the natural gas stream: the absorption method and the cryogenic expander process.

The absorption method is similar to the glycol dehydration process, but instead of using glycol to remove water from the natural gas, an absorbing oil which has an affinity for NGLs is used. The pure oil, called 'lean' absorption oil, is brought into contact with the natural gas stream in a tower and absorbs a high proportion of the NGLs contained in the gas. The 'rich' absorption oil, a mixture of absorption oil, propane, butanes, pentanes, and other heavier hydrocarbons, then exits the tower from the bottom. This rich oil is fed into lean oil stills, where the mixture is heated to a temperature above the boiling point of the NGLs, but below that of the oil. This process allows for the recovery of around 75% of butanes, and 85-90% of pentanes and heavier molecules from the natural gas stream. Another process, called refrigerated oil absorption method, cools the lean oil through refrigeration, allowing for the recovery of up to 90% of propane, around 40% of ethane, and up to 100% of heavier NGLs [22].

Cryogenic processes are also used to extract NGLs from natural gas, especially lighter hydrocarbons, such as ethane. These cryogenic processes consist of dropping the temperature of the gas stream to around -120 degrees Fahrenheit, through a variety of possible methods, among which the turbo expander process is considered the most effective. In this process, external refrigerants are used to cool the natural gas stream. Then, an expansion turbine is used to rapidly expand the chilled gases, which causes the temperature to drop significantly. This rapid temperature drop condenses ethane and other hydrocarbons in the gas stream, while maintaining methane in gaseous form. This process allows for the recovery of about 90-95% of the ethane. In addition, the expansion turbine uses the energy released when the natural gas stream is expanded to recompress the gaseous methane effluent, saving energy costs associated with extracting ethane [22].

After the NGL's are removed they are separated into their base components, through a process known as fractionation. The equipment used to separate the ethane, propane, butanes, and pentanes by volatility is known as the fractionator train. Fractionation works based on the different boiling points of the different hydrocarbons in the NGL stream, which allows to boil off the different hydrocarbons one by one. The entire fractionation process is broken down into steps, starting with the removal of the lighter NGLs from the stream. First, ethane is separated from the stream in the deethanizer, then propane in the depropanizer, then butane in the debutanizer and finally iso butanes in the desisobutanizer. These separated NGL's have a higher selling value and can be used in a multitude of ways. [22].

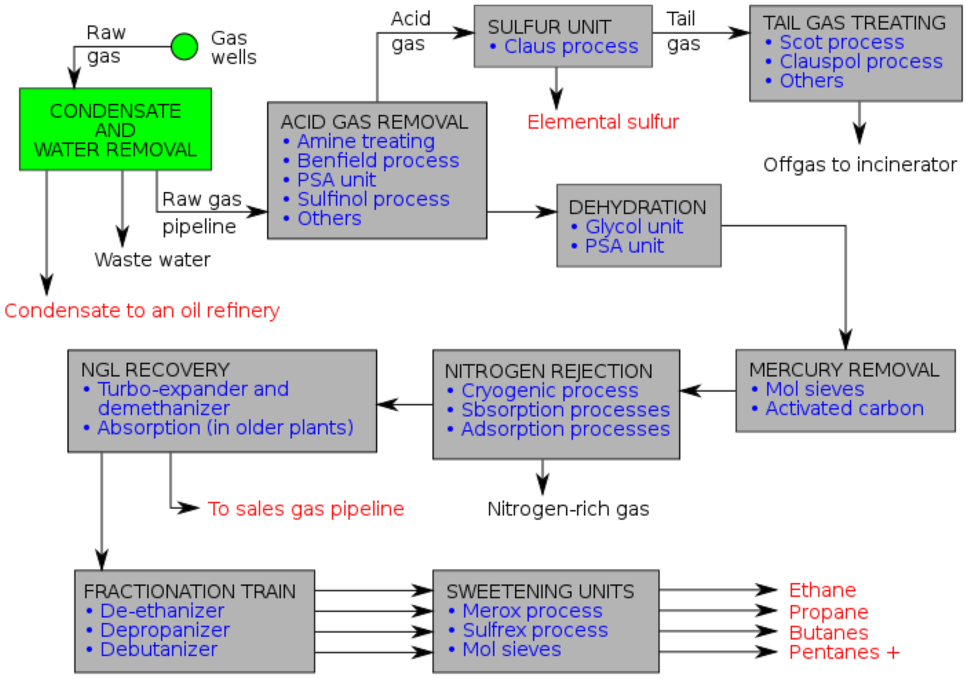


Figure 3.1. Generalized natural gas processing flow diagram [23].

Gas processing is an essential part of the natural gas value chain. It is fundamental in ensuring that the natural gas intended for use is as clean and pure as possible, making it the clean burning and environmentally sound energy choice. Once the natural gas has been fully processed, and is ready to be consumed, it must be transported from those areas that produce natural gas, to those areas that require it [22].

3.2. Transportation

In many instances, natural gas produced from a particular well will have to travel a great distance to reach its point of use. The main form of transportation for natural gas is through a complex pipeline network, in its gaseous state. However, when this option is not feasible, natural gas can be transported in its liquified state on cargo ships. Liquified natural gas has almost the same composition as natural gas, but it has been cooled to -162ºC and its density is lower than water's. The essential difference compared to natural gas transported by pipeline is that at storage temperature certain components (water, hydrocarbons, carbon dioxide, mercury) freeze to solid: they must be extracted almost completely from the liquefied gas [24] [25].

Transportation of natural gas is closely linked to its storage: should the natural gas being transported not be immediately required; it can be put into storage facilities for when it is needed [25]

There are three major types of pipelines along the transportation route: the gathering system, the international pipeline system, and the distribution system. The gathering system consists of low pressure, small diameter pipelines that transport raw natural gas from the wellhead to the processing plant. If the natural gas has a component that needs to be removed (i.e., sulfur, hydrogen sulfide, carbon dioxide) then a specialized gathering pipe must be installed, since some of these components are corrosive. Natural gas that is transported through international pipelines, the ones with the biggest diameter, on the other hand, travels at high pressures, which reduces the volume of the natural gas by up to 600 times [24].

The pipes can be 5-125 cm depending on their function, can be made either from a strong carbon steel material or a highly advanced plastic, and are coated to avoid corrosion. Transmission pipelines are produced in steel mills. For large diameter pipes, the pipes are produced from sheets of metal which are folded into a tube shape, with the ends welded together to form a pipe section. Small diameter pipe, on the other hand, can be produced by heating a metal bar to very high temperatures, then punching a hole through the middle of the bar to produce a hollow tube. In either case, the pipe is tested before being shipped from the steel mill, to ensure that it can meet the pressure and strength standards for transporting natural gas [24].

As mentioned, natural gas travels through international pipelines at very high pressures. To ensure that this high pressure is always maintained, compressor stations are installed along the pipe network, usually at 65 to 160 kilometers intervals. These turbine compressors can obtain the energy they need by using a small proportion of the natural gas that they compress, an electric motor, or reciprocating natural gas engines [24].

In addition to compressing natural gas, compressor stations usually serve to separate water or hydrocarbons contained in the gas stream, using some type of liquid separator, such as scrubbers and filters that capture any liquids or other unwanted particles from the natural gas in the pipeline. Although natural gas in pipelines is considered ‘dry’ gas, it is not uncommon for a certain amount of water and hydrocarbons to condense out of the gas stream while in transit. These liquid separators, therefore, ensure that the natural gas in the pipeline is as pure as possible, and usually filter the gas prior to compression [24].

Metering stations are also placed periodically along the pipelines, to measure the flow of gas along the pipeline, and allow pipeline companies to 'track' natural gas as it flows along the pipeline. The pipelines also include many valves along the network that can be used to stop gas flow along a certain section of pipe, when needed. These valves are used in some circumstances such as when maintenance or replacement is needed in a section of the pipe [25].

In addition, in order to ensure that all customers receive timely delivery of their portion of this gas, sophisticated control systems, such as Control and Data Acquisition (SCADA) systems, are required to monitor the gas as it travels through the lengthy pipeline network. These systems collect, assimilate, and manage data received from the metering stations, compressor stations and valves. This data includes flow rate through the pipeline, operational status, pressure, and temperature readings, in real time. The data is delivered to a centralized control station, allowing pipeline engineers to know exactly what is happening along the pipeline at all times. This allows engineers to quickly react to equipment malfunctions, leaks, or any other unusual activity along the pipeline. Some SCADA systems also have the ability to remotely operate certain equipment, including compressor stations, giving the opportunity to adjust flow rates immediately and easily from the centralized control station [24].

It is important to note that natural gas is flammable, therefore, to reach the goal safely and efficiently, pipeline companies routinely inspect their pipelines for defects. This is done using sophisticated equipment called 'smart pigs', which are intelligent robotic devices that are propelled down pipelines to evaluate the interior of the pipe. Smart pigs can test pipe thickness, roundness, check for signs of corrosion, detect minute leaks, and any other defect along the interior of the pipeline that may either impede the flow of gas, or pose a potential safety risk to the operation of the pipeline [24].

3.2.1. Pipeline Construction

The first step before constructing a pipeline is to obtain all required permits and satisfy all the regulatory requirements. In many cases, natural gas pipeline companies prepare a feasibility analysis to ensure that an acceptable route for the pipeline exists that provides the least impact to the environment and public infrastructure already in place. Then, extensive surveying of the intended route is completed, both aerial and land based, to make sure there is no unexpected event during the assembly of the pipeline [24].

The assembly process starts by clearing the path of the pipeline of any obstacles, including trees, boulders, and brush. Then, sections of pipes are laid out along the intended path in a process called 'stringing' the pipe. Once the pipe is in place, trenches of an specific depth are dug alongside the laid out pipe, and the pipe is assembled and contoured, which includes welding the sections of pipe together into one continuous pipeline, an bending it to fit the contour of the pipeline's path. Coating is applied to the ends of the pipes and the pipeline is inspected for any defects. Finally, the pipelines are lowered into the previously dug trenches, using specialized construction equipment to lift the pipe and lower it into the trench. Once lowered into the ground, the trench is filled. Before using the pipelines to transport natural gas, they are tested with water at high pressures. This serves as a test to ensure that the pipeline is strong enough, and absent of any leaks of fissures before natural gas is pumped through the pipeline [24].

3.3. External factors that affect the supply of natural gas

Increases in natural gas supply normally result in lower prices of this resource, while decreases in supply generally lead to higher prices. The amount of natural gas supplied depends on a series of external factors, among which weather conditions, levels of storage and production, political relations and civil unrest, availability of workers and equipment, capacity of the pipeline system, access to natural gas deposits, and the financial environment, might be the most influential ones [29].

3.3.1. Weather conditions

Natural gas production is always going to be influenced by the weather. The production and distribution process requires pulling resources out of the earth and transporting it long distances, having to keep the natural gas at a certain temperature and pressure to avoid any accidents. Rainstorms can slow down workers out in the natural gas wells, and big storms can be even more disruptive. A hurricane or tornado can cause serious damage to equipment and disrupt the supply chain [29].

In 2005, Hurricanes Katrina and Rita in the Gulf of Mexico disrupted natural gas production, supply fell drastically in the U.S. and prices spiked. A hurricane today in the Gulf of Mexico, however, would not affect U.S. natural gas prices so much since production in the Gulf has fallen from about 25% in 2001 to 2% in 2020 [29].

Very cold weather can also disrupt natural gas production. If these supply disruptions occur when demand for natural gas is high, prices may increase more than expected. An example of this was the blackout that took place in February of 2021 in Texas, U.S.A. Equipment was not prepared to work in freezing temperatures, which caused the natural gas system to collapse during the cold snap. Fracking requires massive amounts of water, which can freeze pipes and wells, which also led to the disruption of the natural gas extraction process. During this time production dropped 5 billion cubic feet, almost half of the Texas' natural gas production was offline. Gas providers canceled their contracts with utilities and power producers, which had to turn to the volatile spot market to obtain the required energy. Before the cold snap, natural gas in Texas had been trading at around $3 per million BTUs. During the cold snap, natural gas companies were selling it for up to $300 per million BTUs, 100 times over typical prices [30].

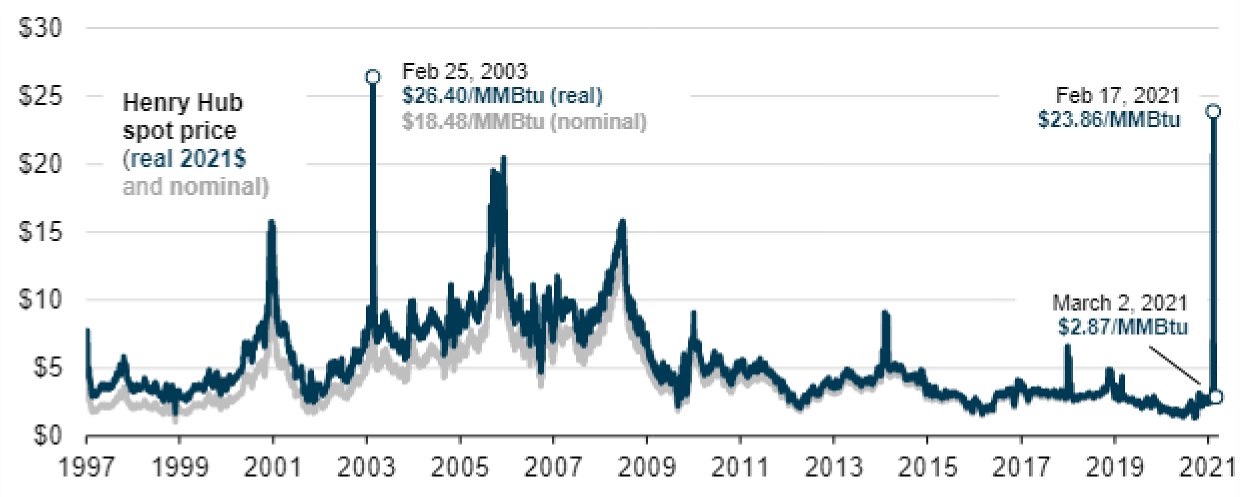


Figure 3.2. Daily Henry Hub natural gas spot prices (Jan 1997- Mar 2021), in $/MMBtu [31].

3.3.2. Production Levels

The level of production is the most direct factor affecting supply. Typically, production tends to increase when demand is high, or reserves are low [29]. As explained above, when production is disrupted due to several factors, supply is interrupted or lowered, depending on the amount of natural gas held in storage. These factors that affect production might include weather conditions that affect the equipment used for production and result in unsafe working conditions, lack of water to perform fracking due to droughts, and lack of workers in the processing facilities due to strikes, among others.

3.3.3. Storage Levels

The level of natural gas in underground storage fields has a large influence on overall supply. When demand is higher than production, natural gas held in storage is used to satisfy the needs for this fuel. On the other hand, when supply is higher than demand, storage serves to absorb this excess in production and saves it for when it is needed. If there is a shortage in production and storage levels are not high enough, supply might fall, failing to meet demand. Storage also supports pipeline operations and trading hub services. Levels of natural gas in storage typically increase from April through November, when overall demand for natural gas is lower. Levels of natural gas in storage typically decrease from November through March, when demand for natural gas for heating is generally high [29].

3.3.4. Political Relations and Civil Unrest

Some countries do not have their own source of natural gas, they do not produce this fuel and they must rely in other countries' supply. International political relations might affect natural gas supply in these countries since the producer countries have the power to set the terms of the fuel exchange.

This is the case of Spain, which until some months ago, relied on the imports from Argelia's pipeline and Magreb's pipeline. However, in October 2021, Morocco terminated the contract with Spain that allowed Spain to import natural gas from the Magreb pipeline. Spain now relies entirely in Argelia for their gas supply. Spanish government needs to take care of its relationship with Argelia's government, since if the exporter country decides to terminate its natural gas exchange with the Iberian Peninsula, Spain would have serious supply shortage problems.

Similarly, when countries become at war, their supply of natural gas might be altered. Both if they rely on their own natural gas production or if they rely on another country, the natural gas supply chain might be disrupted due to lack of production, unsafe conditions in transportation, and lack of imports.

3.3.5. Accidents

In addition, malfunctions and accidents may occur, even if the safety measures in the natural gas industry are very developed. These accidents might disrupt the delivery of natural gas. For example, a compressor malfunction in a large pipeline serving a major hub could temporarily disrupt the flow of natural gas through that important market center [32].

3.3.6. Availability of Skilled Workers

The period needed to hire and train skilled workers when we need to increase supply due to an increase of demand, is sometimes too long to meet consumer needs on time. An example of this is the scenario that took place in 1999, when after eight years of relatively low prices and stable levels of required supply, demand increased suddenly and natural gas companies did not have enough skilled workers to meet it, since a lot of workers had left these companies during the previous years, or they had been laid off. To counter this problem, many production companies offer increasingly high wages, as well as scholarships and educational contributions to attract professionals to the industry [32].

3.3.7. Availability of Equipment

The equipment used for the extraction, production, transportation and distribution of natural gas is normally very expensive. When natural gas demand is low and therefore not much supply is needed, less of all pieces of equipment is required. However, when there is a need to increase supply, more equipment needs to be bought and installed, and this takes time. An example of this equipment are drilling rigs. Producers and production equipment suppliers have difficulties in planning the construction and placement of drilling rigs far in advance, due to price volatility in the industry. Drilling rig counts have traditionally been a good indication of the status of the oil and natural gas production industry. This direct relation between the drilling rigs count and natural gas prices, however, somewhat weakened with the arrival of shale gas production, horizontal drilling and fracking [32].

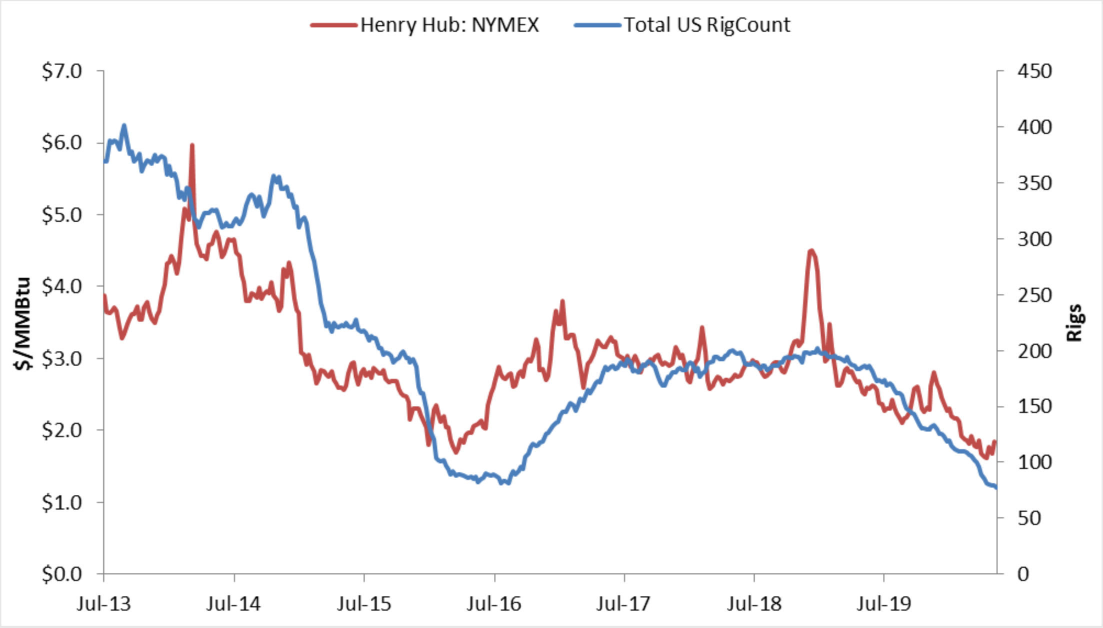


Figure 3.3. Baker-Hughes Gas Rig Count vs. Henry Hub [34].

3.3.8. Permitting and Well Development

Before a natural gas well actually begins producing, there are several procedures and development activities that must take place. After a natural gas reserve is spotted during exploration, production companies might ask for approval to exploit that land. When this approval is received, the well is drilled, and the extraction and field processing equipment is set up, as well as gathering systems. In all, the time elapsed between the location of natural gas deposits and the beginning of production can range from a few months to 10 years [32].

3.3.9. Pipeline Infrastructure

The ability to transport natural gas from producing regions to consumption regions also affects the availability of supplies to the marketplace. The international pipeline infrastructure can only transport a certain amount of natural gas at once, which determines the maximum amount of natural gas that can reach the market at once. Therefore, natural gas pipeline companies must continue to expand the pipeline infrastructure in order to meet growing demand [32].

3.3.10. Onshore and Offshore Access

In order to increase supply in a more long-term period, resources are needed. Since natural gas is not a renewable resource, the amount of natural gas in a well is finite, so there is a need to find more natural gas deposits and drill new wells. Much of natural gas resources are off-limits to exploration and production. A report published in 2010 by the Gas Technology Institute and Science Applications International Corporation estimated 41% of natural gas is inaccessible, and another 49% is restricted beyond standard terms. Coastal resources are the hardest to access, especially after the tragic Deepwater Horizon accident and oil spill in spring 2010, which restricted deep-water drilling permits [32].

3.3.11. The Financial Environment

Exploring for and producing natural gas requires large investments. Production companies need therefore to raise capital to increase production. When the economy is not at its best, raising this capital might turn out to be more complicated. While efficient and transparent financial markets do offer options for raising capital effectively, the rate at which production companies may do so can be a limiting factor in the increasing availability of supplies reaching the market [32].

3.4. Global supply of natural gas

Natural gas is widely expected to remain a relied-upon fuel source for years to come, while renewable sources of energy develop, to achieve a net-zero emissions energy system. Natural gas functions as a bridge between higher-carbon fossil fuels like coal and oil and the growing fleet of renewables like wind and solar [44]. Therefore, many countries are investing in finding and exploiting natural gas reserves.

According to the International Energy Agency (IEA), natural gas supplies approximately 23% of the world's primary energy demand. Global production has risen since the 2008 financial crisis, boosted by the development of unconventional shale fracking technologies. According to the BP Statistical Review of World Energy 2020, natural gas production totaled to 3.99 trillion cubic meters (Tcm) in 2019, growing by 132 Bcm (3.4%) with respect to 2018's production. The US accounted for almost two thirds of net global growth, with the volumetric increase of 85 Bcm. Supply was also boosted by strong growth in Australia (23 Bcm) and China (16 Bcm) [46].

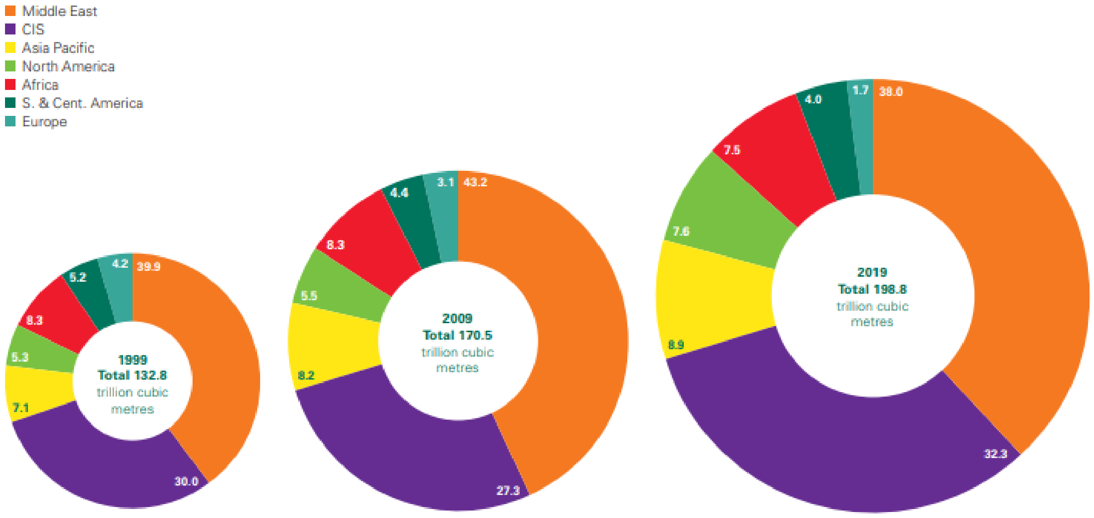


Figure 3.4. Distribution of proved reserves by geographical area in 1999, 2009 and 2019 in percentages [46].

According to the BP Statistical Review of World Energy 2020, the world's total proved reserves of natural gas increased by 1.7 Tcm to 198.8 Tcm in 2019, while in 1999 these proved reserves only amounted to 132.8 Tcm. China (2 Tcm) and Azerbaijan (0.7 Tcm) provided the largest increments, although this was partially offset by a 1.3 Tcm decline in Indonesian reserves. Russia (38 Tcm), Iran (32 Tcm) and Qatar (24.7 Tcm) are the countries with the largest reserves. The current global R/P ratio shows that gas reserves in 2019 accounted for 49.8 years of current production. The Middle East (108.7 years) and CIS (75.8 years) are the regions with the highest R/P ratio [46].

The US accounted for 23% of the world's natural gas production in 2019, with 921 Bcm, being the biggest natural gas producer in the world. Texas and Pennsylvania are the two states which produce the most natural gas in the US, mostly using fracking or horizontal drilling techniques [44].

Russia is the world's second-biggest natural gas-producing country, supplying 679 Bcm in 2019, 17% of the global total. This country is also the one that has the largest-known reserves of the fuel (est. 38 tcm), most of which is located in Siberia. Russia mainly exports to Europe, Turkey and Asia [44].

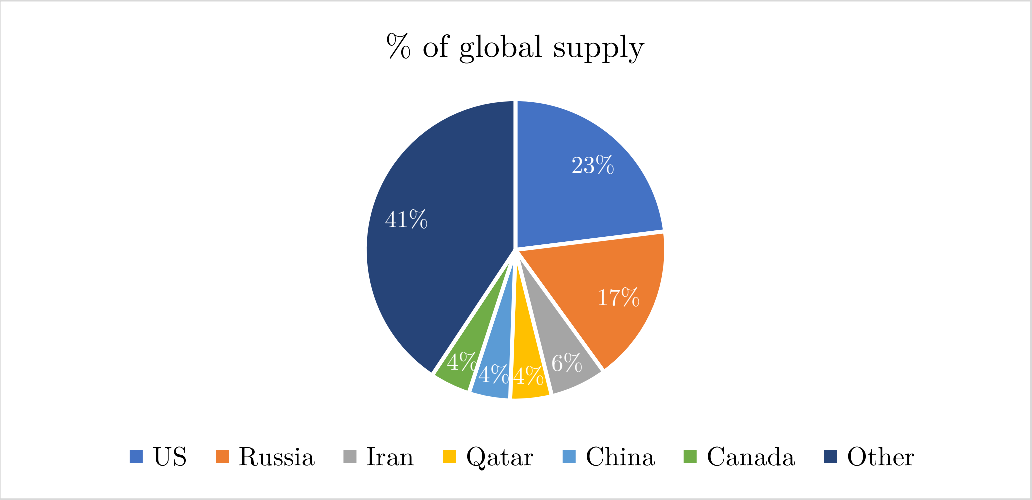
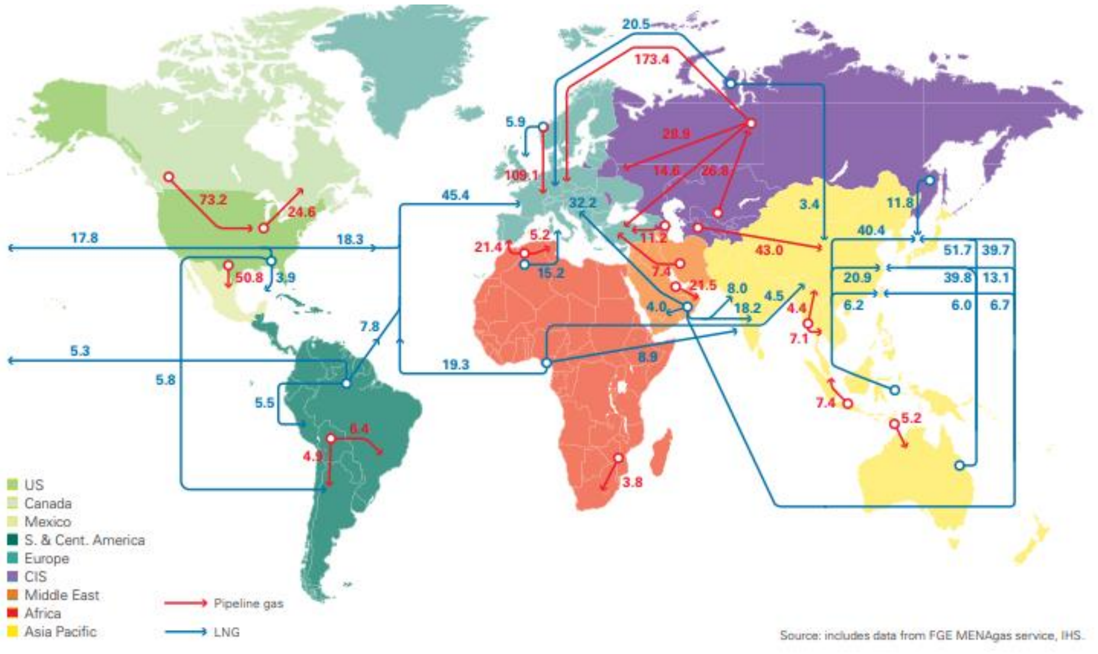


Figure 3.5. World's natural gas supply by country. *Source: own elaboration using data from NS Energy [44].*

Iran produced 6% of the world's natural gas in 2019, amounting to around 244 Bcm. Iran holds the second-biggest reserves globally, which means that even if as of today its production is not even close to that of the U.S., it is probably going to be a key player in the natural gas market in the near future. This delay in the development of the commercial potential of these vast reserves is the consequence of economic sanctions against the country, mostly by the U.S. in response to geopolitical tensions and Iran's nuclear development program [44].

Qatar produced around 4.5% of the global natural gas share in 2019 (178 Bcm). The majority of the Middle Eastern country's production takes place across the North Field, in the gasfield located in the Persian Gulf which Qatar shares with Iran. In addition, Qatar is the world's biggest producer of liquefied natural gas (LNG), and was the biggest LNG exporter in 2019, followed by Australia. The country is working on the North Field East expansion project, to develop what will become the largest LNG project in the world with a capacity of 33 million tonnes per year [44].



Source: includes data from FGE MENAgas service, IHS.

Figure 3.6. Major natural gas trade movements in 2019 (Bcm) [46].

China produced just as much natural gas as Qatar in 2019 (178 Bcm). The most productive regions in the country include Sichuan–Chongqing, Shaanxi, and Xinjiang. Most of the natural gas is produced using traditional techniques, even though the government has recently increased its investments to develop fracking techniques [44].

The sixth largest producer of natural gas in 2019 was Canada in 2019, with 4.3% of the global supply (173 Bcm). Most of the country's natural gas production (71%) takes place in the province of Alberta, followed by British Colombia, which accounts for around 27% of national production. Canada exports to the U.S. via pipeline more natural gas than it consumes [44].

These countries are home for most of the world's biggest natural gas companies. The largest natural gas companies are also some of the largest oil companies as most energy companies are diversified across business sectors. The company that produces the most natural gas in the world is Russian, while the largest natural gas companies by revenues are from China and Saudi Arabia [45].

In the U.S., energy majors ExxonMobil and Chevron are among the world's largest natural gas-producing companies. ExxonMobil produced 0.25 Bcm per day in 2019 and had revenues of $265 billion. Chevron, the second largest integrated American energy giant, reported production of about 0.17 Bcm per day in 2019. Chevron not only produces natural gas but also maintains vast upstream oil operations and downstream activities in petrochemicals, lubricants, additives, and gasoline. In 2019, Chevron reported revenues of $139 billion [45].

In Russia, there are three main natural gas companies. Gazprom, a state-backed company, is the world's largest natural gas producer in quantity, and accounts for around 12% of global production and 68% of domestic production in Russia. In 2019, Gazprom reported revenues of $39 billion. Rosneft is the second largest Russian natural gas company in quantity of natural gas produced, but the first one in revenues. It is also controlled by the Russian government, and it is involved in the exploration and production of hydrocarbons. In 2019, Rosneft's revenues amounted to $136 billion. Lastly, Lukoil, is the third biggest natural gas producer in quantity but the second one in revenues. Lukoil extracts and refines oil and natural gas primarily from western Siberia. In 2019, it had revenues of $107 billion [45].

In Saudi Arabia, Saudi Aramco is the third-largest natural gas company in the world, by revenues. Revenues for 2019 were $295 billion. The company is also the world's largest oil producer, being the sole provider of natural gas and oil to Saudi Arabia. Saudi Arabia's oil and gas industry made up 50% of its GDP in 2018 [45].

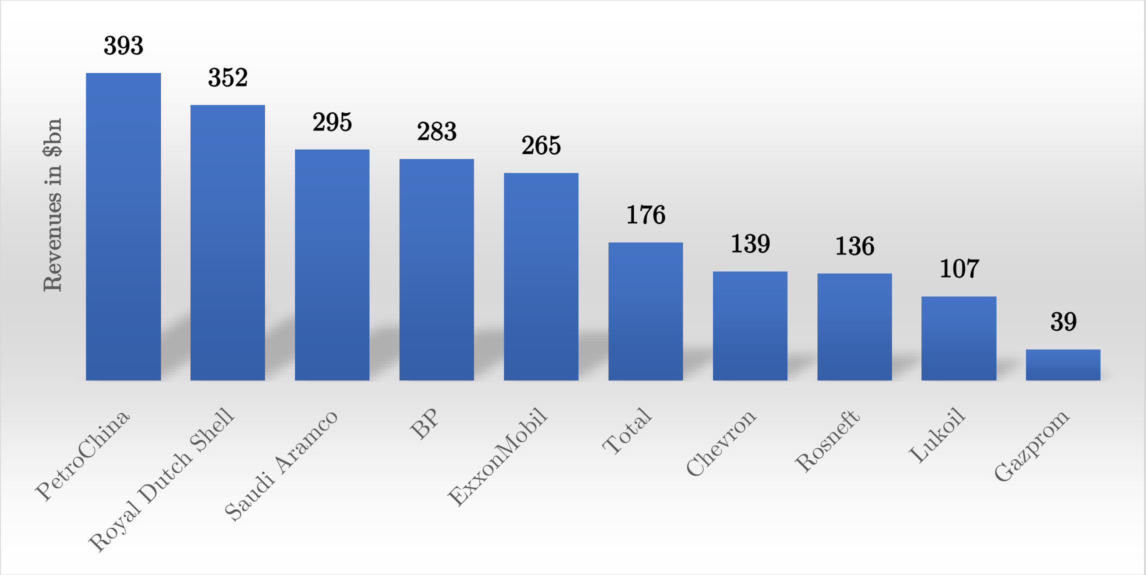


Figure 3.7. Revenues of ten top natural gas companies in the world, 2019. *Source: own elaboration with data from companies' annual reports.*

In China, China National Petroleum Corporation, is the world's biggest natural gas producer in revenues. It also has vast oil and petrochemical production and oil and gas marketing operations. While CNPC is a state-owned enterprise, much of its operations are organized under a publicly listed subsidiary company, PetroChina Company (PTR). PetroChina shares are listed on the NYSE, the Hong Kong Stock Exchange, and the Shanghai Stock Exchange. This subsidiary performs exploring, production, storage, and marketing operations in both the natural gas and oil market. In 2019, PetroChina reported $393 billion of revenues [45].

In Europe, BP, Royal Dutch Shell, and Total are the top three natural gas producers. All of these companies, in addition to producing natural gas, they also carry out worldwide oil exploration and production operations, and petrochemical, lubricant, and retail gasoline businesses. BP is headquartered in London but operates major natural gas production sites around the globe. In 2019, BP had revenues of $283 billion. Royal Dutch Shell is headquartered in the Netherlands and incorporated in the U.K. but its operations expand across the globe. In 2019, it reported revenues of $352 billion. Total is a French oil and gas company that has its main reserves in Europe, Central Asia, Middle East and North Africa. In 2019, its revenues amounted to $176 billion [45].

Chapter 4

Demand of Natural Gas

4.1. Uses of Natural Gas

Demand for natural gas is increasing due to its price-calorific value ratio. According to the U.S. Energy Information Association (EIA), the United States used about 31.5 quadrillion British thermal units (Btu) in 2020 which makes 34% of U.S. total energy consumption [26].

The most common uses of natural gas are for electricity, heating, transportation, and production. The sectors that use this fossil fuel the most are the electric power sector, the industrial sector, the residential sector, the commercial sector, and the transportation sector [26].

The electric power sector uses natural gas to generate electricity. Natural gas power plants usually generate electricity in gas turbines, directly using the hot gases of fuel combustion. Single-cycle gas turbines have an efficiency of 35-40% when converting the heat energy from combustion into electricity. "Combined-cycle" (NGCC) plants are used to obtain higher efficiency rates. These plants first use the combustion gases to drive a gas turbine, then uses the hot gases from the turbine to boil water and drive a steam turbine. Natural gas-fired plants are currently among the cheapest power plants to construct and have greater operational flexibility than coal plants because they can be fired up and turned down rapidly [28]. In 2020, the electric power sector accounted for about 38% of total U.S. natural gas consumption, according to the EIA, and natural gas was the source of about 33% of the U.S. electric power sector's primary energy consumption. Most of the electricity produced by the electric this sector is sold to and used by the other U.S. consuming sectors. Natural gas accounted for 40% of total utility-scale U.S. electricity generation by all sectors in 2020 [26].

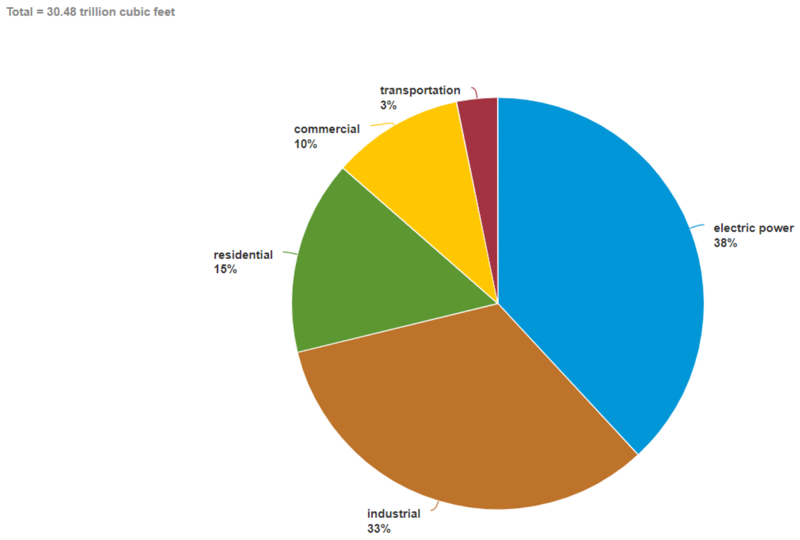


Figure 4.1. US 2020 Natural Gas Consumption by sector [26].

The industrial sector uses natural gas as a fuel for process heating, and as a raw material to produce chemicals, fertilizers, and hydrogen. Most hydrogen gas is produced by making high temperature water vapor react with methane. The resulting hydrogen is used to produce ammonia for fertilizer, one of the most important industrial products derived from natural gas, and as a fuel to produce electricity. This electricity, along with water and heat, are produced in a fuel cell, which combines hydrogen with oxygen. Although the process of reforming natural gas to hydrogen still emits some greenhouse gases, the amount released for each unit of electricity generated is much lower than for a combustion turbine [28]. In 2020, the industrial sector accounted for about 33% of total U.S. natural gas consumption, and natural gas was the source of about 34% of the U.S. industrial sector's total energy consumption [26].

The residential sector uses natural gas to heat buildings and water, to cook, and to dry clothes. According to the EIA, around 50% of the homes in the United States use natural gas for heating. The reason behind this fact is that natural gas heating is more effective than electric heating pumps, since heat from natural gas is delivered from forced-air systems at temperatures between 50-60ºC, whereas the air from an electric heat pump is typically delivered at 30-35ºC [27]. In 2020, the residential sector accounted for about 15% of total U.S. natural gas consumption, and natural gas was the source of about 23% of the U.S. residential sector's total energy consumption [26].

The commercial sector uses natural gas to heat buildings and water, to operate refrigeration and cooling equipment, to cook, to dry clothes, to provide outdoor lighting, and as a fuel in combined heat and power systems. In 2020, the commercial sector accounted for about 10% of total U.S. natural gas consumption, and natural gas was the source of about 19% of the U.S. commercial sector's total energy consumption [26].

The transportation sector uses natural gas as a vehicle fuel (in the form of CNG and LNG) and to operate compressors that move natural gas through pipelines, as mentioned in the last chapter. Compressed natural gas (CNG) can be burned in an internal modified combustion engine, emitting much less carbon monoxide, nitrogen oxides (NOx), and particulates than conventional combustion engines. However, CNG has a low energy density compared with liquid fuels, which makes vehicles to require big, bulky fuel tanks, making CNG practical mainly for large vehicles such as buses and trucks [28]. In 2020, the transportation sector accounted for about 3% of total U.S. natural gas consumption. Natural gas was the source of about 4% of the U.S. transportation sector's total energy consumption in 2020, of which 94% was for natural gas transportation and distribution. Although natural gas is not the main source of energy in this industry, it is petroleum, it is used significantly more than electricity (natural gas was the source of about 4% of the U.S. transportation sector's total energy, while electricity accounted only for about 1% of this energy) [26].

Another increasing use of natural gas is cogeneration and trigeneration. Cogeneration is the simultaneous generation of electricity and heat, while trigeneration is the simultaneous generation of electricity, heat and cooling. These forms of generation increase greatly the efficiencies of natural gas [28].

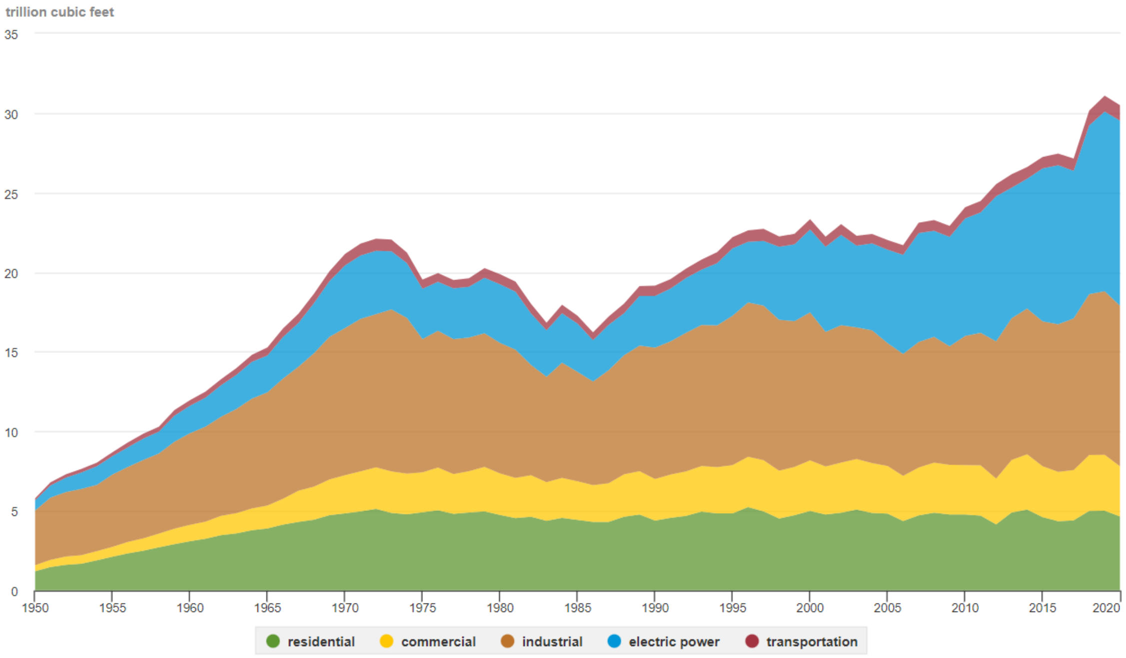


Figure 4.2. US Natural Gas Consumption by sector, 1950-2020 [26].

4.2. External factors that affect the demand of natural gas

Natural gas is believed to be a key fuel for the transition to a zero-emission world. Natural gas, therefore, is expected to play an increasingly important role in meeting demand for energy. This section will address the long term and short-term factors that affect demand for natural gas.

4.2.1. Factors affecting short-time demand for natural gas

Demand for natural gas depends highly on the time of year, and changes from season to season. The highest demand has traditionally been registered for the coldest months (January and February) while the lowest demand has been associated to the warmest months of summer (July and August). The main driver for this primary cycle of natural gas demand is the need for residential and commercial heating [33].

However, this traditional demand cycle for natural gas was shifted when the fuel started to be used as a source for electricity generation. While requirements for natural gas heating decrease during the summer months, demand for space cooling increases during this warmer season, which requires electricity. This way, demand for natural gas in the warmest months is nowadays not as low as it used to be. Thus, natural gas demand experiences its most pronounced increase in the coldest months [33].

In general, in addition to this cyclical demand cycle, there are three primary drivers that determine the demand for natural gas in the short term: weather, fuel switching and the economic environment.

As explained above, the colder the weather, the sharper the increase in demand for natural gas. The warmer the winter, therefore, less noticeable winter peak in demand. An extremely hot summer, on the other hand, can result in a raise in natural gas demand during the summer months. This means that even if normally the peak is registered in the winter during the cold months, untypical weather conditions might reverse the cycle [33].

Demand for natural gas is also affected by the price of natural gas versus other fuels, such as coal. When the price of natural gas is very high, consumers that have the ability to switch between fuels, will choose the cheapest of the fuels available, decreasing demand for natural gas. The contrary also happens, when the other fuels are pricier, demand for natural gas peaks. While most residential and commercial customers rely solely on natural gas to meet many of their energy requirements, some industrial and electric generation consumers have the capacity to switch between fuels [33].

Another factor that might affect natural gas demand in the short term is the state of the global economy. When the economy is expanding, output from industrial sectors is generally increasing at a similar rate. When the economy is in recession, output from industrial sectors drops. The amount of output coming out from industries determine the energy needed by these industrial users, and therefore affects demand for natural gas. For instance, during the economic downturn of 2008, industrial natural gas consumption fell by over 7% [33].

4.2.2. Factors affecting long-time demand for natural gas

Long-term demand factors reflect the basic trends that will determine natural gas use in the future. These factors can be better analyzed by sector.

Factors Affecting Residential and Commercial Demand

The main factor affecting residential and commercial demand in the long term is the use of heating powered by natural gas. The number of houses with installed natural gas heating has been increasing in the past decades. However, the efficiency of natural gas furnaces has increased, so the demand has not grown proportionally to the number of new houses with a natural gas heating system. The EIA expects energy demand in the commercial sector to increase at an average annual rate of 1.1 percent through 2035 [33].

Several other factors are expected to drive residential and commercial natural gas demand, such as increasing demand for electricity, demographics and population centers, and energy efficiency regulations.

Electricity is the greatest competitor to natural gas, meaning that its price and availability directly affects the demand for natural gas. Electricity prices are expected to decrease in the next 20 years, as renewable sources consolidate, and the number of appliances using electricity will increase [33].

The changing demographics of the world population can also affect the demand for natural gas. The more population in the world, the more demand for all kind of resources. Moreover, if the population moved to warmer areas, the demand for natural gas would decrease, since it is the main source for heating, while electricity is the main source for cooling. However, if distributed generation and residential natural gas cooling technologies advanced, and residential consumers could use natural gas to supply their electricity needs, natural gas demand could in fact increase [33].

Natural gas is extremely efficient, losing very little of its energy value as it reaches its point of end use. Electricity, on the other hand, measured from the point of generation to the end use, is much less efficient, even though its efficiency has increased in the past years. In fact, only about 27% of the energy put into generating electricity is available by the time it reaches people's homes, due to the energy that is lost in generation and transmission. Regulations regarding total energy efficiency may therefore push the use of natural gas for residential and commercial appliances [33].

Factors Affecting Industrial Demand

The industrial sector is the moving away from energy-intensive manufacturing processes, which affects the demand for natural gas. This decrease in the energy used is due to the increased energy efficiency of equipment and processes used in the industrial sector, as well as a shift to the manufacture of goods that require less energy input [33].

Despite this shift from energy-intensive processes there are other factors which could affect the demand for natural gas over other sources of energy to meet the medium-long term energy requirements of the industrial sector.

The need of efficient equipment and processes could lead to increased demand for efficient natural gas-powered applications in the sector to replace those processes which are extremely energy inefficient. However, this increase in demand for natural gas depends on the price and availability of electricity in the industrial sector, just like in the commercial and residential sector [33].

Restrictions on industrial air emissions are being tightened significantly. Natural gas represents a cleaner burning alternative to coal and petroleum use in the industrial sector and the imposition of stringent regulations may serve to increase the demand for natural gas in the industrial sector, at least during the transition to a zero-emission world, where all the energy will come from renewables [33].

Factors Affecting Electric Generation Demand

The demand for electricity is predicted by the EIA to increase by an average rate of 1 percent per year through 2035. In order to meet this growing demand natural gas-fired combines cycle generation plants are a feasible option, because of the relatively low capital requirements for building this type of plants, as well as the reduction of emissions that can be earned from using natural gas as opposed to other fossil fuels [33]. In 2020, natural gas power plant capacity continued to expand, with over 40 GW of new capacity, primarily driven by the Middle East, the United States and China [35].

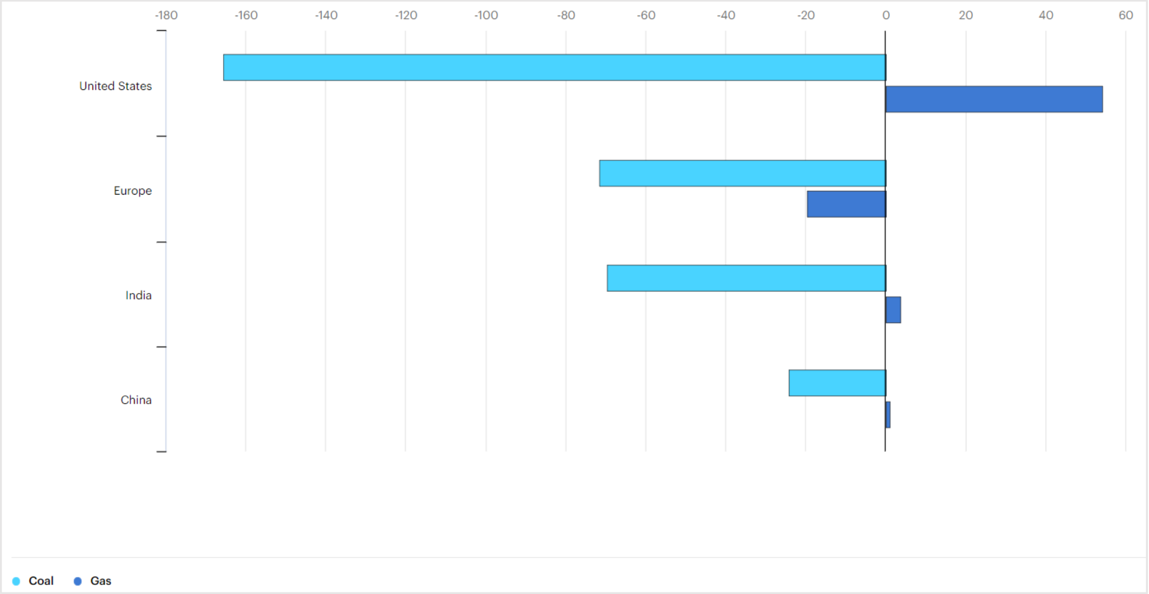


Figure 4.3. Change in coal and gas-fired power generation Q1-Q3, 2020 compared to 2019 [35].

In addition to increased demand for natural gas-powered central station generation, distributed electricity generation may serve to increase the demand for natural gas for electricity generation purposes in the future [33].

The retirement of old nuclear, petroleum, and coal powered generation plants, combined with the increased demand for electricity, leaves a need to fulfill this electric generation demand with other sources of energy, such as renewables and natural gas. Natural gas plants are more flexible, cleaner, require smaller investments and are more efficient than many other types of power plants. That is why capacity for these plants keep growing as we move towards a cleaner world [33].

Factors Affecting Transportation Sector Demand

As long as the batteries for electric vehicles are not further developed, natural gas will be the first alternative to traditional fuels, especially in heavy-duty vehicles. The demand for this type of vehicles is growing primarily due to new legislation and regulation concerning emissions from the transportation sector. This demand will be affected by the development of the electric vehicle, which is the only cleaner alternative to natural gas vehicles [33].

4.3. Global demand of natural gas

As of 2021, the world consumes around 4,000 billion cubic meters (Bcm) of natural gas per year. North America and Europe are the largest consumers of this fuel, consuming 28% and 16% of the world's natural gas, respectively. The Middle East consumes only 12% since they still rely greatly on oil. For countries, the U.S. and Russia are the greatest consumers, using around 22 and 14% of global natural gas production, respectively. China, as of today, consumes 5.5% of the global production, but it is expected to take the lead by 2040 and become the most crucial player in the natural gas market, due to the massive development in Chinese industries and manufacturing based on natural gas [36].

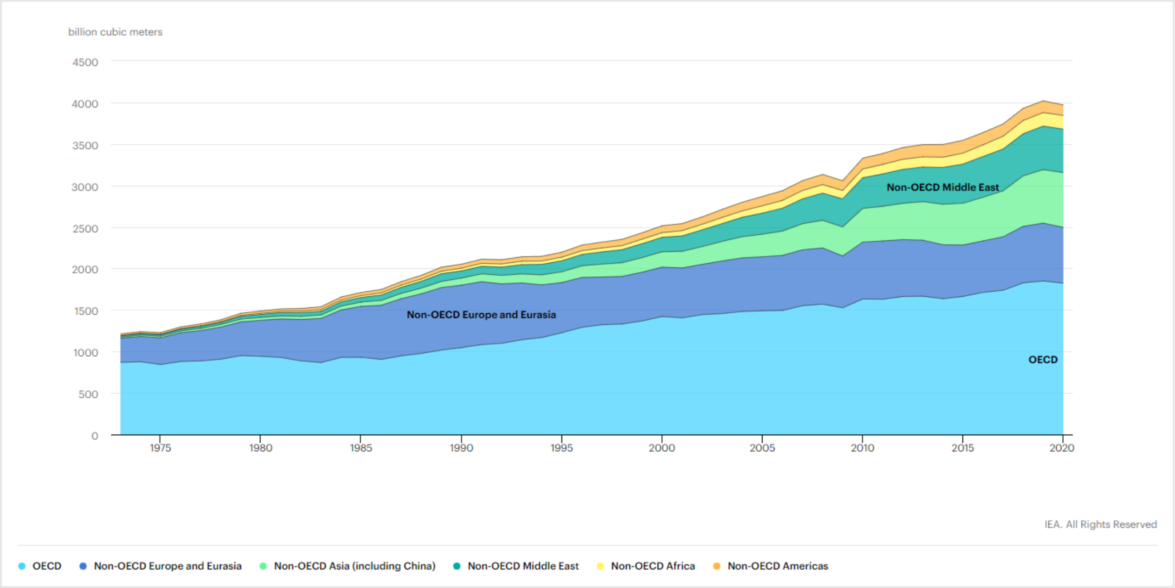


Figure 4.4. World Natural Gas Demand by Region, 1973-2020 [37].

In 2020, according to the EIA, global demand natural gas shrank by 2.5%, falling to 3,910 Bcm. This fall was due to the Covid-19 pandemic, added to historically mild temperatures over the first months of the year. The lower level of industrial activity caused by the pandemic and the decrease of heating demand during the warm winter, resulted in a strong supply and trade adjustment and historically low spot prices and high volatility [38]. However, gas demand declined less than other fossil fuels. In addition, gas consumption began to progressively recover during 3Q2020 as lockdown measures eased, while seasonal electricity demand and competitive prices pushed up gas consumption [42].

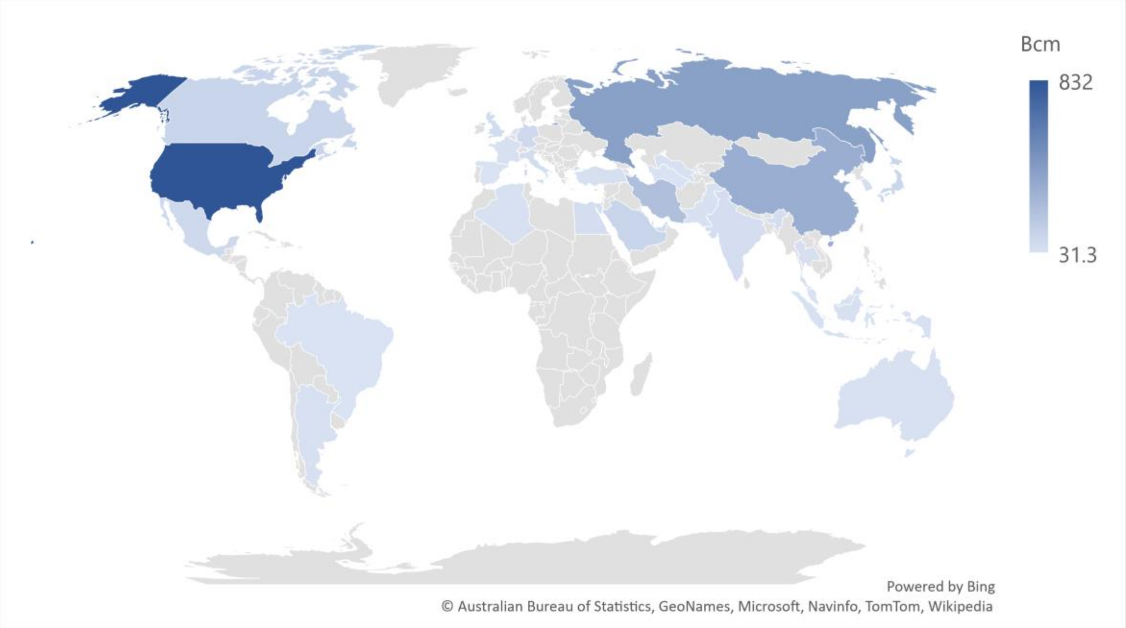


Figure 4.5. Global natural gas demand by country, 2020. Top 30 consumers. *Source: Own elaboration from the data provided by Statista [43].*

In 2021, the EIA forecasts that demand will be 1.3% above the 2019 levels. This growth will be led by China and India, where gas benefits from strong policy support. In both countries, the demand for natural gas is mostly driven by the industrial sector, making the natural gas market highly dependent on the pace of markets for industrial goods [38].

In the fall of 2021, record-high spot gas prices were recorded in Europe and Asia. Storage inventory levels were at their lowest due to robust demand growth as economies recovered from 2020 lockdowns, extreme weather episodes that caused an increase in gas consumption, and a series of outages that interrupted gas production and export capacity [40].

The global shortfalls are tied to the growing popularity of natural gas as a fuel for generating electrical power, because it creates less greenhouse gas emissions than conventional fuels. In many countries, it is serving as a cleaner alternative to coal-burning plants as well as old nuclear generators, and as a form of transition to renewables sources like wind and solar. This increased consumption results in less flexibility in the system, aggravated as the capacity to store gas for times of high use has declined in some countries like Britain [41].

According to the McKinsey report “Global gas outlook to 2050”, gas will be the strongest-growing fossil fuel and will increase by 0.9% from 2020 to 2035. It is the only fossil fuel expected to grow beyond 2030, peaking in 2037. From 2035 to 2050, gas demand will decline by 0.4%, due to an accelerating decline in gas used for power but alleviated by hard-to-replace gas use in the chemical and industrial sectors. Meanwhile, LNG demand is expected to grow 3.4% per year until 2035, with around 100 million metric tons of additional capacity required to meet both demand growth and decline from existing projects. From 2035 to 2050, LNG demand growth will slow down to 0.5% per year, with more than 200 million metric tons of new capacity required by 2050 [39].

Chapter 5

Modelling the Market for Natural Gas

In order to model the market for natural gas, we have gathered a few indicators or variables which could explain the variations in the price of this fuel. We have divided these indicators in two groups: indicators of supply and indicators of demand. In this chapter, we define each of these indicators and explain how they are constructed.

Using these indicators, we have modelled the market for natural gas using a Vector Autoregressive Model (VARM). The fundamentals of this type of models are also developed in the present chapter.

5.1. Indicators of supply

U.S. Natural Gas Gross Withdrawals

This indicator is used to determine the amount of natural gas produced each month in the U.S. This amount is measured in MMcf and the information is available at the EIA website since 1980.

The year-to-year percent change of the amount of natural withdrawn each year in the U.S. was computed to determine whether the change on production levels affects the price of natural gas.

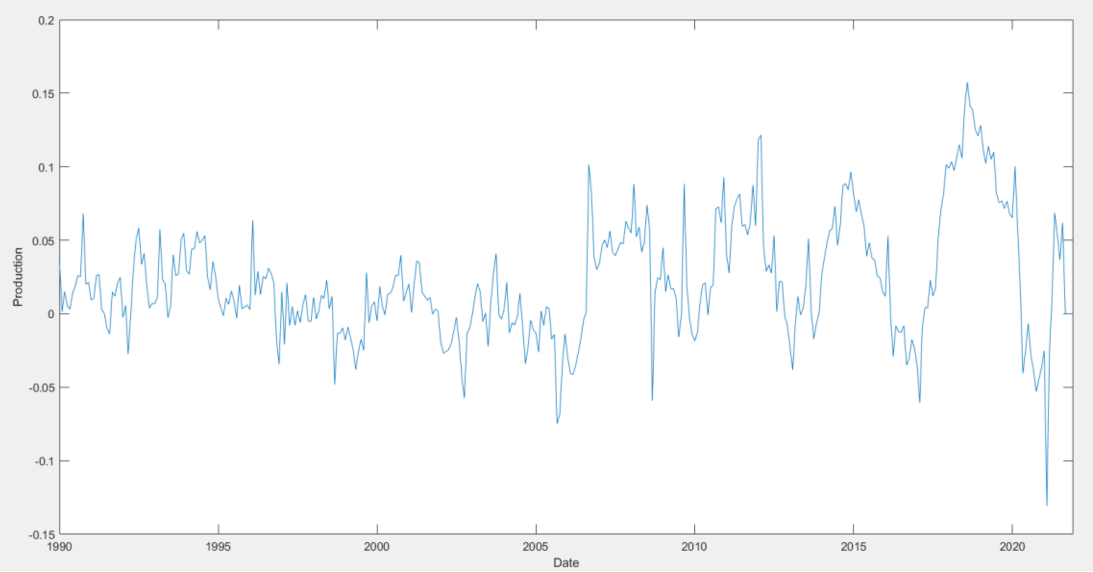


Figure 5.1. Year-to-year percent change of U.S. Natural Gas Gross Withdrawals. *Source: own elaboration with data from EIA [48].*

U.S. Natural Gas Rotary Rigs in Operation

A rotary rig is the equipment used for drilling in most wells, which includes an engine and a hoisting, rotating and mud circulating system. This indicator counts the number of rotary rigs being operated in the U.S. and it is used to determine the level of drilling activity in the U.S. The historical information of the number of rigs in operation is available at the EIA website since 1987.

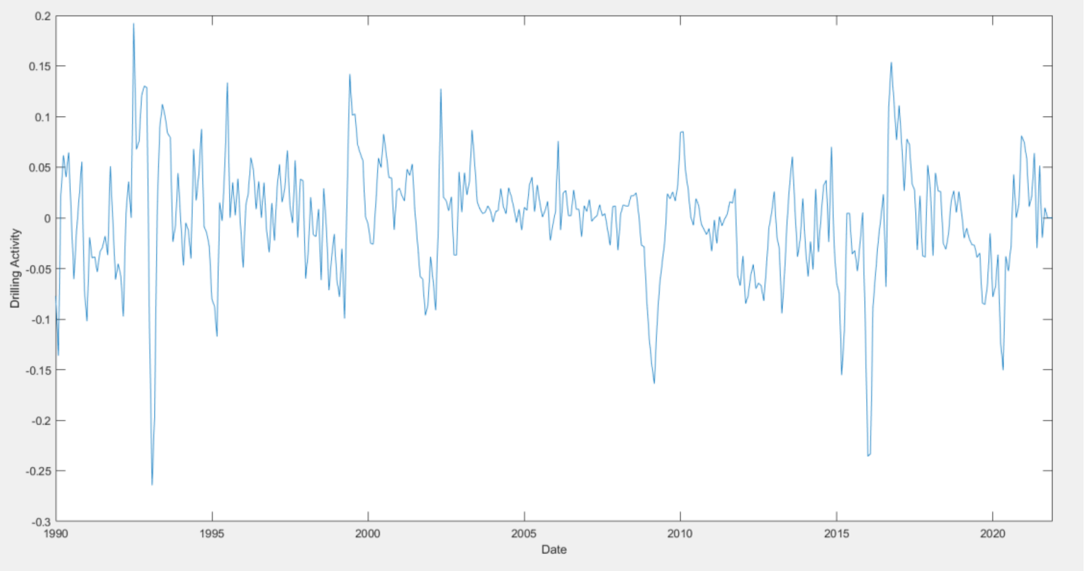


Figure 5.2. Percentage change month-to-month of the number of rotary rigs in operation in the U.S. *Source: own elaboration with data from EIA [48].*

In the model, the percentage month-to-month change of the number of rigs in operation is used to study whether the change on the level of drilling activity has an impact on the price of natural gas.

U.S. Natural Gas Underground Storage Volume

The US Natural Gas underground storage volume was the measure used in this study to determine the levels of inventories of natural gas. This information can be found at the EIA website and is updated every month since 1979. The volume of underground storage is measured in MMcf.

In the model, the year-to-year change of this volume was used, in order to determine the effect of the change of this variable on the price of natural gas.

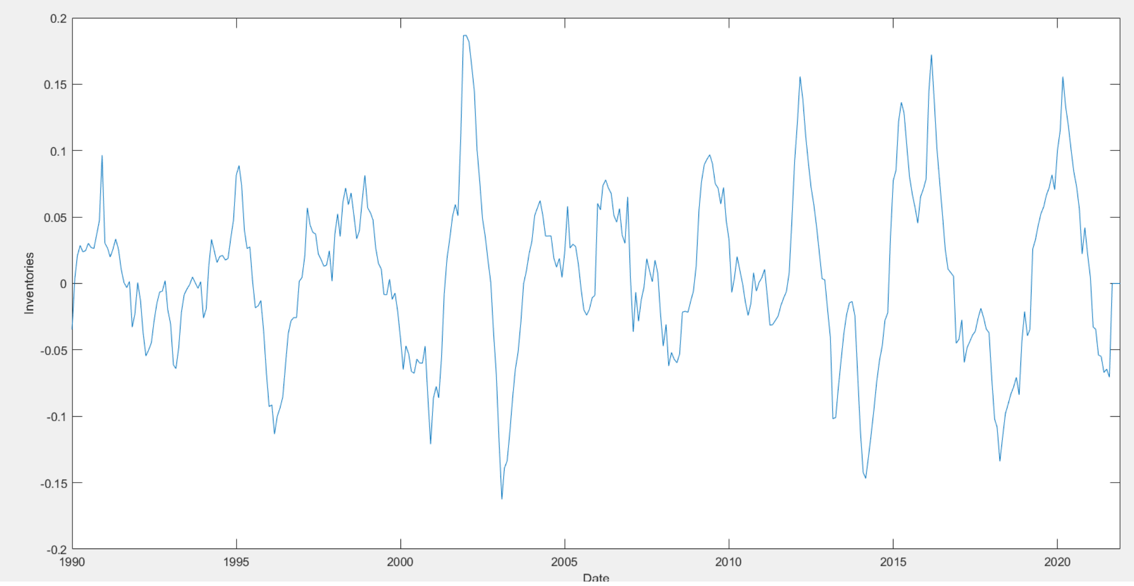


Figure 5.3. Percentage change year-to-year of U.S. Natural Gas underground storage volume. *Source: own elaboration with data from EIA [48].*

5.2. Indicators of demand

Five variables were considered in this study to determine the effect of the change on the demand of natural gas in its price. These variables include the effects on the demand of natural gas of weather conditions, electricity consumption, world industrial production, and monetary policy.

REDTI

The Residential Energy Demand Temperature Index (REDTI) is based on population weighted heating and cooling degree days. This index is a valuable tool for explaining year-to-year fluctuations in energy demand for residential heating and cooling. Residential energy consumption is highly correlated to the number of heating and cooling degree days (HDD’s and CDD’s). Diaz and Quayle (1980) found this correlation between energy use and heating degree days to be as high as 0.97 at the household level. Because of this strong relationship, seasonal changes in the REDTI can provide a good indication of the nation's fluctuating energy demands [47].

The REDTI is calculated on a seasonal basis, using the sum of population weighted HDD's and CDD's (base 65), to provide retrospective information on the impact of seasonal temperatures on residential energy demand from 1895 to the present. To simplify year-to-year comparisons, the index is scaled from 0 to 100. An index of 100 is assigned to the year with the greatest population weighted degree day average while the year with the smallest degree day average receives an index of 0 [47].

The winter season index, for example, is created by calculating the population weighted degree day totals for each winter season. From this series, the maximum and minimum yearly degree day totals are identified. The minimum value is then subtracted from all years in the series so that a new series of values is created which ranges from zero to a value equal to the arithmetic difference between the maximum and minimum. This new series is then scaled to have a range of 0 to 100 using a common scaling factor [47].

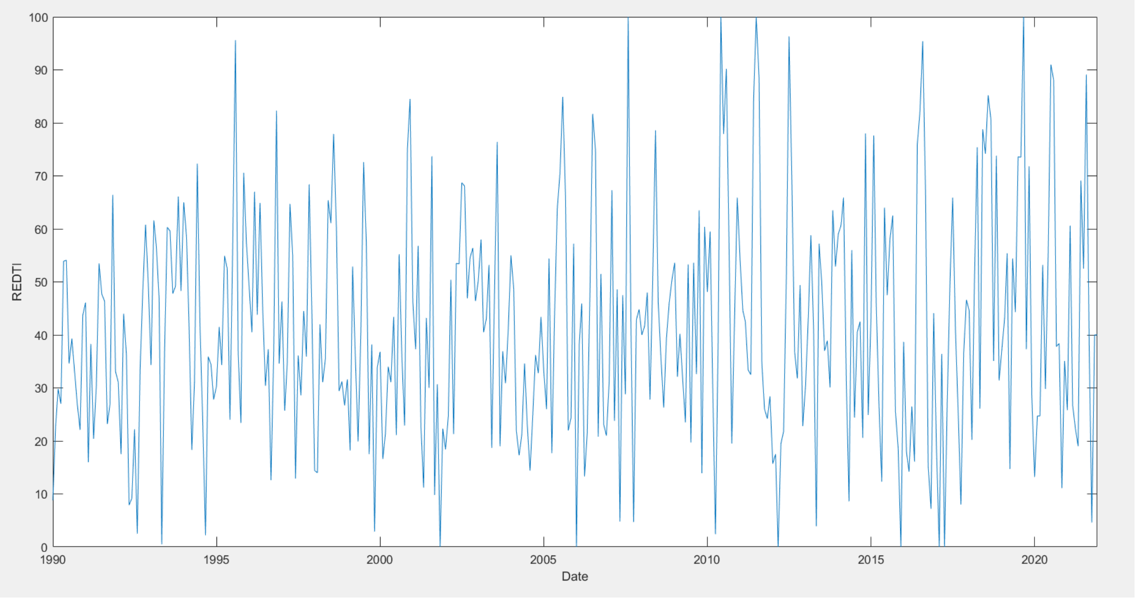


Figure 5.4. Residential Energy Demand Temperature Index 1990-2021. *Source: own elaboration with data from NOAA [47].*

Electricity End Use

In order to determine how the variations in electricity demand affect the price of natural gas, we have included in the model the amount of electricity used historically in the U.S., measured in millions of kilowatts per hour.

This data was obtained from the Monthly Energy Review published by the U.S. Energy Information Administration (EIA). This publication includes total energy production, consumption, stocks, and trade; energy prices; overviews of petroleum, natural gas, coal, electricity, nuclear energy, renewable energy, and carbon dioxide emissions; and data unit conversions values [48].

To use this data in the model, the percent year-to-year change was computed, obtaining the transformed data shown in *Figure 5.5*.

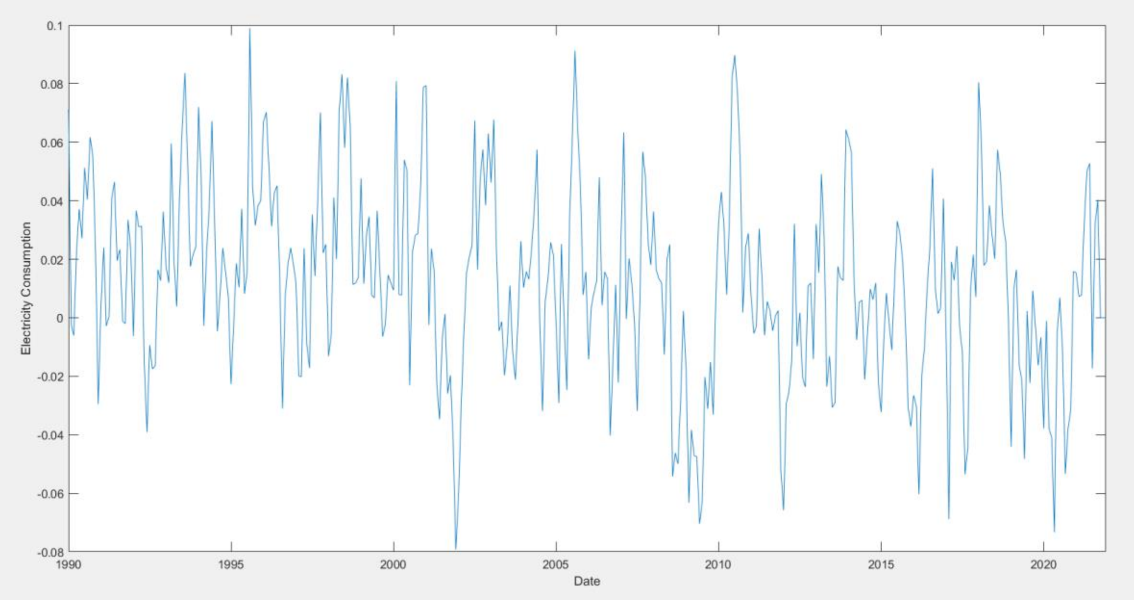


Figure 5.5. Electricity End Use 1990-2021. *Source: own elaboration with data from EIA [48].*

World Industrial Production

The Baumeister and Hamilton's World Industrial Production index (2019) is an indicator of the world's economic activity [53]. For empirical analysis of the determinants of variables like commodity prices researchers often use a monthly measure of economic activity. This global economic activity can be measured either using a market price such as the cost of shipping as a proxy (Kilian, 2009) or an index of global industrial activity. OECD Main Economic Indicators published an estimate of monthly industrial production for the OECD plus 6 other major countries (Brazil, China, India, Indonesia, the Russian Federation and South Africa). The OECD series begins in January 1958 and ends in October 2011. Baumeister and Hamilton (2019) reproduced the methodology by which the original index was constructed to extend the series up to July 2018 [53]. Although shipping costs offer a plausible option for measuring the level of real economic activity, in practice they do not work nearly as well as estimates of global industrial production, particularly after 2015.

The world industrial production index measures levels of production in the manufacturing, mining, oil and gas field drilling services, and electrical and gas utilities sectors. It also measures capacity, which is an estimate of the production levels that could be sustainably maintained, and capacity utilization, which is the ratio of actual output to capacity. This industrial production and capacity levels are expressed as an index level relative to a base year.

In our model, we used the year-to-year percent change of this index of world industrial production to study if the global economic activity had an impact on the demand and therefore on the price of natural gas.

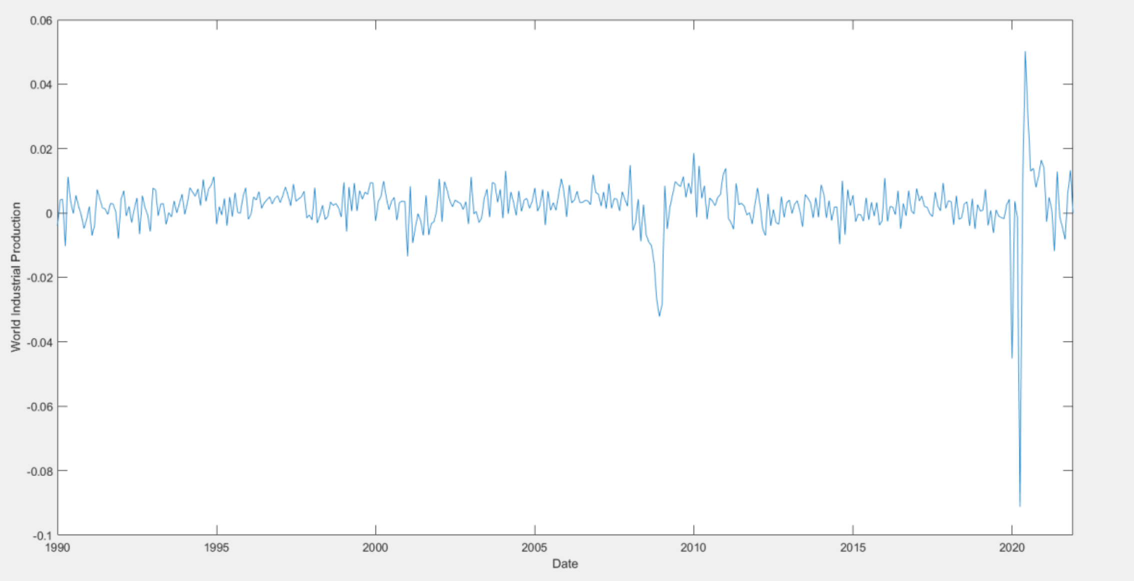


Figure 5.6. Year-to-year percent change of World Industrial Production levels. *Source: own elaboration with data from OECD data [56].*

Wu-Xia Shadow Federal Funds Rate

After the 2007-2010 financial crisis, Xia and Wu (2016) proposed a tool, a “shadow rate,” that can be used in established economic models to measure the economic effects of unconventional monetary policies, such as the Federal Reserve’s quantitative-easing program. Traditional economic models used for research do not capture these effects when key interest rates sit at or near zero, as they do in much of the developed world today [51].

In normal economic times, economists use the federal funds rate, which is the interest rate banks use to lend to each other overnight, in economic models. But in 2009, the fed funds rate hit zero, and monetary policy entered the zone termed the “zero lower bound”, and the fed funds rate stopped working as a measure of monetary policy [51].

Xia and Wu (2016), proposed an alternate shadow fed funds rate that can be negative, reflecting the Fed’s additional easing through unconventional policies [51].

The model of Xia and Wu (2016) uses one-month forward rates beginning n years hence. Xia and Wu use forward rates corresponding to n = 1/4, 1/2, 1, 2, 5, 7, and 10 years. These forward rates are constructed with end-of-month Nelson-Siegel-Svensson (1987) yield curve parameters from the Gurkaynak, Sack, and Wright (2006) dataset [65]. The shadow rate is assumed to be a linear function of three latent variables called factors, which follow a VAR process. The latent factors and the shadow rate are estimated with the extended Kalman filter [50].

By plugging the shadow rate into a vector autoregression model (VAR), the effects of quantitative easing on economic aggregates such as the unemployment rate, industrial production, and housing starts, can be measured [51].

Shadow rate models are used by many researchers to characterize the term structure of interest rates (Kim and Singleton [2012] and Bauer and Rudebusch [2013]) or quantify the stance of monetary policy (Bullard [2012] and Krippner [2013]) [50]. In this model estimates from the Xia and Wu (2016) model of the shadow rate are used.

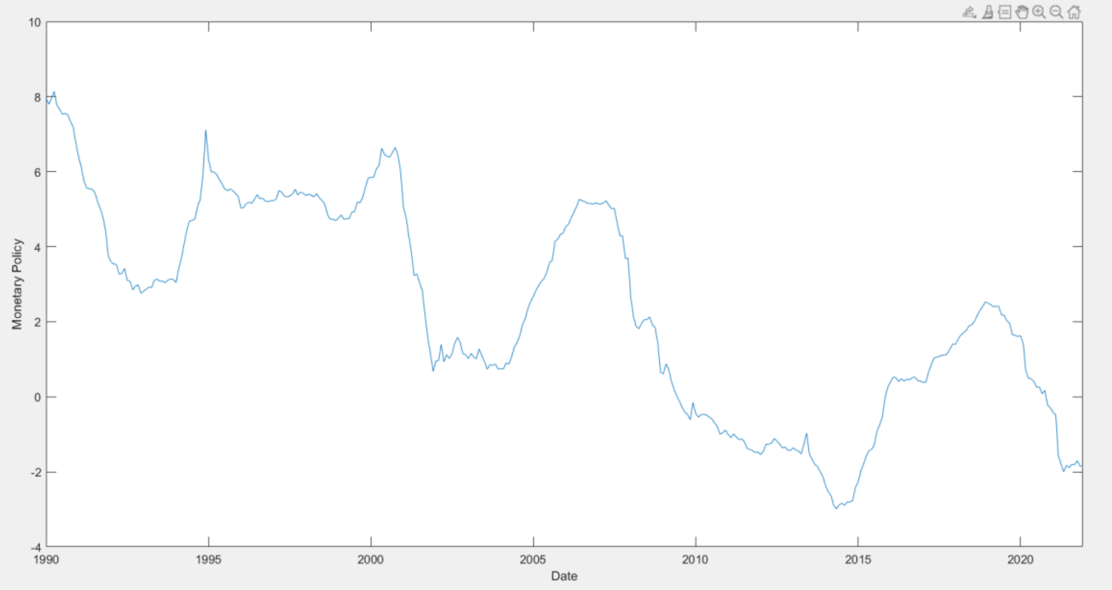


Figure 5.7. Wu-Xia Shadow Rate 1990-2021. *Source: own elaboration with data from Federal Reserve Bank of Atlanta [50].*

CPI

As mentioned above, in this model the Consumer Price Index (CPI) was used to transform the historical price of natural gas.

The Consumer Price Index for All Urban Consumers: All Items (CPIAUCSL) is a measure of the average monthly change in the price for goods and services paid by urban consumers between any two time periods, which can also represent the buying habits of urban consumers. This index includes approximately 88% of the total US population, including wage earners, clerical workers, technical workers, self-employed, short-term workers, unemployed, retirees, and those not in the labor force [52].

These CPIs are based on prices for food, clothing, shelter, fuels, transportation fares, service fees and sales taxes. Prices are gathered monthly from around 4,000 housing units and 26,000 retail establishments across 87 urban areas. To calculate the index, price changes are averaged with weights representing their importance in the spending of the particular group. The price changes are measured from a predetermined reference date [52].

The CPI can be used to recognize periods of inflation and deflation. Significant increases in the CPI in a short period of time might indicate a period of inflation, while significant decreases indicate a period of deflation [52].

5.3. Natural Gas Historical Price

As mentioned in Chapter 2, there are three main natural gas trading markets, the European average import border price, the Henry Hub spot price of the US, and the imported liquefied natural gas (LNG) price of Japan. In this model, however, the Henry Hub spot price of natural gas of the US was the one used to study the historical price of natural gas since 1990 until present.

The Henry Hub spot prices were retrieved from the U.S. Energy Information Administration (EIA) website and then divided by the U.S. CPI in order to correct for inflation. Finally, the monthly percent change was computed since January 1990 to August 2021.

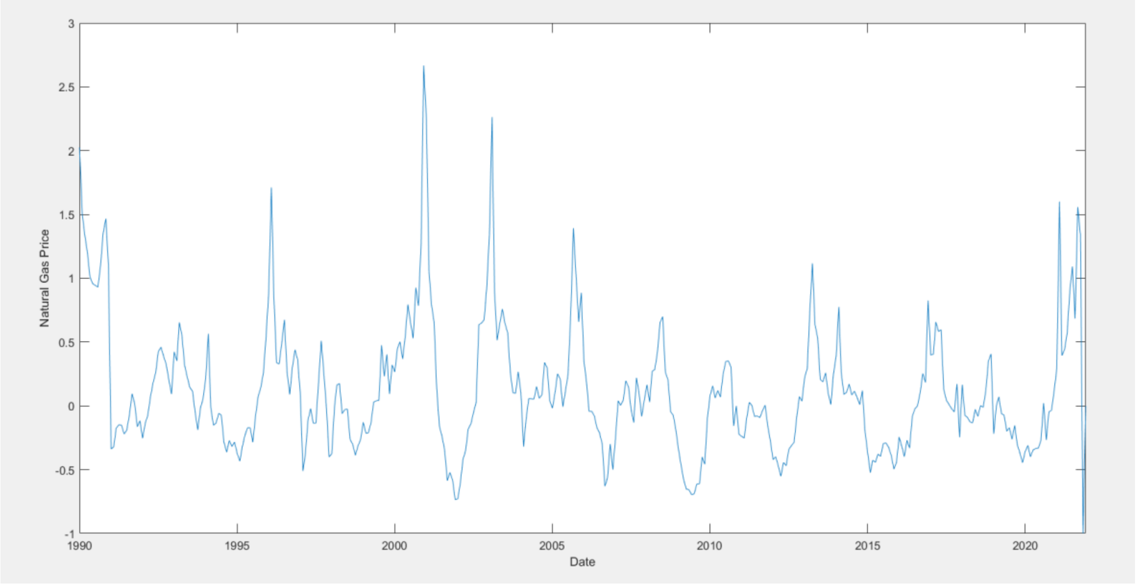


Figure 5.8. Monthly percent change in natural gas Henry Hub spot price 1990-2021. *Source: own elaboration with data from EIA [48].*

The price of natural gas was then used in the model to study how the evolution and changes of other seven factors considered could have affected the price of natural gas historically.

5.4. The Vector Autoregressive Model and Dynamic Response

Once we have gathered all the indicators and variables that might affect the price of natural gas, we need a model to simulate what would happen to this price in the case of a variation in each of these variables. The model used in this study is a Vector Autoregressive model (VAR), which is an extension of univariate autoregression model to multivariate time series data, in which all variables are treated as endogenous. This type of models is often used when one is interested in predicting multiple time series variables using a single model [54].

The autoregressive model analyzes time series data, which is data collected for a single entity over time, rather than for multiple entities at the same point in time (section data). Time series data allows estimation of the effect on Y of a change in X over time. This is what econometricians call a dynamic causal effect. In autoregressive models, the regressors are past values of the dependent variable or other variables [54].

An autoregressive model relates a time series variable to its past values and predicts future behavior based on past behavior. This model specifies that the output variable depends linearly on its own previous values and on a stochastic term which is imperfectly predictable. The simplest autoregressive model (first order) uses only the most recent outcome of the time series observed to predict future values. The model is noted as AR(1) and defined by the following equation:

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + u_t$$

where u_t is white noise, β_0 is a constant, and β_1 is the parameter of the model [54].

An AR(*p*) model assumes that a time series can be modeled by a linear function of the first of its lagged values. The output variable now depends not only on the most recent outcome of the variable observed but rather on a few past outcomes. The equation is similar to the first order equation but has *p-1* more terms:

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \cdots + \beta_p Y_{t-p} + u_t$$

The vector autoregression (VAR) model extends the idea of univariate autoregression to *k* time series regressions, where the lagged values of all *k* series appear as regressors. In a VAR model, we regress a vector of time series variables on lagged vectors of these variables [54]. Now, we try to predict the value of more than one variable which depends not only on its own past values but also on the past values of the other variable we are trying to predict. The equations for this type of model are the following:

$$Y_t = \beta_{10} + \beta_{11} Y_{t-1} + \cdots + \beta_{1p} Y_{t-p} + \gamma_{11} X_{t-1} + \cdots + \gamma_{1p} Y_{t-p} + u_{1t}$$

$$X_t = \beta_{20} + \beta_{21} Y_{t-1} + \cdots + \beta_{2p} Y_{t-p} + \gamma_{21} X_{t-1} + \cdots + \gamma_{2p} Y_{t-p} + u_{2t}$$

Where the βs and γs can be estimated using ordinary least squares (OLS) on each equation.

In this study we used an approach that is widely followed to forecast oil prices, the dynamic model of the global oil market proposed by Alquist et al. (2013) and Baumeister and Kilian (2012) [55]. Their analysis is based on the following reduced-form vector autoregression (VAR),

$$y_t = c + \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + u_t$$

where, applied to our study, y_t is a vector of 8x1 monthly data, c is a 8x1 vector of intercepts, ϕ_i, i=1,...p, are 8x8 coefficient matrices with p indicating the number of lags (twelve in this case), and u_t are white-noise innovations.

The variable y_t is a vector of the eight variables are the ones explained in the subchapter above: REDTI, percent change in drilling activity, percent change in natural gas production, world industrial production, percent change in electricity consumption, percent change in natural gas inventories, changes in monetary policy and the change in price of natural gas itself. Therefore, the model aims to predict the price of natural gas depending on the time series data of these eight variables.

The model was constructed using MATLAB. Firstly, a 384x8 matrix was built, containing the percent changes with the corrections described above of all eight variables. With this matrix, we estimated the VAR model using the functions in MATLAB *varm* and *estimate* (see Annex I: MATLAB Code). This way, we created the VAR model described above in MATLAB.

Once we have the model constructed, the goal is to determine the dynamic response of natural gas prices to a one-standard-deviation shock to each of our eight variables in our VAR model.

For this matter, we use the *irf* function in MATLAB (see Annex I: MATLAB Code). This function returns the dynamic response of each of the eight variables when a one-standard-deviation shock occurs in all eight variables. However, the only response we are interested in, is the response of the price of natural gas when a shock or sudden rise occurs in natural gas production, inventories, drilling activity, price, world industrial production, shadow rate, and REDTI. Therefore, we extract these responses and plot them to analyze them below.

Chapter 6

Results of the Model

In this chapter, we analyze the dynamic response of the price of natural gas when a sudden rise in each of the eight variables studied takes place. The results are showed with an interval of confidence surrounding the median response (see *Figure 2.1*).

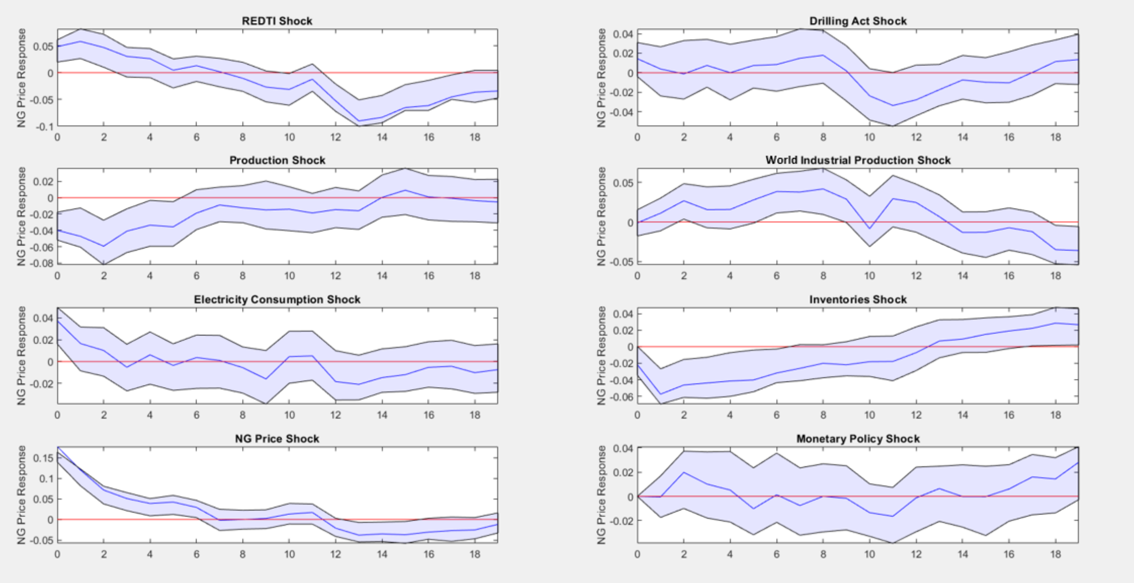


Figure 6.1. Results of model. *Source: own elaboration*

A sudden rise in the production levels of natural gas, leads to a decrease in prices in the immediate, short, and medium term. After thirteen to eighteen periods, the price of natural gas returns to its previous levels before the shock in natural gas production levels. Something similar happens with an increase in natural gas inventories, although in the long run, the price of natural gas rather than going back to previous levels, it rises above them.

A sudden growth in the drilling activity for natural gas does not have an immediate impact on natural gas prices. The impact of this change on the prices can be noticed after ten to eleven periods and does not last very long in time. In addition, the decrease in prices is not as severe as in the case of the increase in production or inventories (it does not reach -0.06). This might be due to time span that has to elapse from when the well begins to be drilled until gas can be extracted from it.

Regarding the indicators of demand, a sudden raise in electricity consumption makes the natural gas prices spike but only in the immediate future, going back to normal after two to three periods. The same happens with an increase of the demand for residential heating and cooling, although the recovery of previous natural gas prices takes longer than in the case of electricity consumption.

When the industrial activity raises, the price for natural gas does not react immediately, and only raises after two to three periods. The median increase in the prices in this case is not as big as in other cases, such as with the increase of electricity consumption or the demand for residential heating and cooling.

If the Xia and Wu (2016) shadow rate increases, increasing the cost of credit throughout the economy and making loans more expensive for both businesses and consumers, the price for natural gas does not react significantly. *Figure 2.1* depicts that the variation in the response of natural gas prices is probably not due to the shock in the shadow rate. Therefore, through this model we cannot conclude that the change in monetary policy influences the price of this commodity.

Having all the above in mind, our model suggests that the variables that decrease natural gas prices are an increase in its production and inventory levels. The ones that increase natural gas prices are the increase in residential cooling and heating demand, a higher demand for electricity, and, to a lesser extent, an increased industrial activity.

Chapter 7

Historical Decomposition

The historical decomposition provides an interpretation of historical fluctuations in the modelled time series and summarizes the history of each endogenous variable in the light of the VAR. It asks the following question: given the estimated model, what is the sequence of shocks that is able to replicate the time series of the price of natural gas? It tells us what portion of the deviation of the endogenous variable from its unconditional mean is due to each shock [57].

The historical decomposition is always backward looking and treats everything as observed. Therefore, having the estimates of the model's parameters and the history of structural shocks is sufficient to calculate the historical decomposition [58].

The figure below represents the historical decomposition for the price of natural gas from 1991 to 2020. The contribution of each of the eight shocks to the deviation of the price of natural gas throughout history can be observed in this graph.

At a first glance the REDTI which represents the residential demand due to changes in temperature is the variable that seems to have been the most determinant throughout history to explain the fluctuations of the price of natural gas.

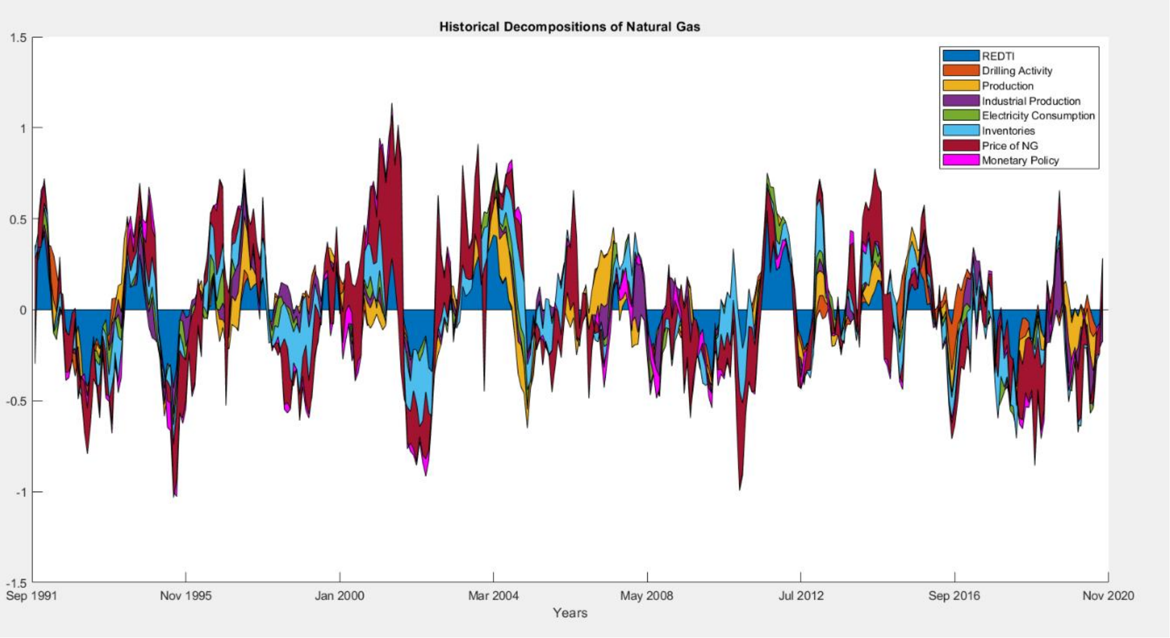


Figure 7.1. Historical decomposition of price of natural gas 1991-2020. *Source: own elaboration*

An example of the effects of the increase of heating and cooling demand on the prices of natural gas occurred in December 2020, added to a decrease in supply due to some congestion problems. Very cold weather and supply disruptions made the prices of natural gas spike. The increased demand for heating, added to the closure of several nuclear reactors which increased demand for natural gas, the lack of tankers, LNG supply disruptions in Indonesia and Australia, and some congestion delays at the Panama Canal, resulted in the spot price of natural gas in Japan reaching a record high [10].

The spike in U.S. prices in February 2021 was due to a winter storm in Texas, with record freezing temperatures, which increased demand for natural gas and caused reductions in supply, since wells and pipelines were shut to prevent freezing. However, spot prices have since then fallen back, especially in the U.S. and Japan [10]. This fact supports the idea that an increased demand for heating and cooling increases prices of natural gas, while a reduction in supply increases the prices. Nevertheless, the effects on natural gas prices of these events do not last very long, and the price of natural gas stabilizes not long after they occur

The variable “Price of natural gas” which represents what we cannot explain with the model, seems to have gained special importance during the early 2000s. This might be due to the speculation given during those years because of the financial bubble, also called the dotcom bubble. The bursting of the bubble caused market panic through massive sell-offs of stocks, and by 2002, investor losses were estimated at around $5 trillion [63].

The effect of production on the price of natural gas is not as important as that of demand, which is usual in this type of commodities. Production becomes more important to explain fluctuations in this price in times when supply bottlenecks take place, such as in the years 2019 and 2020, when the COVID-19 pandemics affected to the supply chain of natural gas. During the years 1998, 2002, 2005-2006, and 2015 production or supply levels also fell (see the *Variables Matrix* at Annex II), exactly where this variable has a bigger impact on the price of the commodity, as we can see in the figure *above*.

The levels of industrial production do not have a very big impact on the price of natural gas. This is explained by the fact that most of the natural gas consumed worldwide is used for residential consumption rather than for industrial purposes, where other fuels are preferred.

A surprising result is that the variable “electricity consumption” is not very significant in the model. In the U.S.A., natural gas accounts for 38% of the electricity generated, while in Europe only 18% of the electricity is generated with this fossil fuel [64]. Therefore, it would have been expected that, since the data used in the model is the electricity consumed in the U.S, this variable would be more significant than it is.

At the beginning of the sample, inventory levels held by the U.S. seem to explain the fluctuations of natural gas more than later in history. The amount of inventories held by a country is driven by strategic purposes, which leads to countries to stockpile natural gas when they believe there will be supply shortages in the near future. In this sense, just before a supply shortage occurs, we can observe how inventories become more relevant in the model that explains the fluctuations in the price of natural gas, due to the increased levels of natural gas stocks. Just after the supply shortage occurs inventories fall and make the price of natural gas rise.

Monetary policy, as expected from the results explained in the last chapter, is not very relevant in the model. Throughout history, the changes in monetary policy have not affected the price of natural gas significantly.

Similarly, drilling activity only gains relevance during September-November 2016, when the activity was abnormally high compared to previous periods (see the *Variables Matrix* in Annex II).

Chapter 8

Conclusions and Future Work

Aware of the length of this document, the most important conclusions and results are presented as a summary in this chapter, so that the reader can identify the data of most interest to them and refer to it without having to read the entire document.

The price of natural gas has been a topic of especial interest in the past few months, due to the energetic crisis taking place in Europe after the outburst of the Russian invasion to Ukraine. Europe applied economic sanctions to Russia to show disapproval for the invasion and this led to a reduction of natural gas supply coming from Russia. This event, added to the closing of a liquified natural gas plant in Texas due to a fire, caused the rocketing of natural gas prices in June 2022, which increased in 60% in only two weeks [61].

Demand for natural gas is increasing due to its price-calorific value ratio. According to the U.S. Energy Information Association (EIA), the United States used about 31.5 quadrillion British thermal units (Btu) in 2020 which makes 34% of U.S. total energy consumption [26]. The most common uses of natural gas are for electricity, heating, transportation, and production.

This paper first explained what natural gas is, the different types of natural gas and how it is priced (see *Chapter 2* above), as well as how it is obtained, produced and distributed (see *Chapter 3* above) and which factors might affect to the supply and demand of this commodity (see *Chapter 3 and 4* above). Then, having identified which factors affect the demand and supply of gas, the gas market was modelled to try to identify which factors affect the price of this commodity (see *Chapters 5, 6 and 7* above).

Increases in natural gas supply normally result in lower prices of this resource, while decreases in supply generally lead to higher prices. The amount of natural gas supplied depends on a series of external factors, among which weather conditions, levels of storage and production, political relations and civil unrest, availability of workers and equipment, capacity of the pipeline system, access to natural gas deposits, and the financial environment, might be the most influential ones (see *Chapter 3* above for more detail).

Similarly, an increased demand for natural gas makes the prices grow, while a reduction of demand sinks them. Demand for natural gas depends highly on the time of year, and changes from season to season. The main driver for this primary cycle of natural gas demand is the need for residential and commercial heating [33]. However, this traditional demand cycle for natural gas was shifted when the fuel started to be used as a source for electricity generation. While requirements for natural gas heating decrease during the summer months, demand for space cooling increases during this warmer season, which requires electricity. In addition to this cycle, other factors that affect the demand of natural gas in the short term are weather, fuel switching and the economic environment. Regarding the factors that affect the demand of the commodity in the long term, a complete analysis for each of the industrial sectors is developed in *Chapter 4* (see above for more information).

For the modelling, a VAR model was used (see *Chapter 5* above) using eight variables that affect the supply and demand and therefore the price of natural gas: demand for residential cooling and heating, production levels of natural gas, inventory levels, drilling activity, industrial activity, electricity consumption, a shadow rate that measures monetary policy initiatives, and the price of natural gas itself.

Each of these variables was included in the model as an indicator. In the supply side, the year-to-year percent change in U.S. natural gas gross withdrawals was used as an indicator for variations in production, the month-to-month percent change in the number of U.S. natural gas rotary rigs in operation as the one for variations in drilling activity, and the year-to-year percent change in U.S. natural gas underground storage volume was used as the indicator for fluctuations in inventory levels. In the demand side, REDTI was the indicator used to determine residential heating and cooling demand variations, the electricity consumption was included in the model measuring the year-to-year percent change of electricity end use measured in millions of kilowatts per hour, industrial activity levels were represented by the World Industrial Production Indicator provided by the OECD, and the Xia and Wu (2016) Shadow Federal Funds Rate represented the changes in monetary policy. For the price of natural gas, the Henry Hub spot price since 1990 was the one considered.

After analyzing the effects on the price of natural gas of a shock of each of the eight variables using this VAR model, it was observed that the variables that significantly decrease natural gas prices are an increase in its production and inventory levels. The ones that significantly increase natural gas prices are the increase in residential cooling and heating demand, a higher demand for electricity, and, to a lesser extent, an increased industrial activity. Monetary policy did not seem to have a great impact on the price of natural gas in this first analysis. Regarding the drilling activity, a sudden growth of this variable does not have an immediate or a significant impact on natural gas prices and this impact does not last very long in time. As expected, a shock in the variable “natural gas price” has a very significant and immediate impact on itself (see *Figure 8.1.* below).

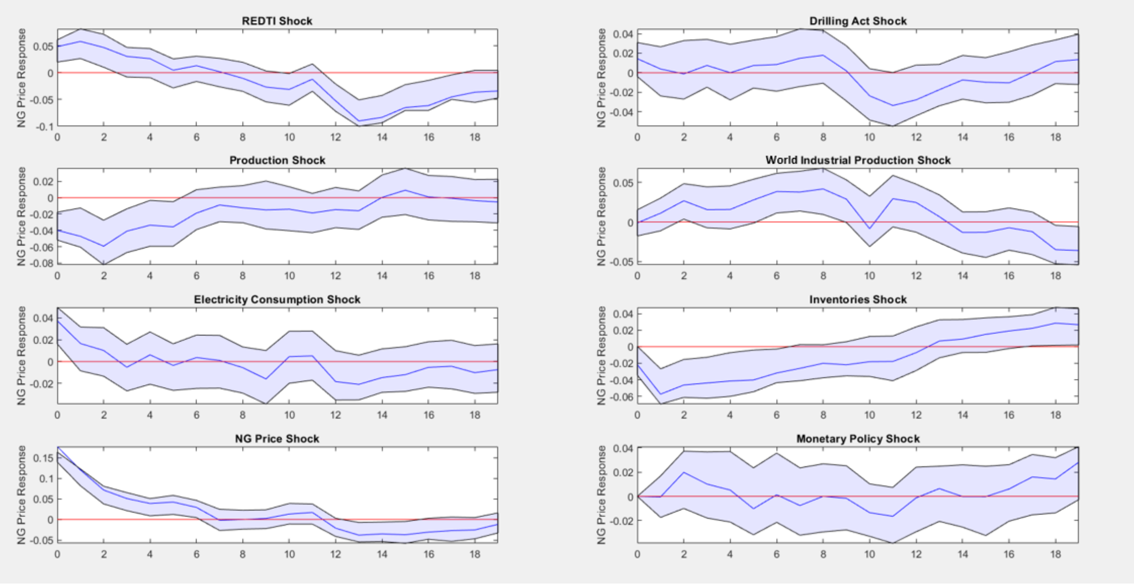


Figure 8.1. Results of the model. *Source: own elaboration.*

Although we did not include it in the model, it could be of interest for future studies to include the supply variations of nuclear power and determine how it affects the natural gas prices. After the Fukushima earthquake and the temporary reduction of nuclear power generation, natural gas prices rocketed, which suggests that the events might be related [9].

Once analyzed the VAR model and the dynamic response to shocks on all the variables, a historical decomposition for the price of natural gas was conducted (see Chapter 7 above). This historical decomposition aimed to determine the contribution of each of the eight shocks to the deviation of the price of natural gas throughout history (1991-2020). This decomposition showed that the indicator REDTI, which represents the residential demand due to changes in temperature, is the one variable that seems to have been determinant throughout history to explain the fluctuations of the price of natural gas. Industrial demand, on the other hand, was not as important as the residential demand, which accounts for most of the demand for natural gas in the U.S.A.

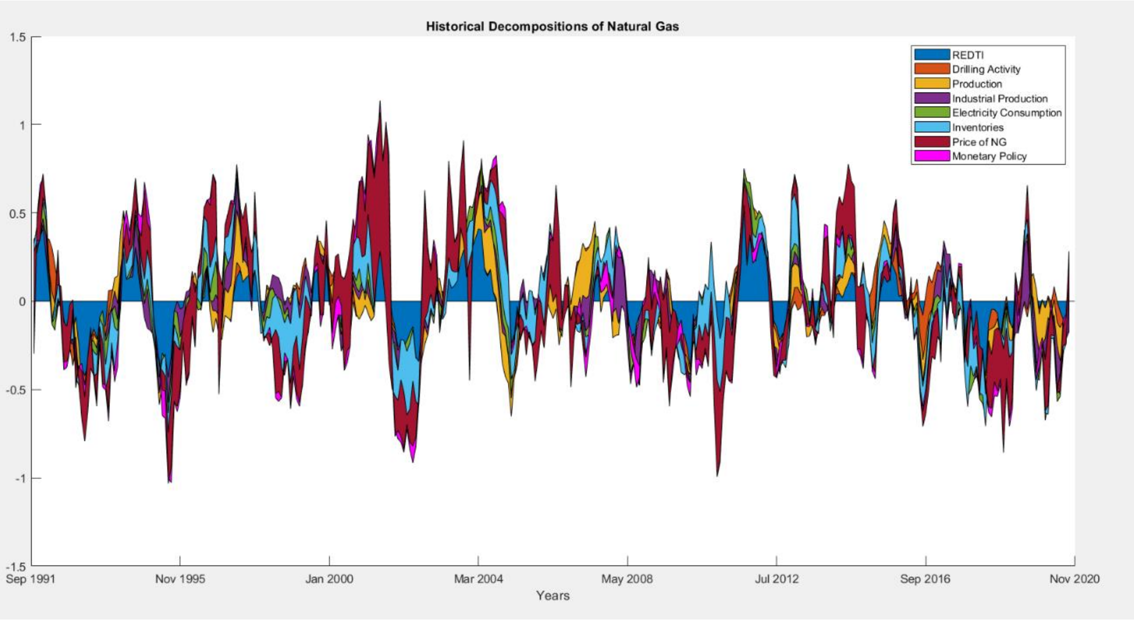


Figure 8.2. Historical decomposition of price of natural gas 1991-2020. *Source: own elaboration.*

Production levels were only relevant when there were supply bottlenecks throughout history, as well as the inventories held, which increased before supply shortages and decreased after those events, causing fluctuations in the price of natural gas. In order to include this supply problems in the model, a possible future modification of the model could be to include the indicator “container trade volume”, which counts the containers traded between certain regions at a certain point in time.

During periods of financial instability, the model could not explain the speculation in the markets, which is reflected by the fact that during those periods the variable “price of natural gas” plays a more important role in the model. Neither the changes in monetary policy nor in the amount of drilling activity explained much part of the fluctuations in the price of natural gas throughout the years studied.

Surprisingly, the variable “electricity consumption” was not very significant in determining natural gas price changes throughout history, according to the results of the historical decomposition. In the U.S.A., natural gas accounts for 38% of the electricity generated, while in Europe only 18% of the electricity is generated with this fossil fuel [64]. Therefore, it would have been expected that, since the data used in the model is the electricity consumed in the U.S, this variable would be more significant than it is.

Results for both analyses, the individual analysis of each of the eight shocks and how they affect to the price of natural gas, and the historical decomposition analysis, agree on the most relevant variables that explain gas price movements: the residential demand due to temperature changes, the production, and the inventory levels. The only exception is the variable “electricity consumption”, which does not seem as significant when the historical decomposition is performed as it seems with the analysis of a shock of this variable. This might be because although there is a significant relation relationship between gas price and quantity of electricity consumed (shown by the IRF), there have not been many historical shocks in electricity consumption. There is a lot of inertia in the amount of electricity we consume and most changes in the amount of electricity consumed are already being explained by the variables in the model, leaving us with few shocks of this variable.

Annexes

Annex I

MATLAB Code

```
infomat = load ('Matrix.mat');
Matrix = infomat.Matrix;
%%
figure;
plot(Matrix.Date, Matrix.WeatherConditionsREDTI);
xlabel('Date');
ylabel('REDTI');

figure;
plot(Matrix.Date, Matrix.WeatherConditionsTemp);
xlabel('Date');
ylabel('Temperature');

figure;
plot(Matrix.Date, Matrix.DrillingActivity);
xlabel('Date');
ylabel('Drilling Activity');

figure;
plot(Matrix.Date, Matrix.Production);
xlabel('Date');
ylabel('Production');

figure;
plot(Matrix.Date, Matrix.WorldIndProd);
xlabel('Date');
ylabel('World Industrial Production');

figure;
plot(Matrix.Date, Matrix.ElectricityConsumption);
xlabel('Date');
ylabel('Electricity Consumption');
```

```
figure;
plot(Matrix.Date, Matrix.Inventories);
xlabel('Date');
ylabel('Inventories');

figure;
plot(Matrix.Date, Matrix.NaturalGasPrice);
xlabel('Date');
ylabel('Natural Gas Price');

figure;
plot(Matrix.Date, Matrix.MonetaryPolicy);
xlabel('Date');
ylabel('Monetary Policy');

%% varm
infomatx = load ('Matrixx.mat');
Matrixx = table2array (infomatx.Matrixx);
Matrixx = Matrixx(1:380,:);
Mdl = varm(8,12);
%% Estimated model
EstimatedMdl = estimate(Mdl,Matrixx);
%% IRF
[Response,Lower,Upper] = irf(EstimatedMdl);
%% Plot IRF
Shock_REDTI= Response (:,1,7);
Shock_Drill= Response (:,2,7);
Shock_Prod= Response (:,3,7);
Shock_WorldIndProd= Response (:,4,7);
Shock_EC= Response (:,5,7);
Shock_Inv= Response (:,6,7);
Shock_Price= Response (:,7,7);
Shock_MP= Response (:,8,7);

Upper_REDTI= Upper (:,1,7);
Upper_Drill= Upper (:,2,7);
Upper_Prod= Upper (:,3,7);
Upper_WorldIndProd= Upper (:,4,7);
Upper_EC= Upper (:,5,7);
Upper_Inv= Upper (:,6,7);
Upper_Price= Upper (:,7,7);
Upper_MP= Upper (:,8,7);

Lower_REDTI= Lower (:,1,7);
Lower_Drill= Lower (:,2,7);
Lower_Prod= Lower (:,3,7);
Lower_WorldIndProd= Lower (:,4,7);
```

```
Lower_EC= Lower (:,5,7);
Lower_Inv= Lower (:,6,7);
Lower_Price= Lower (:,7,7);
Lower_MP= Lower (:,8,7);
%%
x=0:1:19;
figure;
title('Natural Gas Price Response');
hold all
subplot (4,2,1), plot (x,[squeeze(Shock_REDTI)
squeeze(Upper_REDTI) squeeze(Lower_REDTI)], 'b'),
title('REDTI Shock'),  ylabel('NG Price Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_REDTI'
fliplr(Upper_REDTI')], 'blue','FaceAlpha',.1)

subplot (4,2,2), plot (x,[squeeze(Shock_Drill)
squeeze(Upper_Drill) squeeze(Lower_Drill)], 'b'),
title('Drilling Act Shock'),  ylabel('NG Price
Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_Drill'
fliplr(Upper_Drill')], 'blue','FaceAlpha',.1)

subplot (4,2,3), plot (x,[squeeze(Shock_Prod)
squeeze(Upper_Prod) squeeze(Lower_Prod)], 'b'),
title('Production Shock'), ylabel('NG Price Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_Prod'
fliplr(Upper_Prod')], 'blue','FaceAlpha',.1)

subplot (4,2,4), plot (x,[squeeze(Shock_WorldIndProd)
squeeze(Upper_WorldIndProd)
squeeze(Lower_WorldIndProd)], 'b'), title('World
Industrial Production Shock'), ylabel('NG Price
Response')
hold on
plot(x,zeros(size(x)),'-r')
```

```
axis tight
hold all
patch([x fliplr(x)], [Lower_WorldIndProd'
fliplr(Upper_WorldIndProd')], 'blue','FaceAlpha',.1)

subplot (4,2,5), plot (x,[squeeze(Shock_EC)
squeeze(Upper_EC) squeeze(Lower_EC)], 'b'),
title('Electricity Consumption Shock'), ylabel('NG
Price Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_EC' fliplr(Upper_EC')],
'blue','FaceAlpha',.1)

subplot (4,2,6), plot (x,[squeeze(Shock_Inv)
squeeze(Upper_Inv) squeeze(Lower_Inv)], 'b'),
title('Inventories Shock'), ylabel('NG Price
Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_Inv' fliplr(Upper_Inv')],
'blue','FaceAlpha',.1)

subplot (4,2,7), plot (x,[squeeze(Shock_Price)
squeeze(Upper_Price) squeeze(Lower_Price)], 'b'),
title('NG Price Shock'), ylabel('NG Price Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_Price'
fliplr(Upper_Price')], 'blue','FaceAlpha',.1)

subplot (4,2,8), plot (x,[squeeze(Shock_MP)
squeeze(Upper_MP) squeeze(Lower_MP)],
'b'),title('Monetary Policy Shock'), ylabel('NG Price
Response')
hold on
plot(x,zeros(size(x)),'-r')
axis tight
hold all
patch([x fliplr(x)], [Lower_MP' fliplr(Upper_MP')],
'blue','FaceAlpha',.1)
```

```
%% Historical Decomposition
%Matriz Respuesta instantanea
B = chol(EstimatedMdl.Covariance,'lower');
%%
%Historic shock matrix
errors=infer(EstimatedMdl,Matrixx);
B0=inv(B);
%%
shocks = B0*transpose(errors);
tshocks= transpose (shocks);
%%
Rep=Response(:,:,7);
%%
Historical_decomp(1,:) = sum(tshocks(1:20,:).*Rep );
%% Loop
n=1;
m=1;
l=20;
while m<368 && l<368
Historical_decomp(n,:) = sum(tshocks(m:l,:).*Rep );
n=n+1;
m=m+1;
l=l+1;
end;

%% Plot Historical decomp
figure;
hold on;
title('Historical Decompositions of Natural Gas');
area(Historical_decomp), xlabel('Years');
hold on;
colorVector= [0 0.4470 0.7410; 0.8500 0.3250 0.0980;
0.9290 0.6940 0.1250; 0.4940 0.1840 0.5560; 0.4660
0.6740 0.1880; 0.3010 0.7450 0.9330; 0.6350 0.0780
0.1840; 1 0 1];
newDefaultColors = (colorVector);
set(gca, 'ColorOrder', newDefaultColors);
hold on;
xticklabels({'Sep 1991', 'Nov 1995', 'Jan 2000', 'Mar
2004', 'May 2008', 'Jul 2012', 'Sep 2016', 'Nov
2020'});
hold on;
legend ('REDTI', 'Drilling Activity', 'Production',
'Industrial Production', 'Electricity Consumption',
'Inventories', 'Price of NG', 'Monetary Policy');
```

Annex II

Variables Matrix

Date	Weather Conditions REDTI	Drilling Activity	Production	World Ind Prod	Electricity Consumption	Inventories	Natural Gas Price	Monetary Policy
01/1990	8.8	(7.74%)	3.63%	(0.40%)	7.12%	(3.47%)	202.52%	7.95
02/1990	22.8	(13.63%)	0.13%	0.41%	(0.24%)	0.40%	150.18%	7.80
03/1990	29.8	2.18%	1.51%	0.42%	(0.61%)	2.08%	134.29%	7.95
04/1990	27	6.18%	0.58%	(1.02%)	2.26%	2.86%	120.43%	8.14
05/1990	53.9	4.03%	0.30%	1.12%	3.71%	2.37%	101.11%	7.77
06/1990	54.1	6.45%	1.40%	0.36%	2.71%	2.48%	95.80%	7.67
07/1990	34.6	0.20%	1.86%	(0.01%)	5.13%	3.03%	94.41%	7.53
08/1990	39.3	(6.05%)	2.60%	0.55%	4.04%	2.70%	93.01%	7.55
09/1990	33	(1.29%)	2.52%	0.20%	6.17%	2.63%	110.11%	7.51
10/1990	26.9	1.96%	6.82%	(0.07%)	5.53%	3.67%	135.34%	7.34
11/1990	22.1	5.54%	2.01%	(0.48%)	2.25%	4.74%	146.68%	7.19
12/1990	43.7	(7.07%)	2.13%	(0.21%)	(2.95%)	9.66%	110.12%	6.76
01/1991	46.1	(10.22%)	0.93%	0.20%	0.46%	3.04%	(33.86%)	6.39
02/1991	16	(1.94%)	1.06%	(0.70%)	2.40%	2.64%	(32.03%)	6.10
03/1991	38.3	(3.95%)	2.57%	(0.40%)	(0.28%)	1.99%	(17.52%)	5.76
04/1991	20.4	(3.86%)	2.68%	0.73%	0.04%	2.59%	(14.83%)	5.56
05/1991	30.2	(5.35%)	0.30%	0.45%	4.07%	3.35%	(15.16%)	5.54
06/1991	53.5	(3.39%)	0.03%	0.16%	4.64%	2.58%	(22.03%)	5.53
07/1991	47.7	(2.92%)	(0.98%)	0.13%	1.95%	1.09%	(19.13%)	5.45
08/1991	46.4	(1.81%)	(1.38%)	(0.04%)	2.34%	0.07%	(7.20%)	5.21
09/1991	23.2	(3.68%)	1.48%	0.30%	(0.12%)	(0.31%)	9.48%	5.02
10/1991	26.9	5.10%	1.19%	0.28%	(0.20%)	0.15%	1.83%	4.80
11/1991	66.4	(0.61%)	2.09%	0.03%	3.35%	(3.28%)	(16.37%)	4.41
12/1991	33.1	(6.10%)	2.48%	(0.80%)	2.32%	(2.28%)	(11.64%)	3.75
01/1992	31.1	(4.55%)	(0.25%)	0.43%	(0.63%)	0.06%	(25.35%)	3.60
02/1992	17.5	(5.78%)	0.57%	0.69%	3.66%	(1.29%)	(13.47%)	3.53
03/1992	44	(9.75%)	(2.75%)	(0.09%)	3.10%	(3.71%)	(7.43%)	3.53

04/1992	36.3	0.40%	0.09%	0.21%	3.13%	(5.45%)	7.12%	3.27
05/1992	7.9	3.59%	3.09%	(0.30%)	(1.58%)	(5.02%)	17.81%	3.29
06/1992	9.2	0.00%	5.08%	0.14%	(3.91%)	(4.46%)	26.20%	3.42
07/1992	22.2	19.23%	5.82%	0.47%	(0.93%)	(2.82%)	42.56%	3.10
08/1992	2.5	6.77%	3.35%	(0.65%)	(1.75%)	(1.50%)	45.90%	3.08
09/1992	33.6	7.55%	4.11%	0.54%	(1.64%)	(0.64%)	38.79%	2.85
10/1992	48.3	12.08%	1.90%	0.17%	1.64%	(0.57%)	32.38%	2.95
11/1992	60.8	13.03%	0.38%	(0.06%)	1.26%	0.21%	20.01%	2.98
12/1992	49.6	12.86%	0.69%	(0.57%)	3.63%	(2.02%)	9.26%	2.76
01/1993	34.3	(10.81%)	0.67%	0.77%	1.74%	(3.06%)	42.25%	2.82
02/1993	61.6	(26.43%)	1.13%	0.71%	1.19%	(6.13%)	35.28%	2.87
03/1993	56.7	(19.76%)	5.75%	(0.09%)	5.95%	(6.41%)	65.32%	2.93
04/1993	46.8	0.75%	2.31%	0.28%	1.89%	(4.84%)	54.97%	2.91
05/1993	0.5	8.89%	2.02%	0.29%	0.38%	(2.17%)	32.22%	3.10
06/1993	36.9	11.22%	(0.26%)	(0.35%)	4.13%	(0.83%)	22.61%	3.14
07/1993	60.3	10.09%	0.48%	0.01%	6.47%	(0.42%)	14.46%	3.08
08/1993	59.6	8.33%	4.03%	(0.12%)	8.36%	(0.08%)	11.55%	3.09
09/1993	47.8	7.95%	2.58%	0.37%	5.28%	0.49%	(5.20%)	3.04
10/1993	49.2	(2.38%)	2.71%	0.00%	1.75%	0.06%	(18.76%)	3.11
11/1993	66.1	(0.73%)	5.06%	0.30%	2.16%	(0.37%)	(1.80%)	3.13
12/1993	48.3	4.41%	5.48%	0.58%	2.42%	0.13%	5.37%	3.13
01/1994	65	(0.23%)	2.92%	(0.04%)	7.20%	(2.60%)	21.49%	3.05
02/1994	58.5	(4.71%)	2.70%	0.33%	4.59%	(1.91%)	56.42%	3.43
03/1994	41.8	(0.49%)	4.40%	0.78%	(0.28%)	1.30%	(1.24%)	3.69
04/1994	18.3	(1.24%)	4.41%	0.65%	2.23%	3.32%	(15.20%)	4.07
05/1994	31.1	(4.02%)	5.60%	0.52%	3.75%	2.45%	(13.50%)	4.43
06/1994	72.3	6.81%	4.81%	0.75%	6.72%	1.57%	(5.90%)	4.68
07/1994	42	1.72%	5.01%	0.23%	3.27%	2.03%	(7.35%)	4.70
08/1994	23.6	4.34%	5.31%	1.04%	(0.46%)	2.11%	(28.62%)	4.74

09/1994	2.2	8.78%	2.48%	0.36%	0.85%	1.77%	(36.25%)	5.08
10/1994	35.9	(0.85%)	1.62%	0.74%	2.38%	1.87%	(27.15%)	5.27
11/1994	34.4	(1.50%)	3.56%	0.87%	1.55%	3.43%	(31.86%)	5.97
12/1994	27.8	(2.83%)	2.55%	1.13%	0.73%	4.77%	(28.36%)	7.12
01/1995	30.3	(8.05%)	1.01%	(0.35%)	(2.27%)	8.16%	(37.27%)	6.32
02/1995	41.5	(8.76%)	0.36%	0.20%	(0.16%)	8.88%	(43.32%)	5.99
03/1995	34.3	(11.73%)	(0.14%)	(0.06%)	1.86%	7.41%	(32.21%)	6.00
04/1995	54.9	1.51%	1.06%	0.45%	1.04%	4.04%	(22.99%)	5.93
05/1995	52.5	(0.30%)	0.64%	(0.39%)	3.72%	2.63%	(17.17%)	5.79
06/1995	24	5.07%	1.55%	0.50%	0.82%	2.75%	(17.25%)	5.68
07/1995	56.1	13.35%	0.89%	(0.11%)	1.57%	0.19%	(28.55%)	5.54
08/1995	95.6	0.00%	(0.31%)	0.63%	9.90%	(1.83%)	(8.42%)	5.49
09/1995	36.4	3.51%	1.95%	0.01%	4.48%	(1.69%)	7.34%	5.54
10/1995	23.4	0.24%	0.33%	(0.00%)	3.15%	(1.28%)	14.09%	5.49
11/1995	70.6	3.86%	0.48%	0.52%	3.84%	(3.56%)	25.84%	5.42
12/1995	57.5	(0.70%)	0.58%	0.78%	3.99%	(6.66%)	53.67%	5.33
01/1996	49	(4.92%)	0.29%	(0.19%)	6.70%	(9.26%)	88.77%	5.03
02/1996	40.5	1.23%	6.36%	(0.03%)	7.02%	(9.14%)	171.11%	5.05
03/1996	67	2.43%	1.27%	0.50%	5.21%	(11.33%)	86.26%	5.15
04/1996	43.8	5.94%	2.89%	0.40%	3.12%	(9.99%)	33.86%	5.19
05/1996	64.9	4.71%	1.29%	0.66%	4.27%	(9.38%)	32.83%	5.15
06/1996	44.5	0.86%	2.54%	0.15%	4.51%	(8.56%)	49.49%	5.26
07/1996	30.4	3.61%	2.39%	0.31%	1.37%	(6.14%)	67.40%	5.39
08/1996	37.3	0.00%	3.09%	0.42%	(3.11%)	(3.77%)	26.57%	5.28
09/1996	12.6	3.48%	2.73%	0.50%	0.72%	(2.81%)	8.92%	5.29
10/1996	36.4	(1.19%)	2.10%	0.29%	1.81%	(2.57%)	29.92%	5.21
11/1996	82.3	(3.41%)	(1.78%)	0.45%	2.39%	(2.57%)	43.85%	5.20
12/1996	34.6	1.45%	(3.44%)	0.54%	1.85%	0.17%	36.35%	5.22
01/1997	46.3	(2.25%)	1.52%	0.32%	1.17%	0.45%	9.64%	5.23

02/1997	25.7	2.93%	(2.10%)	0.56%		(1.99%)	2.08%	(51.03%)	5.27
03/1997	34.6	5.28%	2.09%	0.81%		(2.02%)	5.69%	(37.66%)	5.49
04/1997	64.7	1.54%	(0.81%)	0.54%		2.38%	4.39%	(11.09%)	5.46
05/1997	55	2.85%	0.49%	0.22%		(0.90%)	3.85%	(2.19%)	5.35
06/1997	12.9	6.65%	(0.79%)	0.90%		(1.72%)	3.71%	(13.58%)	5.32
07/1997	36.1	1.21%	0.20%	0.36%		3.53%	2.23%	(13.57%)	5.35
08/1997	28.6	(0.51%)	(0.60%)	0.44%		1.42%	1.80%	18.95%	5.40
09/1997	44.5	5.68%	0.63%	0.50%		3.99%	1.30%	51.00%	5.53
10/1997	35.9	(1.95%)	1.31%	0.68%		7.02%	1.38%	25.65%	5.38
11/1997	68.4	3.82%	(0.48%)	(0.15%)		2.21%	2.46%	(2.18%)	5.46
12/1997	44.2	3.68%	(0.53%)	(0.06%)		2.51%	0.17%	(40.02%)	5.42
01/1998	14.4	(6.02%)	1.12%	(0.21%)		(1.32%)	3.70%	(37.57%)	5.36
02/1998	14	(3.28%)	(0.35%)	0.79%		(0.55%)	5.24%	(1.42%)	5.41
03/1998	42	2.04%	0.17%	(0.31%)		4.11%	3.54%	16.39%	5.37
04/1998	31.1	(1.66%)	1.24%	(0.07%)		2.01%	6.15%	17.46%	5.33
05/1998	35.5	(1.86%)	1.04%	0.24%		7.08%	7.18%	(6.05%)	5.41
06/1998	65.4	0.86%	2.31%	(0.20%)		8.32%	5.93%	(2.94%)	5.29
07/1998	61.1	(6.15%)	0.33%	(0.10%)		5.81%	6.81%	(2.61%)	5.23
08/1998	77.9	2.91%	1.19%	0.34%		8.20%	5.12%	(26.29%)	5.13
09/1998	60	(1.06%)	(4.81%)	0.24%		6.57%	3.36%	(30.22%)	4.85
10/1998	29.4	(7.16%)	(1.32%)	0.30%		1.14%	3.99%	(38.74%)	4.73
11/1998	31.2	(3.85%)	(1.33%)	0.16%		1.18%	6.24%	(31.38%)	4.74
12/1998	26.7	(1.60%)	(0.95%)	(0.12%)		1.37%	8.14%	(26.50%)	4.69
01/1999	31.6	(6.11%)	(1.79%)	0.95%		4.76%	5.69%	(12.88%)	4.76
02/1999	18.2	(7.81%)	(0.90%)	(0.58%)		1.16%	5.32%	(21.58%)	4.85
03/1999	52.9	(3.06%)	(1.59%)	0.81%		2.77%	4.79%	(21.09%)	4.73
04/1999	35.3	(9.95%)	(2.47%)	0.06%		3.46%	2.64%	(13.14%)	4.74
05/1999	19.9	2.43%	(3.80%)	0.93%		0.77%	1.50%	2.99%	4.74
06/1999	40.7	14.21%	(2.56%)	0.06%		0.68%	1.09%	3.95%	4.93

07/1999	72.6	10.14%	(1.73%)	0.69%	3.65%	(0.84%)	4.22%	4.93
08/1999	57.3	10.25%	(2.51%)	0.43%	1.58%	(0.85%)	47.47%	5.19
09/1999	17.5	7.21%	2.81%	0.65%	(0.64%)	0.33%	23.13%	5.17
10/1999	38.2	6.37%	(0.61%)	0.58%	(0.23%)	(1.20%)	40.32%	5.31
11/1999	2.9	5.66%	0.52%	0.94%	1.46%	(0.72%)	9.36%	5.59
12/1999	33.9	0.16%	0.82%	0.93%	1.20%	(2.12%)	32.10%	5.83
01/2000	36.8	(0.63%)	(0.50%)	(0.24%)	0.94%	(4.14%)	26.57%	5.85
02/2000	16.6	(2.53%)	1.86%	0.36%	8.09%	(6.48%)	45.05%	5.85
03/2000	21.4	(2.60%)	0.54%	0.50%	0.80%	(4.70%)	50.21%	6.06
04/2000	34	1.50%	(0.08%)	0.99%	0.78%	(5.30%)	36.81%	6.16
05/2000	31.1	5.91%	1.32%	0.50%	5.40%	(6.62%)	54.28%	6.62
06/2000	43.4	4.96%	1.37%	0.10%	5.02%	(6.76%)	79.39%	6.46
07/2000	21.1	8.27%	1.77%	0.36%	(2.31%)	(5.70%)	65.47%	6.41
08/2000	55.2	6.28%	2.61%	0.49%	2.25%	(5.99%)	52.94%	6.39
09/2000	35.7	3.98%	2.59%	(0.22%)	2.82%	(6.00%)	92.56%	6.52
10/2000	22.9	3.95%	3.99%	0.33%	2.88%	(4.72%)	78.40%	6.65
11/2000	75	(1.19%)	0.85%	0.36%	4.45%	(8.62%)	127.34%	6.44
12/2000	84.5	2.64%	1.46%	0.36%	7.87%	(12.09%)	266.64%	5.99
01/2001	46.2	2.93%	2.02%	(1.34%)	7.94%	(8.63%)	225.49%	5.04
02/2001	37.3	2.16%	0.08%	0.83%	(0.25%)	(7.75%)	105.21%	4.76
03/2001	56.8	1.67%	1.97%	(0.93%)	2.36%	(8.61%)	79.59%	4.30
04/2001	22.8	4.82%	3.58%	(0.44%)	1.61%	(5.60%)	65.31%	3.83
05/2001	11.2	4.18%	3.47%	(0.02%)	(2.26%)	(0.79%)	13.55%	3.23
06/2001	43.2	5.32%	1.49%	(0.24%)	(3.47%)	1.87%	(16.00%)	3.27
07/2001	30	0.76%	1.19%	(0.70%)	(0.72%)	3.32%	(23.79%)	3.05
08/2001	73.7	(2.46%)	0.92%	0.55%	0.13%	5.01%	(34.88%)	2.83
09/2001	9.8	(5.81%)	1.12%	(0.68%)	(2.59%)	5.94%	(58.58%)	2.17
10/2001	30.7	(6.07%)	(0.03%)	(0.33%)	(1.97%)	5.10%	(52.21%)	1.57
11/2001	0	(9.64%)	0.32%	(0.27%)	(4.23%)	11.05%	(58.27%)	1.13

12/2001	22.3	(8.61%)	0.18%	0.08%	(7.92%)	18.67%	(73.50%)	0.67
01/2002	18.4	(3.85%)	(1.87%)	1.06%	(6.11%)	18.68%	(72.79%)	0.95
02/2002	24.7	(6.34%)	(2.69%)	(0.27%)	(2.88%)	18.18%	(59.43%)	0.97
03/2002	50.4	(9.13%)	(2.58%)	0.97%	(0.58%)	16.48%	(42.07%)	1.40
04/2002	21.3	(0.81%)	(2.46%)	0.70%	1.55%	14.48%	(34.92%)	0.93
05/2002	53.5	12.75%	(2.07%)	0.38%	2.07%	10.09%	(18.12%)	1.12
06/2002	53.4	2.03%	(1.20%)	0.20%	2.46%	7.60%	(14.13%)	1.02
07/2002	68.7	1.70%	(0.25%)	0.40%	6.74%	4.87%	(5.26%)	1.15
08/2002	68.1	0.70%	(1.86%)	0.34%	1.64%	3.50%	2.95%	1.43
09/2002	46.9	2.08%	(4.30%)	0.30%	4.76%	1.68%	63.57%	1.59
10/2002	54.5	(3.67%)	(5.75%)	0.11%	5.75%	0.06%	64.82%	1.44
11/2002	56.4	(3.67%)	(1.33%)	0.35%	3.84%	(3.73%)	67.41%	1.14
12/2002	46.4	4.54%	(1.01%)	(0.34%)	6.30%	(6.78%)	91.92%	1.12
01/2003	50.2	0.56%	(0.05%)	1.12%	4.62%	(11.88%)	133.81%	1.02
02/2003	58	4.46%	1.18%	(0.02%)	6.77%	(16.25%)	226.26%	1.16
03/2003	40.5	2.27%	2.05%	0.05%	2.50%	(13.91%)	90.50%	1.06
04/2003	43	3.65%	1.48%	(0.29%)	(0.45%)	(13.36%)	51.37%	1.01
05/2003	53.2	8.68%	(0.55%)	(0.16%)	(0.14%)	(11.18%)	64.17%	1.28
06/2003	18.7	5.32%	0.04%	0.46%	(1.97%)	(8.60%)	75.83%	1.10
07/2003	47.7	1.54%	(2.22%)	0.74%	(0.96%)	(6.46%)	64.57%	0.94
08/2003	76.4	0.87%	0.75%	(0.13%)	1.10%	(5.15%)	57.38%	0.74
09/2003	19	0.43%	2.80%	0.95%	(1.18%)	(2.85%)	26.21%	0.86
10/2003	36.9	0.53%	4.08%	0.91%	(2.11%)	(0.02%)	10.26%	0.83
11/2003	30.9	1.17%	(0.07%)	0.33%	(0.00%)	0.95%	9.95%	0.87
12/2003	40.7	0.74%	(0.37%)	0.74%	2.62%	2.24%	26.67%	0.74
01/2004	55	(0.42%)	0.29%	(0.16%)	1.03%	3.17%	10.50%	0.75
02/2004	48.6	0.63%	2.13%	1.30%	1.58%	5.11%	(31.95%)	0.75
03/2004	21.9	0.73%	(1.31%)	(0.02%)	1.31%	5.66%	(10.80%)	0.91
04/2004	17.3	2.89%	(0.61%)	0.65%	2.36%	6.23%	5.65%	0.87

05/2004	21.2	1.10%	(0.77%)	0.33%	3.69%	5.15%	5.47%	1.07
06/2004	34.6	0.40%	(0.22%)	(0.08%)	5.75%	3.56%	5.32%	1.32
07/2004	23	2.97%	1.38%	0.69%	(0.05%)	3.57%	15.07%	1.44
08/2004	14.4	2.11%	(0.84%)	0.05%	(3.19%)	3.58%	5.85%	1.63
09/2004	25	0.94%	(3.40%)	0.40%	0.59%	1.91%	8.65%	1.93
10/2004	36.2	(0.47%)	(2.33%)	0.45%	1.32%	1.23%	34.04%	2.08
11/2004	32.8	0.84%	(0.44%)	0.15%	2.57%	1.88%	29.75%	2.35
12/2004	43.4	(1.21%)	(1.08%)	0.35%	2.14%	0.46%	3.95%	2.53
01/2005	33.2	1.03%	(1.35%)	0.78%	(0.20%)	2.44%	(1.81%)	2.68
02/2005	26	0.74%	(2.62%)	0.06%	(2.91%)	5.81%	10.84%	2.84
03/2005	54.4	3.23%	0.19%	0.24%	2.52%	2.67%	25.10%	2.96
04/2005	17.7	4.03%	(0.79%)	0.73%	(0.09%)	2.96%	21.05%	3.08
05/2005	43.2	0.60%	0.46%	(0.38%)	(2.47%)	2.78%	(0.74%)	3.15
06/2005	63.8	3.25%	0.37%	0.67%	3.32%	1.45%	11.74%	3.32
07/2005	70.5	1.49%	(1.73%)	0.09%	6.02%	(0.42%)	24.81%	3.58
08/2005	84.9	0.08%	(1.41%)	0.32%	9.13%	(1.99%)	72.19%	3.63
09/2005	65.9	0.73%	(7.47%)	0.08%	6.46%	(2.38%)	139.21%	4.14
10/2005	22	1.62%	(6.87%)	0.58%	4.53%	(1.96%)	102.11%	4.20
11/2005	24.3	(2.23%)	(3.43%)	1.07%	0.78%	(1.08%)	65.83%	4.33
12/2005	57.2	(0.65%)	(1.37%)	0.66%	1.57%	(0.90%)	88.61%	4.36
01/2006	0	0.66%	(2.94%)	(0.13%)	(1.42%)	6.03%	35.29%	4.53
02/2006	38.3	7.57%	(4.08%)	0.87%	0.38%	5.54%	17.58%	4.60
03/2006	45.9	(1.21%)	(4.14%)	0.31%	0.84%	7.37%	(4.26%)	4.77
04/2006	13.3	2.45%	(3.56%)	0.41%	1.25%	7.80%	(4.28%)	4.91
05/2006	21.4	2.69%	(2.69%)	0.68%	4.80%	7.18%	(7.86%)	5.07
06/2006	48.3	0.22%	(1.73%)	0.33%	0.43%	6.77%	(17.28%)	5.26
07/2006	81.7	0.22%	(0.45%)	0.33%	1.57%	5.11%	(21.28%)	5.23
08/2006	74.9	2.76%	0.07%	0.39%	1.33%	4.62%	(30.11%)	5.20
09/2006	20.8	0.85%	10.16%	0.38%	(4.03%)	5.63%	(62.98%)	5.15

10/2006	51.5	0.84%	8.26%	0.26%	(1.58%)	3.63%	(56.52%)	5.15
11/2006	23.1	(1.87%)	3.82%	1.19%	1.13%	3.03%	(29.92%)	5.13
12/2006	21	1.20%	3.01%	0.64%	(2.22%)	6.52%	(49.98%)	5.17
01/2007	31.1	0.63%	3.43%	0.58%	2.81%	0.40%	(25.52%)	5.14
02/2007	67.3	1.81%	4.67%	0.21%	6.33%	(3.64%)	3.96%	5.13
03/2007	23.8	(0.34%)	5.02%	0.65%	(0.04%)	(0.66%)	0.44%	5.18
04/2007	48.6	0.00%	4.50%	0.14%	2.03%	(2.84%)	4.25%	5.22
05/2007	4.8	0.21%	5.63%	0.92%	1.20%	(1.23%)	19.60%	5.10
06/2007	47.5	1.30%	4.18%	0.15%	(0.19%)	(0.27%)	14.85%	5.01
07/2007	28.8	0.20%	3.95%	0.45%	(3.19%)	1.86%	(2.72%)	5.02
08/2007	100	0.40%	4.36%	0.43%	0.79%	0.95%	(13.08%)	4.64
09/2007	42.1	(1.14%)	4.84%	0.06%	5.67%	0.14%	21.93%	4.29
10/2007	4.7	(2.71%)	4.76%	0.66%	4.84%	1.75%	10.04%	4.29
11/2007	42.9	1.11%	6.29%	0.42%	2.57%	0.76%	(8.25%)	3.69
12/2007	44.8	1.17%	5.85%	0.21%	1.80%	(2.30%)	4.40%	3.70
01/2008	40	(3.20%)	5.49%	1.49%	3.63%	(4.72%)	16.50%	2.66
02/2008	41.7	0.35%	8.83%	(0.54%)	1.63%	(3.09%)	2.98%	2.14
03/2008	48	1.26%	5.23%	(0.31%)	1.33%	(6.21%)	26.94%	1.87
04/2008	27.8	1.18%	5.90%	0.43%	1.19%	(5.19%)	28.52%	1.81
05/2008	50.5	1.16%	4.19%	(0.88%)	(1.26%)	(5.70%)	41.71%	1.96
06/2008	78.6	2.17%	4.90%	0.26%	2.00%	(5.97%)	65.38%	2.05
07/2008	46.3	2.19%	7.40%	(0.67%)	2.51%	(5.30%)	69.88%	2.05
08/2008	35.6	2.46%	5.65%	(0.90%)	(5.42%)	(2.16%)	26.45%	2.13
09/2008	26.3	0.25%	(5.92%)	(1.01%)	(4.62%)	(2.09%)	20.26%	1.91
10/2008	39.3	(2.71%)	1.47%	(1.54%)	(4.99%)	(2.17%)	(4.51%)	1.84
11/2008	46	(2.85%)	2.44%	(2.70%)	(2.77%)	(1.34%)	(7.51%)	1.42
12/2008	50.3	(7.88%)	2.34%	(3.21%)	0.23%	(0.57%)	(18.93%)	0.65
01/2009	53.6	(11.96%)	4.50%	(2.83%)	(1.84%)	1.30%	(34.41%)	0.61
02/2009	32.1	(14.65%)	1.49%	0.85%	(6.32%)	5.53%	(47.15%)	0.88

03/2009	40.2	(16.39%)	2.65%	(0.49%)	(3.83%)	7.67%	(57.79%)	0.75
04/2009	31.5	(10.61%)	1.67%	0.19%	(4.71%)	8.95%	(65.26%)	0.43
05/2009	23.5	(6.71%)	1.72%	0.57%	(4.74%)	9.35%	(65.73%)	0.21
06/2009	53.3	(4.43%)	1.03%	0.98%	(7.04%)	9.69%	(69.62%)	0.02
07/2009	19.7	(2.32%)	(1.60%)	0.88%	(6.29%)	9.02%	(68.98%)	-0.12
08/2009	53.6	2.37%	(0.04%)	0.82%	(2.03%)	7.51%	(61.27%)	-0.28
09/2009	32.6	1.88%	8.84%	1.13%	(3.12%)	7.18%	(60.97%)	-0.41
10/2009	63.5	2.56%	2.03%	0.49%	(1.52%)	5.98%	(40.12%)	-0.47
11/2009	13.9	1.66%	(0.26%)	0.93%	(3.31%)	7.23%	(45.74%)	-0.61
12/2009	60.4	3.27%	(1.38%)	0.59%	0.79%	4.72%	(9.95%)	-0.15
01/2010	48.1	8.44%	(1.86%)	1.86%	3.30%	3.29%	7.96%	-0.45
02/2010	59.5	8.52%	(1.27%)	(0.13%)	4.30%	(0.67%)	15.59%	-0.54
03/2010	31.2	4.60%	0.62%	1.46%	3.17%	0.38%	6.23%	-0.48
04/2010	2.4	2.79%	1.97%	0.45%	0.78%	2.02%	11.99%	-0.47
05/2010	38.1	0.10%	2.10%	0.85%	3.26%	1.01%	6.94%	-0.48
06/2010	100	(0.73%)	(0.08%)	(0.19%)	8.19%	(0.02%)	24.64%	-0.54
07/2010	77.9	1.89%	1.78%	0.47%	8.98%	(1.37%)	34.66%	-0.59
08/2010	90.2	1.24%	1.94%	0.38%	7.68%	(2.41%)	35.20%	-0.70
09/2010	55.8	(0.61%)	7.13%	0.23%	5.39%	(1.52%)	30.36%	-0.80
10/2010	19.5	(1.13%)	7.27%	0.48%	0.18%	0.80%	(15.69%)	-1.00
11/2010	43.5	(1.66%)	6.18%	0.58%	2.43%	(0.58%)	(0.09%)	-0.96
12/2010	65.9	(1.05%)	9.29%	1.17%	2.88%	0.08%	(22.15%)	-0.88
01/2011	54.2	(3.30%)	4.03%	1.39%	0.70%	0.44%	(23.91%)	-1.01
02/2011	44.6	(0.22%)	2.76%	(0.17%)	(0.54%)	1.06%	(25.22%)	-1.09
03/2011	42.5	(2.54%)	5.90%	(0.29%)	(0.31%)	(0.86%)	(9.84%)	-0.99
04/2011	33.4	0.11%	7.28%	(0.50%)	3.05%	(3.14%)	2.74%	-1.07
05/2011	32.5	(0.79%)	7.80%	0.92%	1.47%	(3.10%)	0.21%	-1.14
06/2011	84.4	(0.11%)	8.14%	0.26%	(0.60%)	(2.78%)	(8.34%)	-1.12
07/2011	100	0.34%	5.96%	0.30%	0.56%	(2.45%)	(7.91%)	-1.19

08/2011	88.4	1.59%	6.06%	0.22%	0.25%	(1.66%)	(9.24%)	-1.38
09/2011	34.7	1.45%	5.36%	(0.06%)	(0.45%)	(1.08%)	(3.74%)	-1.40
10/2011	26	2.87%	6.17%	0.01%	0.06%	(0.61%)	0.44%	-1.44
11/2011	24.2	(5.68%)	8.75%	(0.34%)	0.25%	0.80%	(15.91%)	-1.48
12/2011	28.4	(6.70%)	5.97%	0.23%	(5.18%)	4.74%	(27.54%)	-1.47
01/2012	15.7	(3.78%)	11.83%	0.78%	(6.58%)	9.24%	(42.11%)	-1.54
02/2012	17.5	(8.48%)	12.15%	0.21%	(2.91%)	12.19%	(39.92%)	-1.45
03/2012	0	(7.75%)	4.70%	(0.50%)	(2.55%)	15.57%	(46.83%)	-1.27
04/2012	19.5	(5.70%)	2.88%	(0.70%)	(1.50%)	13.86%	(55.13%)	-1.26
05/2012	21.8	(4.61%)	3.31%	0.60%	3.21%	11.22%	(44.40%)	-1.24
06/2012	51.4	(7.00%)	2.76%	(0.40%)	(0.97%)	9.11%	(46.91%)	-1.11
07/2012	96.3	(6.45%)	5.33%	0.11%	0.17%	7.25%	(34.19%)	-1.18
08/2012	69.1	(6.70%)	0.15%	(0.30%)	(2.03%)	5.94%	(31.15%)	-1.26
09/2012	36.8	(8.21%)	2.21%	(0.35%)	(2.37%)	4.25%	(28.56%)	-1.36
10/2012	31.8	(4.92%)	2.19%	0.51%	1.09%	2.33%	(8.99%)	-1.34
11/2012	49.4	(0.94%)	(0.19%)	(0.14%)	1.19%	0.36%	7.19%	-1.42
12/2012	22.8	0.48%	(0.79%)	0.32%	(1.41%)	0.28%	3.71%	-1.43
01/2013	30.5	2.60%	(2.31%)	0.40%	3.20%	(1.97%)	22.14%	-1.36
02/2013	43.4	(1.84%)	(3.82%)	(0.02%)	1.53%	(4.07%)	29.54%	-1.42
03/2013	58.8	(3.05%)	(0.80%)	0.27%	4.91%	(10.19%)	73.12%	-1.44
04/2013	41	(9.44%)	1.19%	0.38%	2.69%	(10.09%)	111.64%	-1.52
05/2013	3.9	(5.61%)	(0.08%)	0.07%	(2.35%)	(7.82%)	63.49%	-1.27
06/2013	57.2	(0.28%)	0.36%	(0.43%)	(1.31%)	(5.72%)	53.18%	-0.97
07/2013	49.7	3.41%	1.92%	0.57%	(3.07%)	(3.77%)	20.71%	-1.52
08/2013	37	6.04%	5.10%	0.47%	(2.90%)	(2.32%)	18.85%	-1.67
09/2013	38.9	0.78%	0.17%	0.31%	1.76%	(1.46%)	25.86%	-1.80
10/2013	30.1	(3.86%)	(1.72%)	(0.15%)	1.36%	(1.36%)	9.78%	-1.85
11/2013	63.5	(2.14%)	(0.66%)	0.48%	1.28%	(2.46%)	1.00%	-2.00
12/2013	52.9	1.91%	0.09%	(0.13%)	6.43%	(6.81%)	24.97%	-2.13

01/2014	59	(2.95%)	2.71%	0.87%	6.10%	(11.14%)	39.08%	-2.38
02/2014	60.7	(5.80%)	3.84%	0.57%	5.64%	(14.24%)	77.43%	-2.54
03/2014	65.9	(2.35%)	4.79%	(0.15%)	1.48%	(14.67%)	26.11%	-2.62
04/2014	31.1	(5.11%)	5.62%	0.39%	(0.76%)	(13.04%)	9.01%	-2.89
05/2014	8.6	2.85%	5.81%	(0.23%)	0.54%	(11.33%)	10.53%	-2.99
06/2014	56	(3.38%)	7.32%	0.19%	0.60%	(9.44%)	17.03%	-2.89
07/2014	24.4	0.00%	4.65%	0.18%	(2.11%)	(7.41%)	8.55%	-2.84
08/2014	40.5	3.18%	6.01%	(0.97%)	(0.53%)	(5.80%)	11.49%	-2.89
09/2014	42.5	3.70%	8.74%	1.00%	0.98%	(4.69%)	6.55%	-2.81
10/2014	20.6	(2.38%)	8.86%	(0.67%)	0.62%	(2.77%)	1.04%	-2.80
11/2014	78	7.01%	8.42%	0.73%	1.19%	(2.22%)	11.97%	-2.77
12/2014	24.9	(2.56%)	9.66%	0.23%	(2.22%)	3.46%	(19.50%)	-2.42
01/2015	43	(6.43%)	8.14%	0.56%	(3.23%)	7.75%	(36.58%)	-2.27
02/2015	77.6	(7.50%)	6.94%	(0.27%)	(0.67%)	8.52%	(52.28%)	-1.97
03/2015	45.7	(15.54%)	7.76%	(0.04%)	0.84%	12.17%	(42.58%)	-1.81
04/2015	26.5	(11.20%)	6.77%	(0.06%)	(0.19%)	13.63%	(44.27%)	-1.59
05/2015	12.3	0.45%	5.98%	(0.25%)	(1.11%)	12.84%	(37.81%)	-1.43
06/2015	64	0.45%	3.91%	0.47%	1.23%	10.34%	(39.50%)	-1.40
07/2015	47.5	(3.57%)	4.83%	(0.21%)	3.30%	8.04%	(29.58%)	-1.29
08/2015	58.1	(3.24%)	3.77%	0.34%	2.87%	6.72%	(29.03%)	-0.92
09/2015	62.5	(5.26%)	3.65%	(0.10%)	1.91%	5.71%	(32.45%)	-0.74
10/2015	25.6	(2.53%)	2.57%	0.33%	(0.10%)	4.54%	(38.70%)	-0.53
11/2015	18.5	0.52%	2.42%	(0.37%)	(3.07%)	6.53%	(49.55%)	0.00
12/2015	0	(10.31%)	1.52%	(0.24%)	(3.72%)	7.09%	(44.34%)	0.26
01/2016	38.7	(23.56%)	1.18%	1.08%	(2.65%)	7.85%	(24.47%)	0.40
02/2016	17.9	(23.31%)	5.29%	(0.26%)	(3.02%)	14.41%	(31.85%)	0.53
03/2016	14.2	(8.82%)	(0.09%)	0.20%	(6.03%)	17.22%	(39.77%)	0.51
04/2016	26.5	(5.38%)	(2.90%)	0.18%	(1.99%)	13.75%	(27.02%)	0.41
05/2016	16.1	(2.27%)	(0.82%)	(0.05%)	(1.06%)	10.13%	(33.01%)	0.48

06/2016	75.9	0.00%	(1.20%)	0.69%	0.99%	7.59%	(8.31%)	0.42
07/2016	82.2	2.33%	(1.27%)	(0.49%)	2.35%	5.23%	(2.34%)	0.47
08/2016	95.4	(6.82%)	(0.81%)	0.30%	5.10%	2.58%	(0.03%)	0.45
09/2016	66.6	10.98%	(3.50%)	(0.09%)	0.99%	1.08%	10.49%	0.51
10/2016	15.1	15.38%	(3.06%)	0.69%	0.14%	0.82%	25.27%	0.52
11/2016	7.2	11.43%	(1.76%)	0.07%	0.34%	0.55%	18.39%	0.43
12/2016	44.1	7.69%	(2.33%)	(0.03%)	4.07%	(4.50%)	82.54%	0.42
01/2017	18.7	11.11%	(3.52%)	0.76%	(0.76%)	(4.20%)	39.86%	0.38
02/2017	0	7.14%	(6.05%)	0.37%	(6.88%)	(2.74%)	40.39%	0.39
03/2017	36.4	2.67%	(0.99%)	0.53%	1.92%	(5.94%)	65.73%	0.64
04/2017	0	7.79%	0.42%	0.20%	1.28%	(4.84%)	58.31%	0.85
05/2017	27.2	7.23%	0.40%	0.18%	2.44%	(4.38%)	59.58%	1.03
06/2017	50	3.37%	2.29%	(0.02%)	(0.33%)	(3.89%)	12.71%	1.06
07/2017	65.9	2.72%	1.20%	(0.11%)	(1.15%)	(3.60%)	4.41%	1.08
08/2017	40.9	(3.17%)	1.73%	0.65%	(5.35%)	(2.63%)	1.07%	1.11
09/2017	25	2.19%	5.22%	0.22%	(4.45%)	(1.87%)	(2.37%)	1.10
10/2017	8	(3.74%)	7.03%	0.07%	0.92%	(2.55%)	(4.71%)	1.16
11/2017	36.6	(3.89%)	8.17%	0.93%	2.15%	(3.43%)	17.07%	1.28
12/2017	46.6	5.20%	10.15%	0.15%	0.70%	(3.70%)	(24.58%)	1.41
01/2018	44.6	2.75%	9.90%	0.38%	8.05%	(7.18%)	16.56%	1.40
02/2018	20.2	(3.74%)	10.35%	0.35%	5.95%	(10.20%)	(7.42%)	1.55
03/2018	50.2	4.44%	9.73%	(0.37%)	1.79%	(10.82%)	(8.93%)	1.65
04/2018	75.4	2.66%	10.64%	0.54%	1.93%	(13.39%)	(12.54%)	1.71
05/2018	26.1	2.59%	11.50%	(0.19%)	3.84%	(11.58%)	(13.28%)	1.77
06/2018	78.8	(2.53%)	10.58%	(0.15%)	2.81%	(9.80%)	(2.82%)	1.89
07/2018	74.2	(3.11%)	13.95%	0.28%	2.02%	(9.10%)	(8.18%)	1.92
08/2018	85.2	(1.60%)	15.76%	0.34%	5.74%	(8.33%)	0.23%	2.01
09/2018	80.6	1.63%	14.14%	(0.40%)	4.91%	(7.78%)	(1.09%)	2.17
10/2018	35.1	2.67%	13.85%	0.45%	3.25%	(7.07%)	11.85%	2.30

11/2018	73.8	0.52%	12.53%	(0.49%)	2.60%	(8.38%)	35.20%	2.40
12/2018	31.4	2.59%	12.10%	0.26%	(0.05%)	(4.38%)	40.66%	2.53
01/2019	37.3	0.51%	12.81%	0.06%	(4.41%)	(2.11%)	(21.81%)	2.49
02/2019	43.2	(2.01%)	11.11%	0.09%	0.98%	(3.94%)	0.21%	2.46
03/2019	55.4	(1.03%)	10.22%	0.74%	1.64%	(3.45%)	7.05%	2.40
04/2019	14.7	(2.07%)	11.40%	(0.39%)	(1.61%)	2.59%	(6.08%)	2.41
05/2019	54.4	(2.65%)	10.50%	0.08%	(2.14%)	3.29%	(7.31%)	2.41
06/2019	44.3	(2.72%)	11.00%	(0.62%)	(4.83%)	4.37%	(19.82%)	2.19
07/2019	73.6	(3.91%)	8.21%	0.10%	0.23%	5.24%	(17.15%)	2.17
08/2019	73.5	(3.49%)	7.55%	(0.10%)	(2.23%)	5.77%	(26.12%)	2.02
09/2019	100	(8.43%)	7.69%	(0.15%)	0.93%	6.66%	(15.39%)	1.96
10/2019	37.3	(8.55%)	7.16%	(0.17%)	(0.29%)	7.22%	(30.34%)	1.66
11/2019	71.8	(6.47%)	7.65%	0.26%	(1.63%)	8.17%	(37.18%)	1.64
12/2019	28.6	(1.54%)	6.81%	0.43%	(0.67%)	7.06%	(44.54%)	1.61
01/2020	13.2	(7.81%)	6.52%	(4.51%)	(3.78%)	10.01%	(35.66%)	1.63
02/2020	24.7	(6.78%)	10.03%	0.36%	(0.10%)	11.53%	(31.09%)	1.41
03/2020	24.7	(3.64%)	5.89%	(0.13%)	(3.77%)	15.57%	(39.83%)	0.69
04/2020	53.2	(12.26%)	1.78%	(9.12%)	(4.10%)	13.32%	(34.52%)	0.50
05/2020	29.8	(15.05%)	(4.06%)	0.72%	(7.33%)	11.89%	(33.46%)	0.48
06/2020	55.3	(3.80%)	(2.49%)	5.02%	(0.55%)	10.05%	(33.19%)	0.40
07/2020	91	(5.26%)	(0.66%)	3.03%	0.69%	8.40%	(27.24%)	0.25
08/2020	88.1	(2.78%)	(2.85%)	1.30%	(1.15%)	7.29%	2.13%	0.26
09/2020	37.8	4.29%	(3.87%)	1.38%	(5.34%)	5.59%	(26.67%)	0.08
10/2020	38.4	0.00%	(5.30%)	0.80%	(3.80%)	2.22%	(4.74%)	0.17
11/2020	11.1	1.37%	(4.47%)	1.16%	(3.13%)	4.20%	(3.45%)	-0.23
12/2020	35.1	8.11%	(3.67%)	1.64%	1.59%	2.21%	11.76%	-0.29
01/2021	25.8	7.50%	(2.52%)	1.40%	1.53%	0.47%	29.50%	-0.42
02/2021	60.6	5.81%	(13.07%)	(0.27%)	0.72%	(3.29%)	160.03%	-0.48
03/2021	26.7	1.10%	(2.79%)	0.48%	0.77%	(3.43%)	39.38%	-1.56

04/2021	22.3	2.17%	1.03%	0.10%		3.23%	(5.39%)	44.13%	-1.80
05/2021	19	6.38%	6.86%	(1.18%)		4.99%	(5.49%)	57.08%	-2.00
06/2021	69.1	(3.00%)	5.40%	1.29%		5.28%	(6.70%)	90.25%	-1.83
07/2021	52.5	5.15%	3.67%	(0.12%)		(1.73%)	(6.45%)	109.19%	-1.89
08/2021	89.1	(1.96%)	6.18%	(0.44%)		3.19%	(7.05%)	68.45%	-1.80
09/2021	38.6	1.00%	0.00%	(0.82%)		4.03%	0.00%	155.75%	-1.81
10/2021	4.6	0.00%	0.00%	0.60%		0.00%	0.00%	134.30%	-1.70
11/2021	40	0.00%	0.00%	1.33%		0.00%	0.00%	(100.00%)	-1.85
12/2021	40	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	-1.85

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