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Economic Analysis of Global Fossil Energy Markets

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Abstract

This thesis is an investigation of the relationships between three primary energy markets, crude oil, coal and natural gas. We study both the short-run and long-run relationships between these fossil fuels markets. Our main purpose is to study the effects of each market on the other markets in both the short-run and the long-run.

The oil market is a global market, and we can find data on the world oil production, oil consumption and oil prices in many periods. However, the coal market to some extent is comprised of some segmented markets, and the natural gas market is nearly regionally markets. However, with technical progress and the establishment of a new cartel for natural gas market, the coal and natural gas markets are gradually moving to become global markets. As the coal and natural gas markets still are not global, we cannot find data on world production of coal and natural gas, thus in the short-run this dictates us to investigate the relationships between crude oil and natural gas, and crude oil and coal, separately. For this purpose, we use the decomposition of the real price of crude oil recently proposed by Kilian (2009): crude oil supply shocks, global demand shocks, and crude oil precautionary demand shocks to distinguish between the effects of oil market shocks and global aggregate demand shocks.

In chapter one, we provide a general introduction of fossil fuels. In chapter two, we study the relationship between crude oil and natural gas using a four-variable structural vector autoregressive model (SVAR) for oil production, real activity, oil prices and natural gas prices. In the chapter three, we investigate the relationships between crude oil and coal prices. For this purpose, we developed a four-variable SVAR. The results of chapters two and three provide some evidence that oil supply shocks have no significant effect on the real price of crude oil and natural gas, while they have significant effect on coal prices.

Regarding the demand shocks effect, a positive aggregate demand shock has a positive significant effect on the prices of oil, coal and natural gas, as an increase in the demand for

goods and services leads to increase in the demand for energy sources, which are mainly fossil fuels.

Meanwhile, a positive aggregate demand shock has a positive and significant effect on the oil production. Our result is consistent with the view of some researchers that the natural gas market has no effect on oil prices, while the coal market can affect oil prices.

The precautionary demand for oil that Kilian (2009) introduced as an oil specific demand shock shows a fear of future lack of crude oil. Precautionary demand shock gradually transfer to coal and natural gas markets and has significant effects on coal and natural gas prices as they are the main substitutes for crude oil.

In the chapter four, we concentrate on the effect of an aggregate demand shock on oil production. While Kilian (2009) shows that an aggregate demand shock has no significant effect on oil production, this chapter shows that his data during the second oil shock and the subsequent decade exhibit a puzzle, namely, a positive aggregate demand shock has a negative and significant effect on oil production. As our results on the relationships between coal and natural gas prices with crude oil price show that an aggregate demand shock has a significant positive effect on the oil production, we investigate more about this relationship. We solve the puzzle by adding the prices of coal and natural gas. We interpret our results as suggesting that ignoring the strong interactions between fossil fuel markets may lead to misleading results.

In the chapter five, we investigate the long-run relationship between the prices of crude oil, coal and natural gas. We apply two cointegration tests, first the Johansen maximum likelihood test, and second Park's Canonical Cointegration Regression (CCR) test. The results provide some evidence that there are at least two cointegration relationships between fossil fuels prices.

We conclude that there are high interactions between the crude oil, coal and natural gas markets in both the short-run, and the long-run. The oil market has significant effects on the coal and natural gas markets in the short-run, while the effect of the natural gas market on the oil market is not significant, and the coal market affects the crude oil market prices for some months. Meanwhile, in the long-run the cointegration relationships between crude oil, coal and natural gas prices show they affect other fossil fuels markets.

Dedication

This dissertation is dedicated to my father, my spouse, my mother, my daughters and all members of my family and friends who have believed in me and support me spiritually throughout my life.

Acknowledgements

I would like to thank all of those people who helped make this dissertation possible. First, I would like to express my sincere gratitude to my research supervisor, Professor Masao Ogaki for giving me the opportunity to work with him on such a fascinating project with all necessary supports and continuous guidance throughout my study at Keio University. He has always been very supportive and nice to me. Besides my supervisor, I would like to thank from Professor Colin McKenzie for constructive advice throughout my graduate studies and my PhD pre-defense.   I am grateful to Professor Masaya Sakuragawa for his advice in my PhD pre-defense and during his courses.

Contents

Chapter 1

Introduction

1.1 Overview

The main energy resources in the world from many years ago until now, are fossil fuels including crude oil, coal and natural gas. Figure … illustrates the total primary energy supply in 1973 and 2013. During this period, world experienced high speed of progressing in technology and discovering new sources of energy, but according to **Figure 1.1**, the total supply of fossil fuels in world energy basket declined only from 86.7 percent to 81.4 percent. Thus, fossil fuels play important role in the world energy basket.

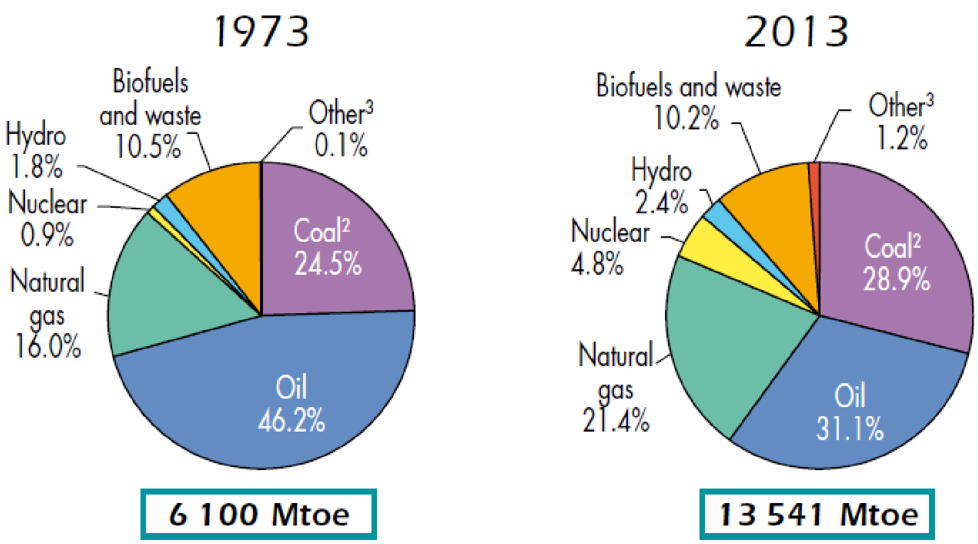


Figure 1.1 World[1] total primary energy supply (TPES) from 1973 to 2013 by fuel (Mtoe), 1. World includes international aviation and international marine bunkers, 2. In these graphs, peat and oil shale are aggregated with coal, 3. Includes geothermal, solar, wind, heat, etc.

Researchers forecast that with progressing in technology, and increasing the world population, production of fossil fuels will increase to the biggest amount in the future decades and then the production of these non-renewable energy resources will decrease, **Figure 1.2**. As a result, crude oil and coal approximately from 1850 and natural gas from nearly 1945 until many decades in the future play main role in producing the world energy.

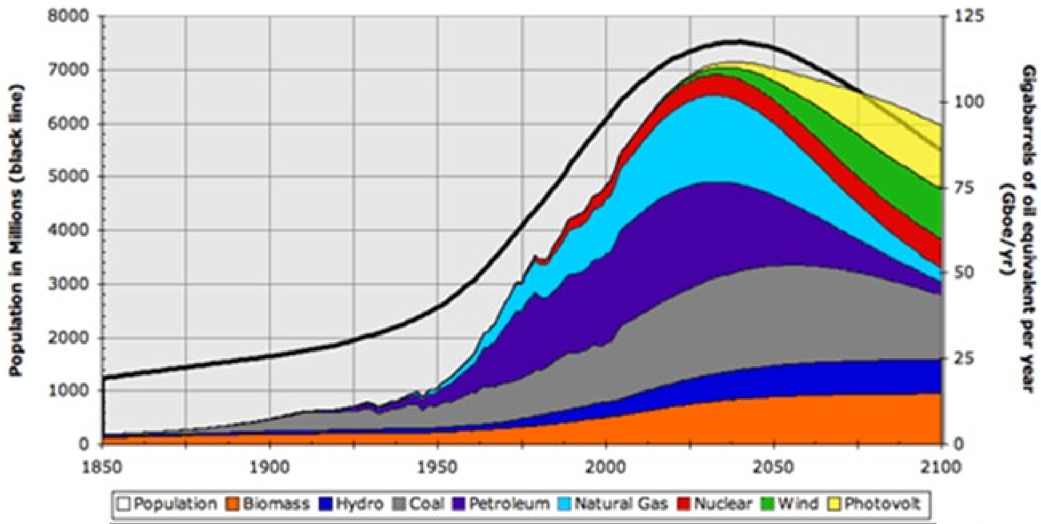


Figure 1.2 World energy production, Source: The Quicker Economist, Volume 7, Number 155, page 2, http://tqe.quaker.org/2007/TQE155-EN-WorldEnergy-2.html.

Figure 1.3 shows the consumption percent of all fuels in 2013. It demonstrates that fossil fuels cover more than 85 percent of world energy consumption while the percent of nuclear and hydroelectric energy resources is 4.42 percent and 6.72 percent, respectively. Meanwhile, wind, solar, biofuels and other sources of energy still cover less than 3 percent of world energy consumption.

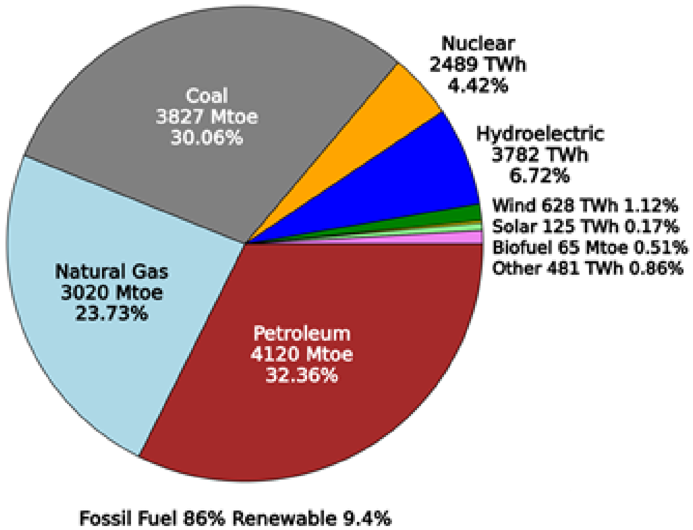


Figure1.3 World energy consumption in 2013.

Consequently, fossil fuels in both production and consumption sides of goods and services have vital role for countries. It cause many researchers study the markets of fossil fuels, and the relationships between crude oil, coal and natural gas markets. Meanwhile, the relationships between fossil fuels markets as one factor of producing goods and services and macroeconomy is investigated by researchers. These relationships are important for producers, consumers, policy makers and investors of the energy markets. Progressing in technology, especially in recent years make the relationships between crude oil, coal and natural gas more complicated, for example new technology helps to extract oil from coal which increases the relationship between coal and oil.

The productions of crude oil, coal and natural gas have some common variables: labor and capital which countries and policy makers allocate them to energy markets. Therefore, it is important that policymakers when, where and how divide capital and labor between these markets, although technical fields may produce limitations.

One factor that connects the markets of fossil fuels is substitutability. Crude oil, coal and natural gas are best substitute fuels. Meanwhile, crude oil and natural gas are complement fuels in production and consumption sides. In consumption side, crude oil, coal and natural gas consumed in common sectors, such as industries, residential, and transportation. The usage of them in each sector depends on the availibility of each fuels, the thermal content of fuels, the type of transportation that needs to transport fuels from sources to consumers, the amount of CO2 that fossil fuels release in the air, and many other factors.

Furthermore, many countries similar to U.S decide to separate the usage of energy in some sectors, for example transportation and producing electricity. **Table 1.1** demonstrates the amount of fuels that produce electricity. According to this table, the amount of using crude oil to producing electricity decline to less than 7.4 percent in the world in 2012.

Table 1.1 World electricity production 2012, Source: IEA electricity information 2014

Fuel	**Coal**	**Gas**	**Hydro**	**Nuclear**	**Solar &Wind**	**Other**
Percent	40.2	22.4	16.5	10.8	2.7	7.4

The common quality of crude oil, coal and natural gas cause many researchers expect long run and short run relationships between their markets.

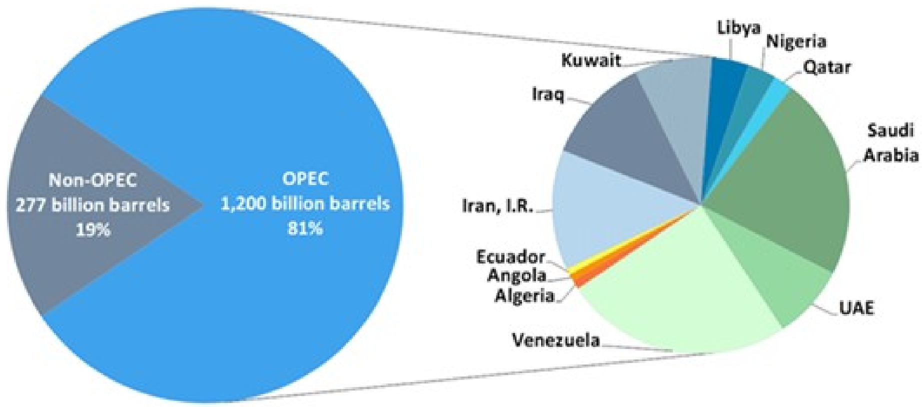
The rest of this chapter is developed in three sections. In the next section, we explain the markets of fossil fuels. In section three, the effect of crude oil on the macroeconomy and the indicator of this effect will be explain. And in the last section, we discuss on the results of this thesis and report the main conclusions.

1.2 Fossil Fuels Market

In this section, we explain the crude oil, natural gas and coal markets. Meanwhile, to investigating the relationships between fossil fuels, we explain how the prices of them are determined.

1.2.1 Oil Market

Oil market is one of the complicated markets that cause many researchers study this market. Most of goods and services markets consist of two side, demand and supply, which determine the price of goods and services. The significant difference of oil market with other goods and services is policy. Many economists attempt to show that policy in the oil market can change the supply of oil which leads to high fluctuations in oil prices and it may affect all variables of economy. Crude oil against coal and natural gas has a powerful market consist of some big cartels similar to Organization of the Petroleum Exporting Countries (OPEC). **Figure 1.4** shows that OPEC proven crude oil reserves is 81 percent in 2012. It means OPEC countries have main role in oil market. It causes that their policy can change the price of oil, substantially.



OPEC proven crude oil reserves, end 2012
(billion barrels, OPEC Share)

Venezuela	297.7	24.8%	Iraq	140.3	11.7%	Libya	48.5	4.0%	Algeria	12.2	1.0%
Saudi Arabia	265.9	22.1%	Kuwait	101.5	8.5%	Nigeria	37.1	3.1%	Angola	9.1	0.8%
Iran, I.R.	157.3	13.1%	United Arab Emirates	97.8	8.1%	Qatar	25.2	2.1%	Ecuador	8.2	0.7%

Figure 1.4 OPEC share of world crude oil reserves 2012, Source: OPEC Annual Statistical bulletin 2013.

The first oil crisis began in October 1973 when some OPEC countries proclaimed an oil embargo. The next oil crisis was happened when OPEC experienced a sudden decline in the oil production due to a revolution of Iran as member of OPEC that causes they change their policy and stop the export of crude oil and after that a war between two oil producing countries of OPEC. **Figure 1.5** illustrates the events that cause high fluctuations in the price of crude oil.

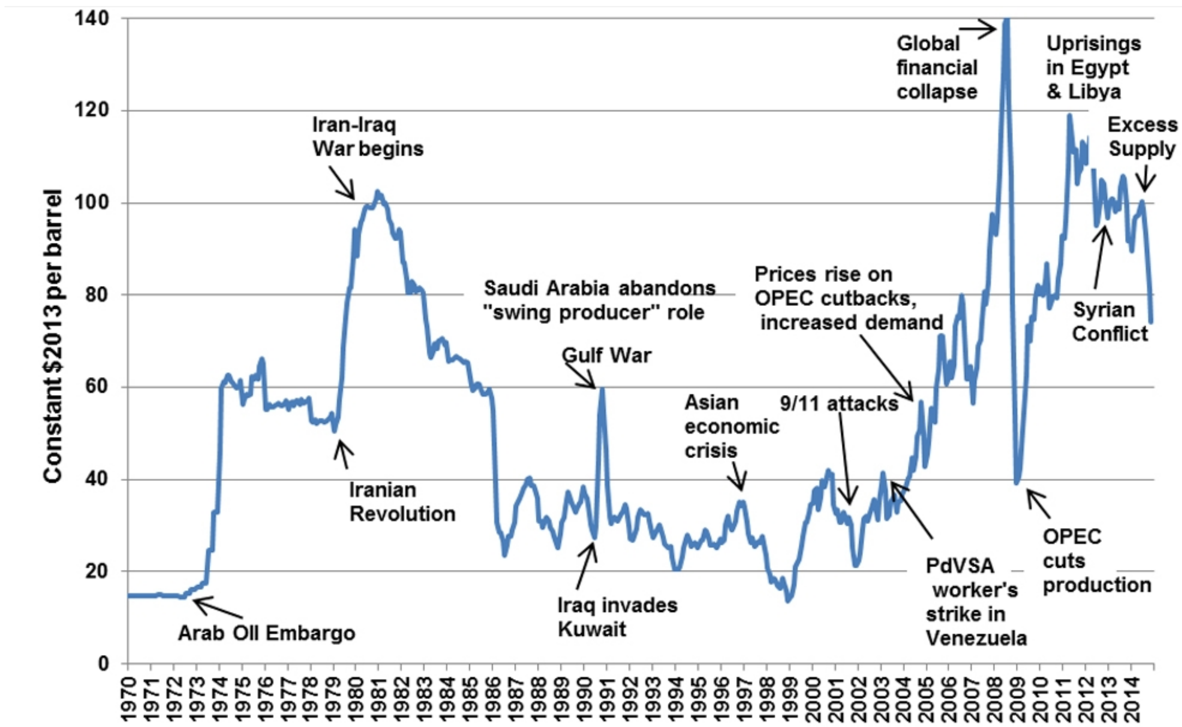


Figure 1.5 World crude oil price and associated events, 1970-2014. Source: ENERGY.GOV, Office of Energy Efficiency & Renewable Energy.

It can be seen in **Table 1.2** that top proven world oil reserves in 2013 are all OPEC members except Canada. Therefore, the main power of oil market arises from power of OPEC and the OPEC policy makers can change the price of oil. How they can change and what variables are important? This is a controversial issue between economists. Oil prices are affected by oil supply or oil demand shocks? We will explain more in the next section.

Table 1.2 Top proven world oil reserves 2013. Source: EIA, Oil and Gas Journal

Country	Venezuela	Saudi Arabia	Canada	Iran	Iraq	Kuwait	United Arab Emirates
Billion barrels	298	265	173	155	141	102	98

1.2.2 Natural Gas Market

Natural gas is the third fossil fuel which its industrial extraction has started at U.S. in 1825. The first and main natural gas wells were associated natural gas wells which are common wells with crude oil wells. The second natural gas wells that discovered were non-associated natural gas wells. After second oil shock and with progressing in technology the number of non-associated natural gas wells has increased. Nowadays, the high percent of natural gas is extracted from non-associated natural gas wells. **Figure 1.6** shows that the world natural gas extraction increased rapidly in the end of twentieth century.

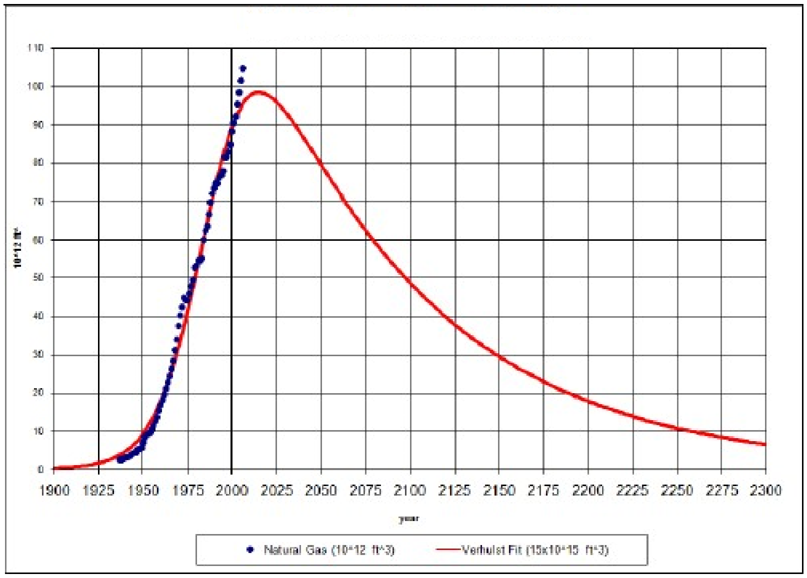


Figure 1.6 World natural gas extraction.

The price of natural gas that is traded in each region of the world depends on some factors special to the natural gas wells of that region that contain the quantity of natural gas, the amount of processing to prepare for the buyer, and the type of transportation that need to transport natural gas to destination. For example, Japan imports natural gas from some countries far from Japan which makes transporting via pipeline impossible. Therefore, they have to convert natural gas to liquefied natural gas (LNG) and transport it via ships. It causes the price of natural gas for Japan is higher than most other countries. Alternative Fuel Indexation is the most common form of gas pricing in markets outside of North America, especially in the Japan in recent years.

As a result, the lowest price is for the buyers that purchase the natural gas where it flows from a well which is famous to the wellhead price. However, producers can demand whatever price they want for their gas as long as they can find a willing buyer. Under these conditions supply and demand will determine prices at a regional level.

After 1950's and 1960's the number of homes and businesses which consumed natural gas were growing. Meanwhile, the new technologies lead to increasing the usage of natural gas in new fields, for example producing electricity. Increasing the demand of natural gas increased its price. Policy makers in these years established some rules to control the natural gas prices.

Over the years, natural gas price controls led to many serious distortions including, ultimately, natural gas shortages in the 1970s. These distortions forced many factories and institutions to close. Economists decontrolled the natural gas prices to reform the natural gas shortages in the 1970s. They decide to increase the ceiling price of natural gas that after second oil shock and disruption of oil they increased the ceiling price of natural gas more and more. During these years, because of natural gas price increasing, the production of natural gas increased rapidly. It was accompany with increasing in the demand of natural gas. The rapid rise in price of natural gas starting at about year 2000 was caused mainly by the combination of increased demand for natural gas and rising energy prices in general.

The current surge in unconventional oil and gas in the U.S. has resulted in lower gas prices in the U.S than other regions in the world as it increases the production of natural gas substantially. It can be seen in **Figure 1.7** that after discovering shale gas the production of natural gas has increased significantly.

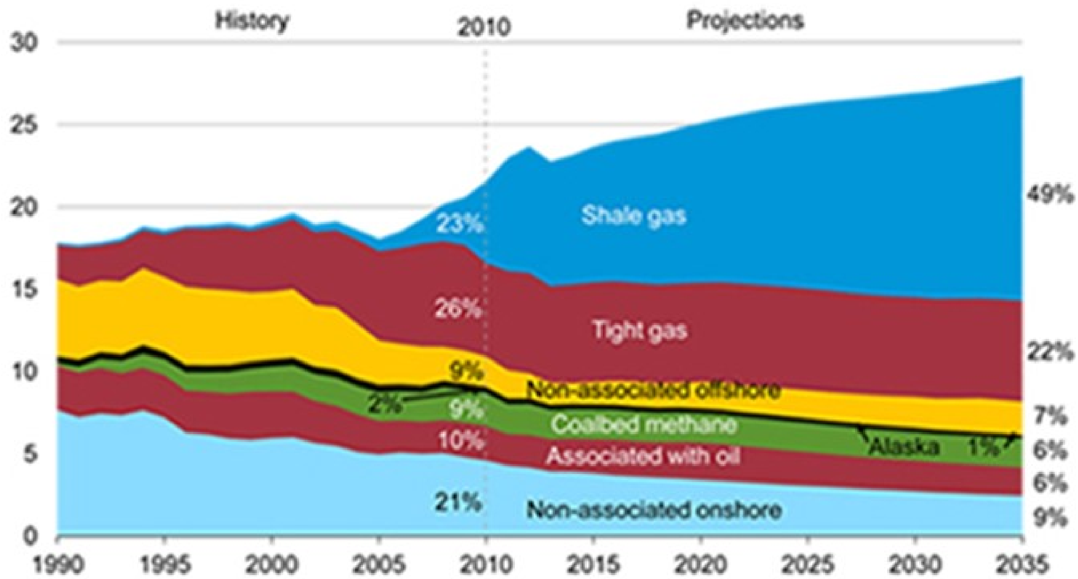


Figure 1.7 U.S. natural gas production 1990-2035, Trillion cubic feet per year, Source: U.S Energy Information Administration, Annual energy outlook 2012.

Figure 1.8 illustrates the world's largest natural gas reserves. It shows U.S. natural gas reserves even after discovering shale gas is after Iran, Russia, Turkmenistan and Qatar. However its production is higher than its natural gas reserves. U.S. even with this amount of production, imports natural gas via pipeline from Canada and Mexico, and LNG from Algeria, Egypt, Nigeria, Norway, Qatar, Yemen and Trinidad. These have led to discussions in Asia' oil linked gas markets to import gas based on Henry Hub index.

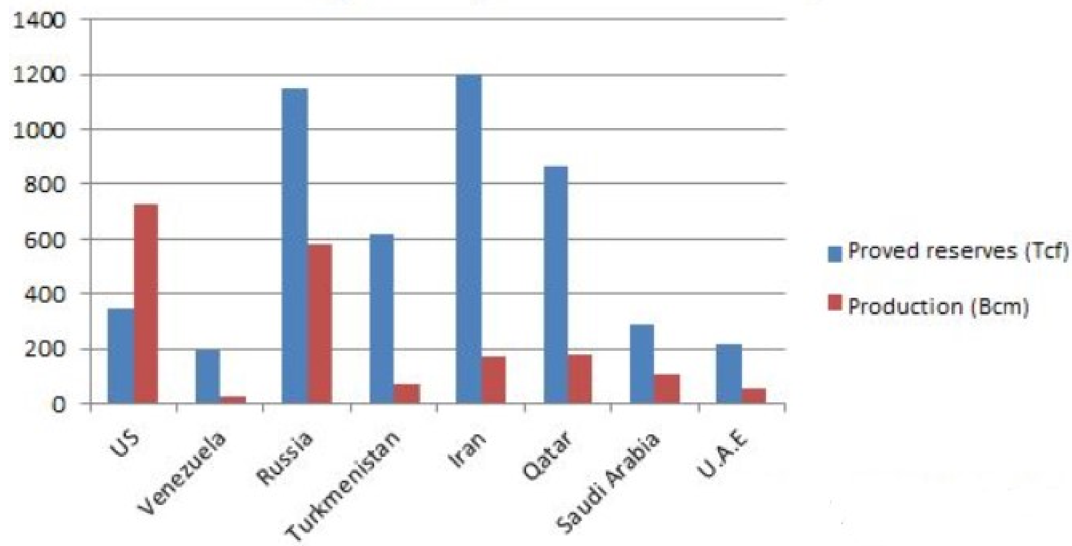


Figure 1.8 Natural gas total proved reserves and production 2014, Source: BP Statistical Review of World Energy.

1.2.3 Coal Market

Coal is first fossil fuel discovered. It is primarily used as a solid fuel to produce electricity and heat through combustion. Today, coal produces a high amount of world energy. The type of transportation of coal is the factor that makes its market different from crude oil and natural gas markets. It has high costs and is harder than transportation of crude oil and natural gas. These reasons make coal a relatively local commodity and less than a fifth of worldwide coal trade is international. The main part of coal export to countries via ships. Another way is train.

Figure 1.9 demonstrates the world consumption of coal by region. It shows that China and United states are the biggest coal consumers in the world. Furthermore, China is the biggest producer in the world. China as a net coal exporter became a net coal importer in 2009 for the first time in over two decades. In 2012, China consumed an estimated 4 billion short tons of coal, representing close to half of the world total. The global amount of coal export and import can be seen in **Figure 1.9**.

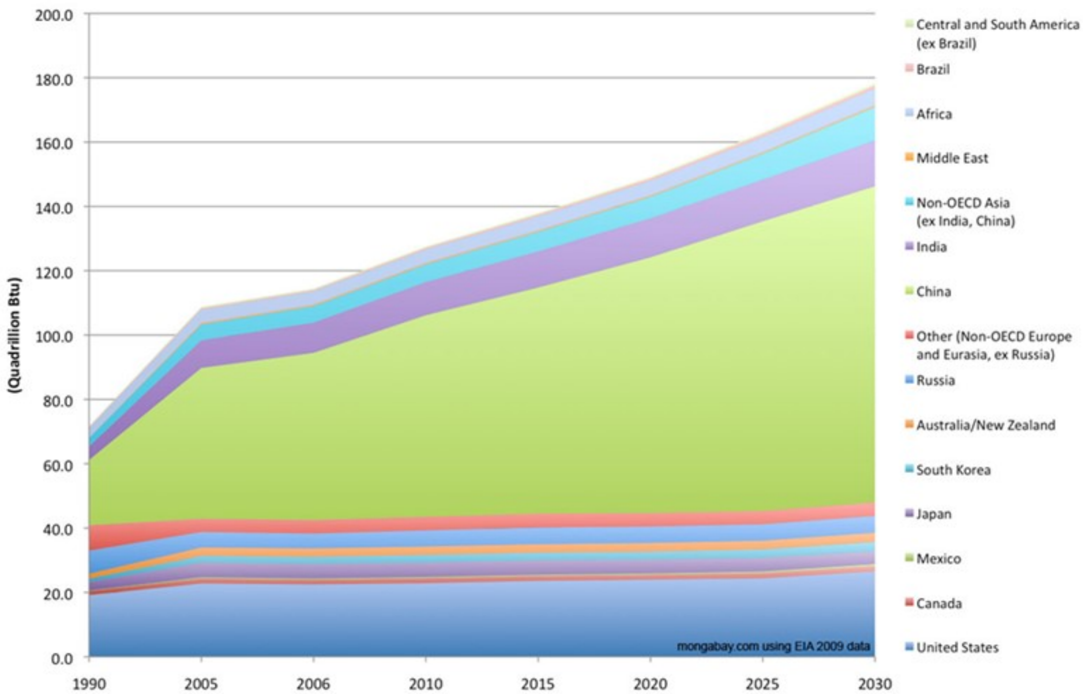


Figure 1.9 World coal consumption by region, Reference case, 1990-2030.

Indonesia and Australia are the largest coal exporters to China, supplying more than 60% of China's imports in 2012. EIA predicts that China and India will double their consumption of coal from 2004 to 2030. The United States' consumption will increas by about 50 percent during the same period. Coal is produce in 70 countries all over the world. **Figure 1.10** shows that Indonesia is first and Australia is the second coal exporters countries in the world. After them Russia, South Africa, Colombia and U.S. are the biggest coal exporters in the world. Actually, most of the coal consumed in the country which is produced.

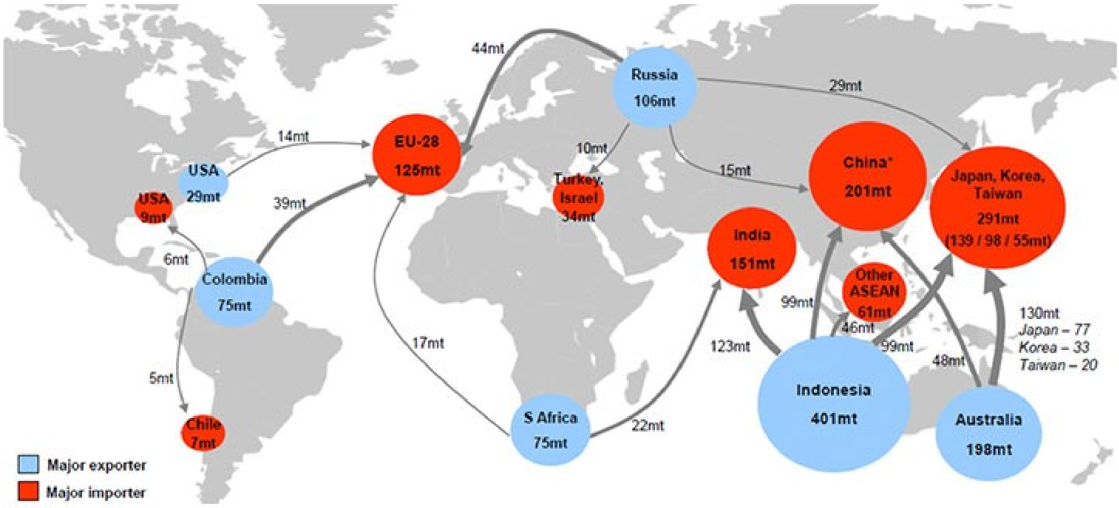


Figure 1.10 Global coal import and export dynamics 2014, Source: Trade data; Macquarie Research, February 2015.

In recent years, the main consumption of coal is producing electricity. **Figure 1.11** iluustrates the consumption of coal in electricty sector is near to haif of its consumption in the world and this amount will incrase in the future.

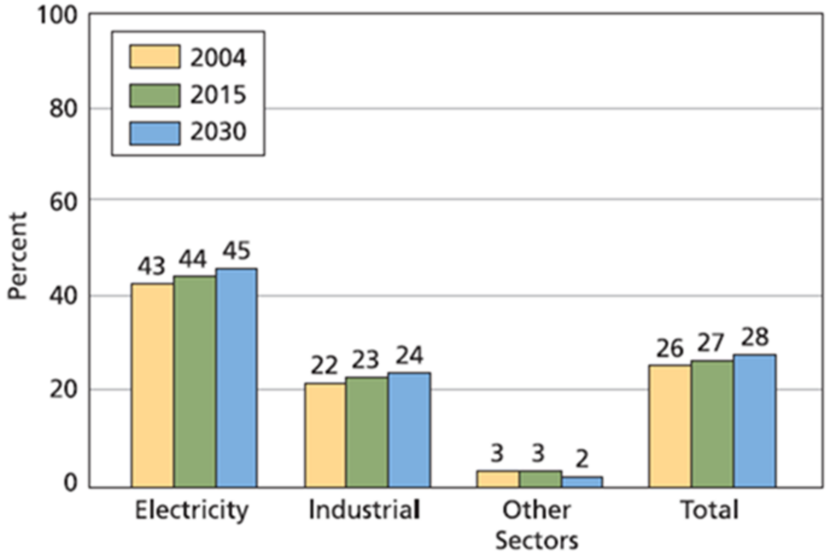


Figure 1.11 Coal's share of world energy consumption by sector, 2004, 2015, and 2030. Source: EIA.

How the price of coal is determine? The important factors to determine the price of coal are capacity utilization of mines, mining capacity, labor productivity, the user cost of capital of mining equipment, the cost of factor inputs (labor and fuel), and transportation. Factors such as colder winters, warmer summers, changes in environmental laws, alternative fossil fuel markets (Natural gas/Oil prices), technological innovations, natural disasters, labor issues, and equipment failures all impact pricing volatility of coal. Since 2001 price volatility increased greatly due to a variety of factors such as regulatory restrictions and reserve depletion.

The coal mining productivity has increased from 1980 because of structural changes in the industry and technological improvements. However, there are three imprtant factor that make disadvantage for consumption of coal in comparison with crude oil and natural gas. First is trasportation which we explain before. About 63% of the world's oil production moves on maritime routes while this amount is 90% for coal and just 10% traded over land.

It means coal mostly can be traded between coutries that have access to maritime. Second is the thermal unit that burning coal produce in comparison with oil and natural gas. Oil as a fuel has the double thermal content of coal. And the last factor is the pollution and amount of CO2 that coal release in the air which is significantly higher than crude oil and natural gas. Actually, coal is the largest contributor to climate changes in the world.

The amount of pollution of coal causes policy makers establish strict rules during many years to restrict its consumption. With the Middle East oil crisis, policymakers began to adopt policies to try and shift the nation toward greater coal consumption, which was a domestic energy resource.

1.3 The Relationship between Crude Oil and Macroeconomy

Researchers attempt to find some evidence that oil market has significant effect on the macroeconomy. For this purpose, they study the oil supply shocks based on global crude oil production. They show that supply disruption of oil lead to sudden and high increase in the price of crude oil. Crude oil as energy is one out of three variables to producing goods and services. Therefore, their results say oil price shocks as a contributing factor in recessions affect macroeconomy significantly. This approach mostly has expanded on the results of Hamilton (1983, 1988 a, b, 1996) which finds some evidences that there is a historical correlation between oil shocks and recessions.

The new approach has started mainly by the Barsky and Kilian (2002) which they discussed on the causality from aggregate demand to oil prices in contrast with previous studies. Kilian (2008a) illustrate that the oil supply shocks do not explain the bulk of oil price fluctuations. For example, in 1979 and 1980, second oil shock, the Iranian revolution lead to decrease in the oil supply, which other countries approximately offset it. However, after that Iran-Iraq war causes a disruption in the global oil production. The main point is that in the 1978, 1979, and 1980 repeated large positive shocks to the global aggregate demand happened. Therefore, the increasing prices of oil may happen not because of oil supply disruption, but because of aggregate demand increase.

A useful approach to classifying the key determinants of the real price of oil is distinguishing the three demand and supply shocks (Barsky and Kilian(2002,2004)): first, shocks to the current physical availability of crude oil (oil supply shocks), second, shocks to the current demand for crude oil driven by fluctuations in the global business cycle (aggregate demand shocks) and third shock, shocks driven by shifts in the precautionary demand for oil (precautionary demand shocks).

Kilian (2009) find some evidence that a combination of global demand shocks and precautionary demand shocks is the main reason of big changes of the crude oil price. He defines precautionary demand of consumers as uncertainty about shortfalls of expected supply relative to expected demand and shows that in 1979 a large unanticipated increase in oil specific demand was happened.

Quantifying demand shocks was a problem because of two reasons, first, there were no available indices in order to capture shifts in the demand for industrial commodities driven by the global business cycle and second, the expectation shifts underlying precautionary demand shocks are not observable. Kilian (2009) established an alternative strategy to modeling expectations directly. He explains an explicit monthly measure of the changes in global real economic activity that affects the demand for all industrial commodities. It's based on dry cargo single voyage ocean freight rates to capture shifts in the demand of industrial commodities in global business markets.

1.3.1 The Construction of the Kilian (2009) Index:

The index of global real economic activity is based on various bulk dry cargoes consisting of grain, oilseeds, coal, iron ore, fertilizer, and scrap metal, in US dollars per metric ton.

According to the **Figure 1.12**, dry cargo freight rates may increase during oil price shocks because of the provision of shipping services uses bunker fuel oil as an input.

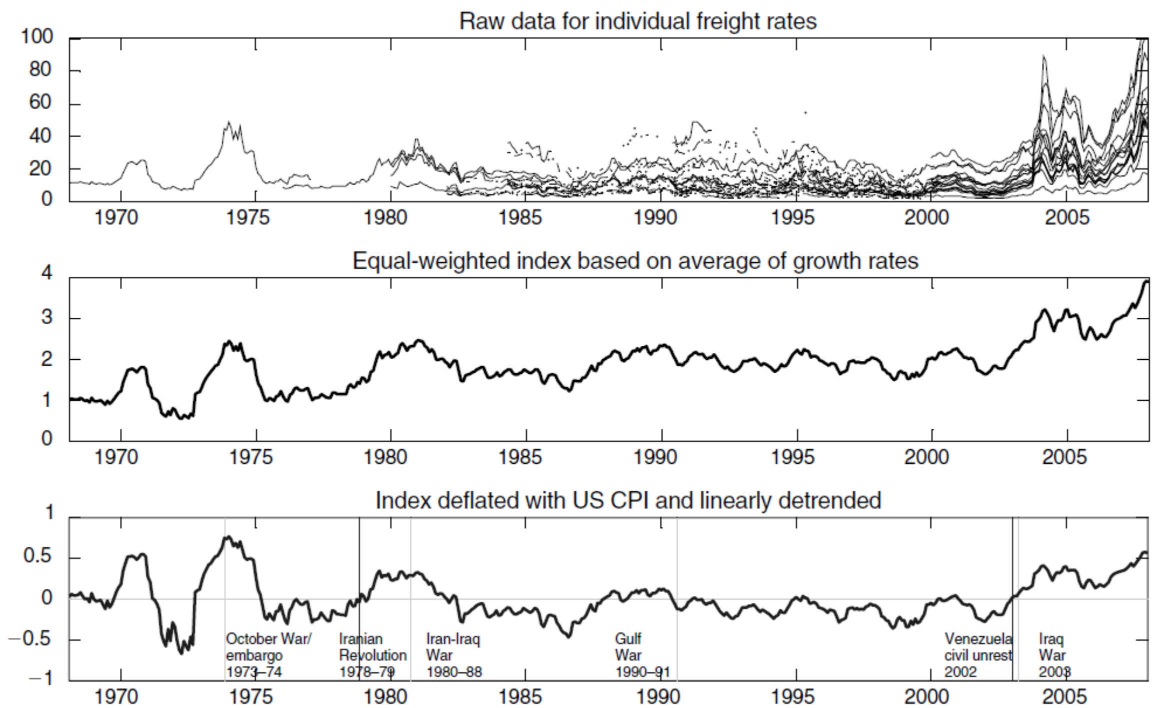


Figure 1.12 Monthly index of global real economic activity based on dry cargo bulk freight rates.

We use the Kilian (2009)'s index, the above index, in our research to decompose the real price of oil to three mutually orthogonal components to distinguish between oil supply shocks, global aggregate demand shock and oil specific demand shock. Our main purpose is investigating the relationships between crude oil, natural gas and coal with considering these three shocks in oil market.

1.4 Results

As we mentioned before, the crude oil, coal and natural gas markets have many common qualities in both production and consumption sides which may produce some relations between their markets. Are there any relationships between the crude oil, coal and natural gas markets? The oil market affect macroeconomy or macroeconomy affect oil market? Are there relationships between all fossil fuels and macroeconomy? They are some questions that during many years, economics investigate on the fossil fuels markets to answer them. In this research, we concentrate on the short run and long run relationships between fossil fuels using the new index of kilian (2009) for economic real activity.

To investigate the relationships between fossil fuels markets, we concentrate on the first and second oil shocks as main shocks of oil markets and the years after them until today. For this purpose, we encounter some data limitation, especially for natural gas, as we study world markets of fossil fuels. Therefore, we focus on the second oil shocks and subsequent years. Meanwhile, it dictates us to investigate the relationships between fossil fuels separately, first the relationships between crude oil and natural gas and second, the relationships between crude oil and coal.

Our results show some evidence that there is short run relationship between crude oil and natural gas, and between crude oil and coal. The main relations come from demand shocks. The global aggregate demand shocks have effect on the all fossil fuels markets. Furthermore, the fear of future lack of crude oil transfer gradually to other fossil fuels markets, and increase their prices. Oil supply shock has no effect on the crude oil price and natural gas price, while it has significant effect on the coal price. Another main finding of this research is that global aggregate demand shocks have positive and significant effect on the crude oil production. Ignoring the high interactions between fossil fuels may lead to misleading results. At the end, we study the long run relationships between fossil fuels, and our results shows some evidence that there is cointegration relationships between crude oil, coal and natural gas prices.

Chapter 2

How the crude oil market affects the natural gas market: Demand and supply shocks

Abstract

In this paper, the global structural relationship between the prices of crude oil and natural gas is investigated using the recently introduced decomposition of the real price of crude oil by Kilian (2009): crude oil supply shocks, global demand shocks, and crude oil precautionary demand shocks. A four-variable structural vector autoregressive model (SVAR) for oil and natural gas markets is developed for this investigation. We find some evidence that the crude oil market affects the natural gas market through a combination of demand shocks rather than through oil supply shocks. The uncertainty about future oil supply causes precautionary demand in the oil market, which shifts quickly to the natural gas market and increases the natural gas price because natural gas is the primary substitute for oil. In addition to precautionary demand shocks, global demand shocks influence both crude oil and natural gas prices, which leads to similar fluctuations in the prices of oil and natural gas. Consequently, these aggregate demand shocks link oil and natural gas markets and produce similar changes in their prices. (JEL Q41, Q43)

Keywords: Crude oil price, Natural gas price, Aggregate demand shock, Crude oil supply shock, Natural gas price shock, Structural Vector Autoregression (SVAR)

2.1 Introduction

We investigate the structural relationship between crude oil and natural gas and the effect of various shocks on the prices of crude oil and natural gas. We employ the new index introduced by Kilian (2009) for global real economic activity, which is based on data for dry cargo bulk freight rates. By applying this index, we develop a new decomposition of crude oil price, similar to that of Kilian (2009), which consists of oil supply shocks, global aggregate demand shocks and precautionary demand shocks. Precautionary demand shocks arise from uncertainty about shortfalls of expected future supply relative to expected demand.

Many studies have investigated the relationship between crude oil and natural gas. Their main results were finding the answer of this question that the crude oil and natural gas prices are related together or not.

Why do researchers expect the prices of natural gas and crude oil to be related?

Crude oil and natural gas are both fossil fuels with generally similar uses; for example, they can be used for generating electricity, for heating, and in industrial applications. Technology and machinery that are designed to switch between these two types of fuels create the first link between crude oil and natural gas. Brown and Yücel (2008) noted that for many years, fuel switching between natural gas and residual fuel oil kept natural gas prices closely aligned with those for crude oil. According to Villar and Joutz (2006), approximately 18 percent of natural gas usage can be switched to petroleum products. Generally, natural gas and oil are close substitutes in the electric generation, industrial and residential sectors.

However, in recent years, due to rapid changes in technology, some countries have completely separated the use of oil and natural gas. For example, in the U.S., natural gas is currently used for heating, power generation and industrial processes, while 70% of the country's oil consumption is for transportation. **Table 2.1** shows the estimated U.S. energy use in 2012 which is equal to 95.1 Quads. It shows that the usage of energy for transportation mainly comes from petroleum, about 70%. Meanwhile, some small parts come from natural gas, biomass and electricity generation which the electricity is produced by other fuels, for example solar and hydro.

Table 2.1 Estimated U.S. energy use in 2012, all numbers are in percent. Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May 2013.

Kind of energy	Electricity Generation	Residential	Commercial	Industrial	Transportation	Total
Biomass	0.429	0.420	0.109	2.2	1.16	4.32
Coal	15.9	-	0.0433	1.48	-	17.4
Geothermal	0.163	0.0396	0.0197	-	-	0.227
Hydro	2.67	-	-	0.018	-	2.69
Natural gas	9.31	4.26	2.96	8.70	0.764	26.0
Nuclear	8.05	-	-	-	-	8.05
Petroleum	-	1.02	0.632	8.12	24.70	34.7
Solar	0.048	0.193	-	-	-	0.235
Wind	1.36	-	-	-	-	1.36
Electricity Generation		4.69	4.52	3.35	0.0256	
Total of sector	38.1	10.6	8.29	23.9	26.7	

In production side, there are three types of well for oil and natural gas. The most common wells are oil wells or associated natural gas wells. Most of these oil wells produce crude oil, with natural gas as a by-product. The next type is natural gas wells that contain crude oil, but the quantity of oil is too low to be economically extracted. The last type is wells that produce just natural gas. The second and third types of wells are referred to as non-associated natural gas wells. **Figure 2.1** illustrates different types of natural gas wells. In recent years, technology progressing in the fields of oil and natural gas lead to discovering new wells, shale wells. These kinds of wells still are limited to few countries.

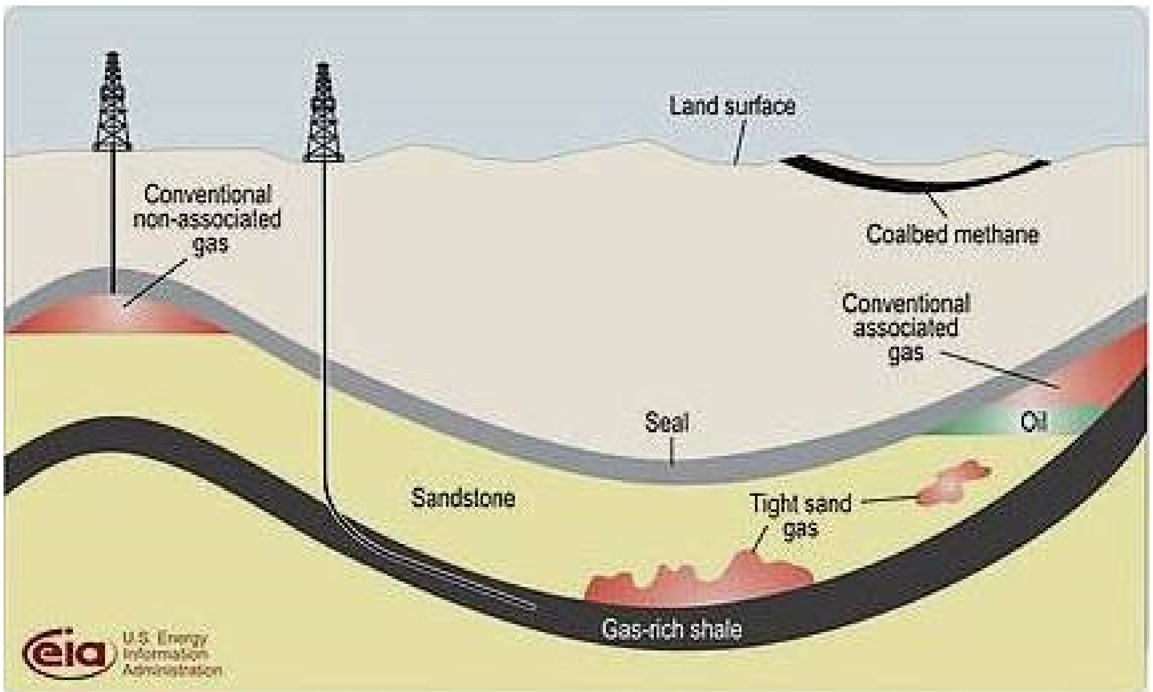


Figure 2.1 Different kinds of natural gas wells. Source: US Energy Information Administration.

Associated natural gas wells are the second link between crude oil and natural gas due to the complementary nature in which they are produced in these types of wells. In associated natural gas wells, when extraction of crude oil begins, small and light gas carbon chains are released from the reservoir to the surface. To stop the flow of this natural gas, the oil production must be stopped as well, which may not be economical. To solve this issue, producers can either flare off the natural gas, which creates environmental problems, or they can sell it. The first solution is rarely preferred. As a result, natural gas production is linked to crude oil production as a complement in associated natural gas wells.

These links, both in the consumption and in the production of crude oil and natural gas, cause researchers to expect a relationship between the markets and prices of these fuels.

Researchers have studied the cointegration relationship between crude oil and natural gas prices in the long run. They find some evidence that the price of crude oil and natural gas are cointegrated (see, e.g., Villar and Joutz (2006), Brigida (2014)). Some researchers find that there are short-term departures from the longer-term relationship between oil and natural gas prices that are caused by product inventories, weather, and supply shocks (e.g., Hartely et al. (2008)).

Historically, two simple rules of thumb have been used to correlate the prices of crude oil and natural gas. The first rule of thumb is the 10-to-1 rule, in which the price of crude oil is 10 times the price of natural gas. The second rule, which has been advanced by some energy analysts, is that the prices of crude oil and natural gas are the same on a British thermal unit basis, therefore implying a 6-to-1 rule, in which the price of crude oil is six times the price of natural gas. The actual (Henry Hub) and implied natural gas prices using 10-to-1 and 6-to-1 rules are shown in **Figure 2.2**. However, some researchers believe the ratio of oil price to natural gas price has decreased in recent years.

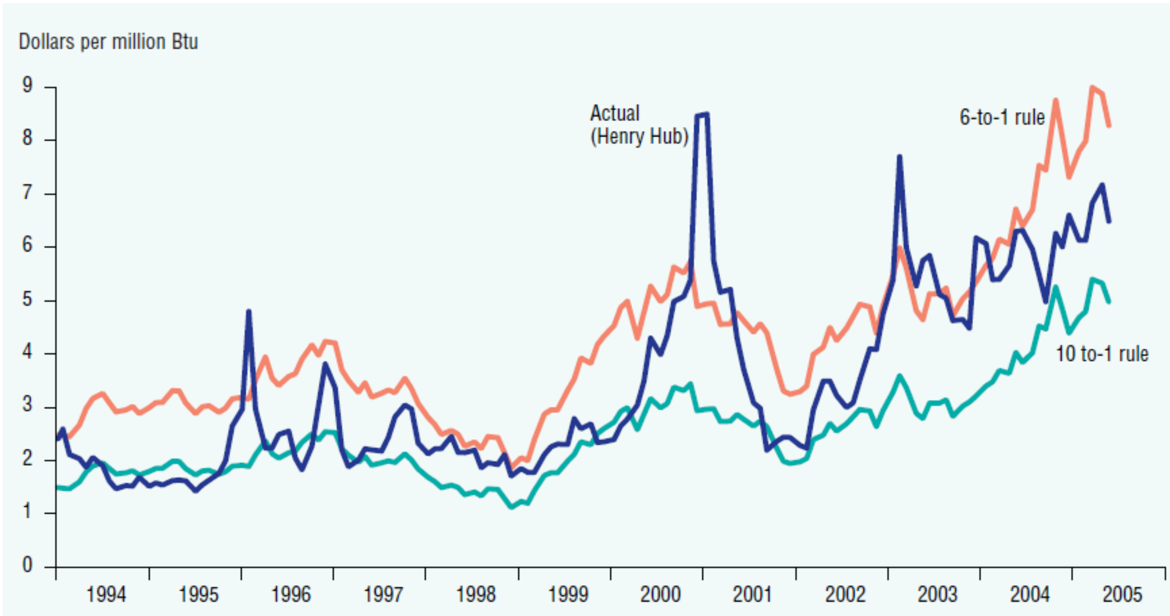


Figure 2.2 Actual and implied natural gas prices using 10-to-1 and 6-to-1 rules of thumb. Source: Natural gas pricing: do oil prices still matter? Stephen Brown, Southwest Economy, 2005, issue Jul, pages 9-11.

Recently, some researchers have also discussed the decoupling of crude oil and natural gas prices (see, e.g., Bock and Gijon (2011)). Following them, Ramberg and Parsons (2012) argue that although the two price series may be cointegrated, the confidence intervals for both short and long time horizons are large. Most such studies concentrate on the Henry Hub natural gas price and the WTI crude oil price of the United States (e.g., Villar and Joutz (2006)).

In this study, we concentrate on the global markets of crude oil and natural gas, given previously cited studies that provide evidence for the relationship between crude oil and natural gas markets, as well as the production and usage linkages explained earlier, we focus on short term relationships of how the global oil market affects the global gas market without specifying the number of cointegration relationship.

For this purpose, we apply a four-variable structural vector autoregressive (SVAR) model. Our results suggest that the main factors that produce identical fluctuations in many periods for crude oil and natural gas are aggregate demand, consisting of global aggregate demands and precautionary aggregate demands for oil, which we further interpret as precautionary demands for oil and its main substitute, natural gas.

The rest of the paper is structured as follows: in section 2, the data used for our analysis are given, the structural VAR framework is described, and the results are discussed. Section 3 reports the robust results of our model, and finally, section 4 provides concluding remarks.

2.2. The Structural Relationship between Prices of Crude Oil and Natural Gas

In this section, we explain the relationship between oil and natural gas prices. In first subsection, our data is explained. In the second subsection, the SVAR model is showed. And in the last section, we report the results of the model.

2.2.1 Data

Our data set comprises monthly data from January 1989 to February 2014. It consists of the percent change in world crude oil production, the index of real economic activity, the real price of crude oil, and the real price of natural gas.

The percent change in global crude oil production is the average monthly data in millions of barrels pumped per day from the U.S. Energy Information Administration (EIA). It is the log differences of world crude oil production. The index of real economic activity is the monthly index of global real economic activity based on dry cargo bulk freight rates, as Kilian (2009) demonstrated. The availability of this index dictates that we limit our data to February 2014. The real oil price is the monthly imported crude oil price of the United

States. The real natural gas price is the U.S. natural gas imported price. The prices of natural gas and crude oil are obtained from the EIA. They are expressed in log units and have been deflated by the U.S. CPI. **Figure 2.3** plots the imported crude oil and natural gas prices of the U.S. from January 1989 to February 2014.

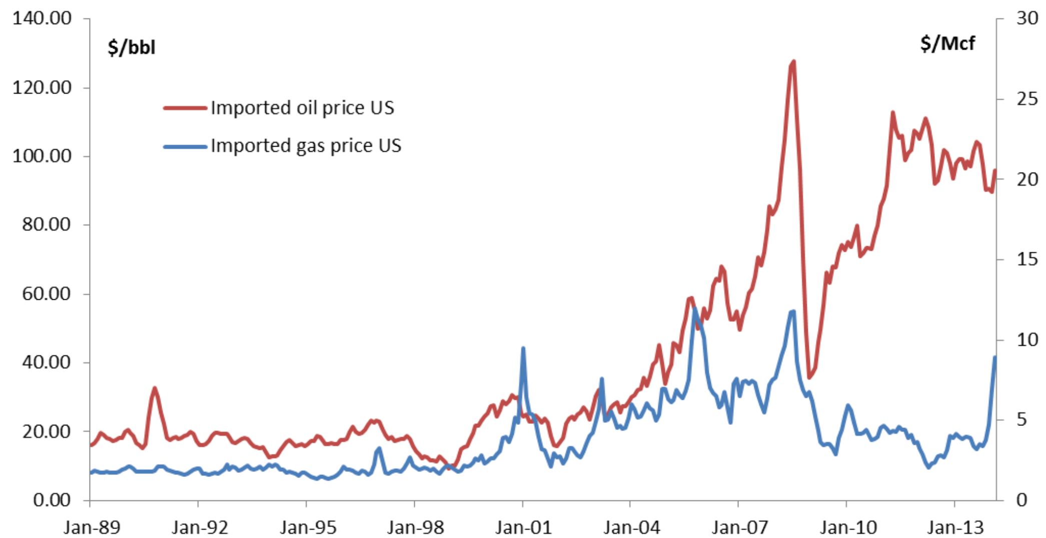


Figure 2.3 US Oil and Natural Gas Imported Prices (1989:1-2014:2).

It shows that natural gas prices are more closely correlated to the crude oil prices until 2009. After sharply falling off by 70 percent from $126.22 in Jun 2008 to $36.84 in January 2009, the price of oil increases to a maximum of $113.02 in April 2011, a 207 percent increase. Similarly, the imported natural gas price declines approximately 71 percent from $11.71 in June 2008 to $3.29 in August 2009. However, it reaches a maximum of $5.95 in January 2010 and fluctuates between these amounts until September 2013. After this, it suddenly increases to $8.94 in February 2014, suggesting that the natural gas price may once again be moving towards the previous correlation with the crude oil price.

2.2.2 The Structural Vector Autoregressive (SVAR) Model

We employ structural vector autoregression for modeling the relationship between crude oil prices and natural gas prices to examine the effects of different types of crude oil shocks on natural gas. Our model is based on monthly data for $z_t = (\Delta prod_t,\ rea_t, rpo_t, rpg_t)$, where $\Delta prod_t$ denotes the percent change in global crude oil production, rea_t is the index of real economic activity, rpo_t is the real price of oil, and rpg_t refers to the real price of natural gas. In the reduced-form representation, our model is denoted as

$$z_t = \delta + \sum_{i=1}^{p} B_i z_{t-i} + e_t \qquad \textbf{(2.1)}$$

where e_t is the vector of reduced-form errors. We estimate the reduced-form VAR model using the least-square method, which is used in the structural VAR model.

The model in its structural VAR representation is written as

$$A_0 z_t = \alpha + \sum_{i=1}^{p} A_i z_{t-i} + \varepsilon_t \qquad \textbf{(2.2)}$$

where ε_t is the vector of serially and mutually uncorrelated structural errors. We postulate a recursive structure for our model, A_0^{-1}, such that the reduced form errors e_t can be written according to $e_t = A_0^{-1}\varepsilon_t$:

$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \\ e_t^{rpg} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \\ \varepsilon_t^{Natural\ gas\ price\ shock} \end{pmatrix} \qquad \mathbf{(2.3)}$$

The six restrictions on A_0^{-1} may be motivated as follows. Oil supply shocks are defined as unpredictable innovations to global crude oil production. Innovations to global real economic activity are explained base on two different shocks, oil supply shocks and aggregate demand shocks (shocks to the global demand for industrial commodities). Innovations to the real price of oil are based on oil supply shocks, aggregate demand shocks and oil specific-demand shocks (precautionary demand shocks). These restrictions are based on Kilian's assumptions in his paper. Finally, innovations of real price of natural gas are based on all shocks to the crude oil market consist of oil supply shocks, aggregate demand shocks and oil specific-demand shocks and shocks to the natural gas market (natural gas price shocks which consist of natural gas supply and demand shocks). The world oil market is a single, highly integrated economic market (Bachmeier and Griffin (2006)) which has some cartels, for example the Organization of Petroleum Exporting Countries (OPEC). These cartels could control the amount of supply and price of crude oil in the world. While natural gas market consists of some small and segmented markets. Although in recent years some countries attempt to establish a natural gas cartel, The Gas Exporting Countries Forum (GECF) which is an intergovernmental organization of 11 of the world's leading natural gas producers, still natural gas market is not powerful as much as oil market to control its prices. Therefore, because of these differences in the power of markets, we assume that real price of natural gas is affected by oil market and natural gas market shocks but that natural gas price shocks have no effect on the real price of oil.

2.2.3 Results

We generate Impulse responses of oil supply shock, aggregate demand shock, oil-specific demand shock, and natural gas price shock on oil production, real activity, the real price of oil, and the real price of natural gas. All of our shocks are normalized. The error of reduced-form VAR of the model is based on a recursive-design wild bootstrap with 2000 replications (Goncalves and Kilian (2004)).

First, we evaluate the impacts of oil supply shocks on the real activity, real price of oil and real price of natural gas. **Figure 2.4** shows that when an unexpected disruption happened for oil supply, it changed the global oil production, substantially. However, after that the production of oil increases slightly until approximately 3 months and remains roughly the same even after 20 months. The reason of this increase is that the oil cartels attempt to compensate for the decline in the oil supply. Depending on the capacity of the oil producers, their effort may not sufficiently

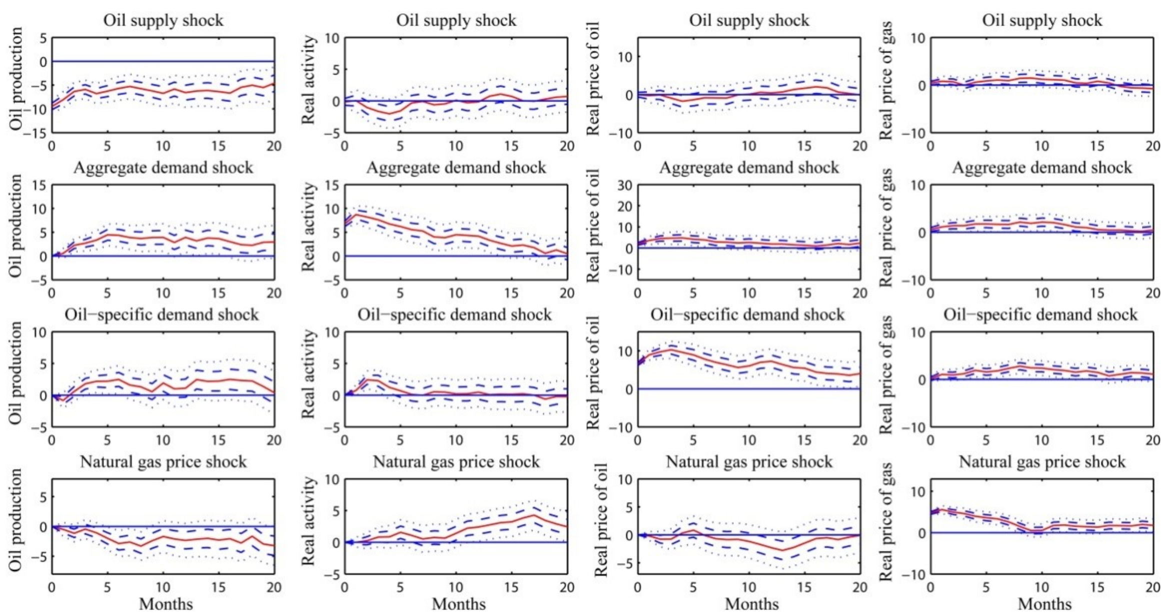


Figure 2.4 Impulse responses of structural shocks.

offset the initial production shortfalls, as **Figure 2.4** shows. It is obvious from **Figure 2.4** that the real activity, the real price of oil, and the real price of natural gas have not been significantly affected by the oil supply shocks until the end of our time horizon.

In response to the demand shocks, the results illustrate that a positive aggregate demand shock causes an increase in the prices of oil and natural gas for some months which is statistically significant. An unanticipated increase in the global aggregate demand causes an increase in the price of oil to the highest amount through the first three months, and after that, the oil price starts to decrease to the initial amount. Meanwhile, global aggregate demand shock causes a gradual increase in the price of natural gas until 12 months, approximately; after that, the natural gas price decreases over a period of nearly two months. Therefore, increase of oil price happens more quickly than increase of natural gas price.

In response to the global aggregate demand shocks, we demonstrate nearly the same results as Kilian (2009) demonstrated for oil prices. However, the effect of aggregate demand shocks on the oil production is different from Kilian's (2009) result. **Figure 2.4**. illustrates that an unanticipated aggregate demand increase has a positive and significant effect on the production of oil. It increases the production of oil gradually over a period of 5 months and then decreases it until the 20^{th} month.

These results are consistent with economic reasoning. When global aggregate demand increases, this implies a higher demand for energy, which is a critical factor in the production of goods and services. Because crude oil and natural gas are two out of three main sources of energy, the demand for these fuels is expected to increase, which should simultaneously increase their prices. According to our results, the price of oil increases sooner than the price of natural gas, which may be due to the historical dependency of oil in the world.

What about the effects of crude oil precautionary demand shocks on the real price of oil and the real price of natural gas? **Figure 2.4** illustrates an unanticipated increase in oil market-specific demand increases both oil and natural gas prices, statistically significant. It causes an immediate increase in the price of oil while causing a gradual increase in the price of natural gas. The price of oil increases to a higher amount after 3 months and starts to decrease slightly. However, the price of oil ultimately remains higher than before. This implies that precautionary demand can change the price of oil considerably for more than 20 months. An increase in the crude oil precautionary demand causes the natural gas price to increase for 8 months and then decrease slightly. Similar to price of oil, the price of natural gas does not return to its initial amount. Thus, the precautionary demand of crude oil has a significant effect on not just crude oil prices but also natural gas prices. In other words, the uncertainty about the future supply of crude oil makes consumers attempt to compensate for potential future shortfalls with higher demand for not just oil but also natural gas because it is an important substitute for oil. We note however that, in comparison with oil, the natural gas price does not increase immediately, implying that this higher demand transfers gradually to the natural gas market.

Furthermore, the results show that an unanticipated oil-specific demand increase has an effect on the real activity from the time of occurrence; the real activity increases quickly over a period of 2 months, which is statistically significant. Then, it starts to decrease.

What about the effects of an unanticipated increase in natural gas price on the real price of oil? A natural gas price shock can happen in both supply and demand shock scenarios. The natural gas supply shocks or the natural gas demand shocks may produce a natural gas price shock. Due to the lack of global natural gas production data, we are not able to determine which one of these is responsible for the natural gas price shock in our results. **Figure 2.4** shows that an unexpected increase in the natural gas price has a large and significant effect on the real price of natural gas. This effect then decreases over a period of 9 months. Furthermore, it illustrates that an unanticipated natural gas price increase does not have a significant effect on the real price of crude oil.

We can conclude that there is a structural relationship between crude oil and natural gas that mainly comes from demand shocks. Meanwhile, demand shocks are the main reasons that the changes in oil and natural gas prices are similar. While oil supply shocks do not have a significant effect on the natural gas price, global aggregate demand shocks and oil-specific demand shocks have a significant effect for more than 15 months on the price of natural gas.

Uncertainty about future supply of oil or instability in the oil market quickly increases the demand for oil. In addition to increasing current consumers demand for oil, consumers attempt to replace oil with substitutes, primarily natural gas, resulting in an indirect transfer of demand from the oil market to the natural gas market. This means that the natural gas market is not affected directly by oil market fluctuations.

Meanwhile, aggregate demand shocks arise from high fluctuations of global aggregate demand that do not originate from the oil market and have affected both the oil market and the natural gas market at same time, which causes similar fluctuations for both crude oil and natural gas prices in many periods.

2.3 Robustness check

Natural gas prices vary across the globe and are determined by region, the distance to natural gas sources, and other factors. There is evidence to suggest cointegration of global natural gas markets, but the price of natural gas is different in different regions.

Figure 2.5 demonstrates the trends in natural gas spot prices at major global markets. It can be seen that the natural gas price of U.S. and UK are approximately near to each other, until 2010, but the natural gas price of Japan in most years are far from them. This difference mainly comes from the distance between natural gas exporter countries and Japan, which produces high amount of transportation cost. Another reason for the difference between natural gas prices of U.S. and UK with Japan is the cost of changing natural gas to liquid natural gas (LNG). Therefore, these reason cause that the prices of natural gas from one region to another region are different.

As a result, we apply different natural gas prices to check the robustness of our main results.

Figure 2.5 The prices of natural gas in three different regions, U.S. dollars per million British thermal units (MMBtu). Source: U.S. Energy Information Administration, based on Bloomberg, L.P. https://www.eia.gov/todayinenergy/detail.cfm?id=3310.

After the United States, the largest producers of natural gas in the world are Russia and the European Union, in that order. European countries import natural gas from Russia, which cause their natural gas prices to be approximately the same.

Figure 2.6 shows the biggest natural gas producers countries in the world in 2014. Approximately this order was similar during our periods for many years.

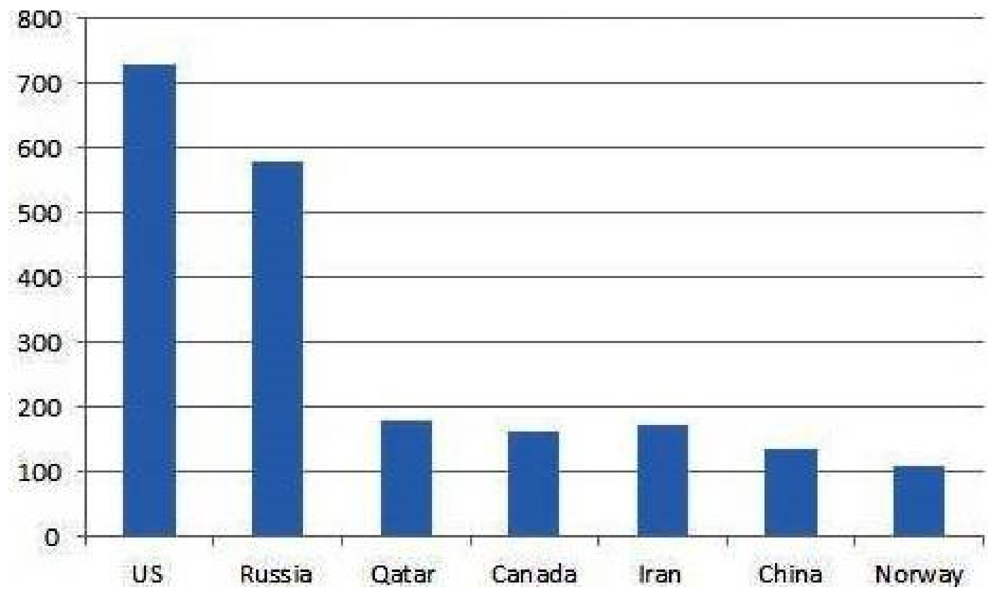


Figure 2.6: The biggest natural gas producers in the world in 2014.

Our new data for natural gas prices can be based on the natural gas price of Russia. The natural gas price of Russia demonstrated in **Figure 2.7**.

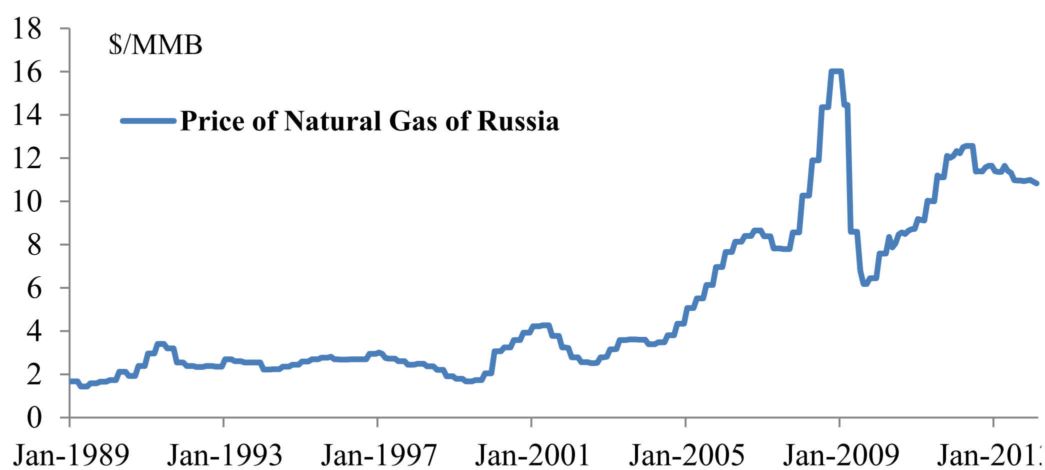


Figure 2.7 Russia natural gas price (1989:1-2014:2).

Figure 2.8 illustrates Impulse responses of oil supply shock, aggregate demand shock, oil-specific demand shock, and natural gas price shock on oil production, real activity, the real price of oil, and the real price of natural gas which natural gas prices are the Russia natural gas prices.

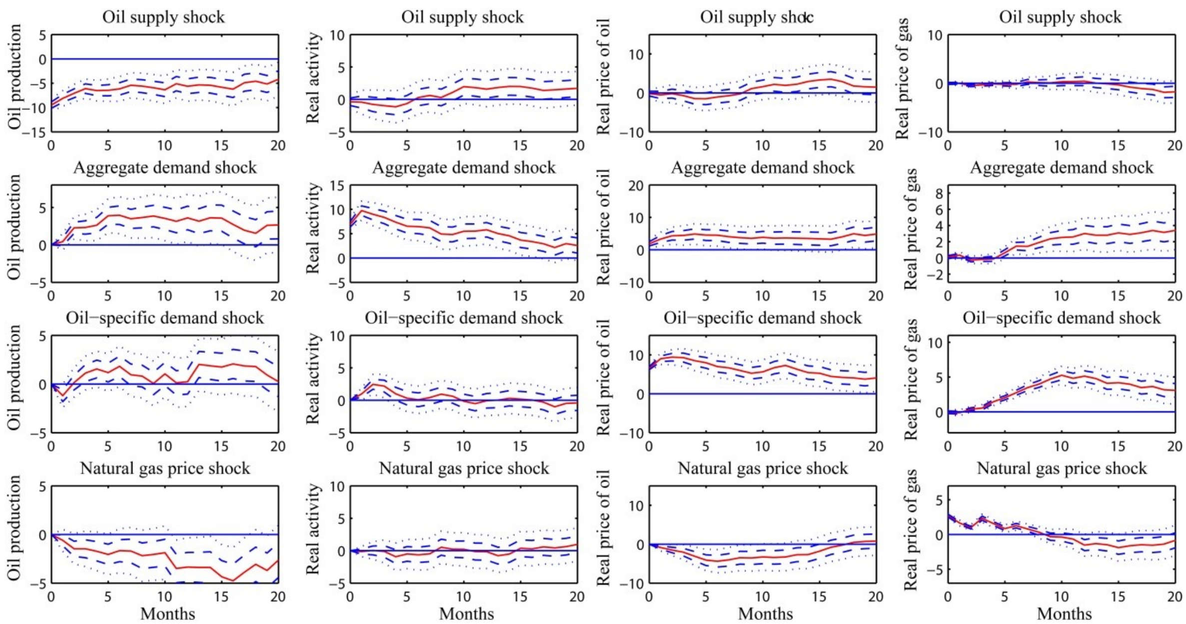


Figure 2.8 Impulse responses of structural shocks for robustness check.

Similar to our main results, **Figure 2.8** shows that an unanticipated oil supply decline does not have a significant effect on the real activity, the real price of oil and the real price of natural gas. It also illustrates that an unanticipated global aggregate demand increase has a statistically significant and positive effect on the real price of oil, the real price of natural gas and oil production. The effect of aggregate demand shock on the natural gas price started with an approximately 5-month delay in contrast to its effect on the real price of oil, which started from the first month.

What are the effects of oil-specific demand shock on the real price of oil and the real price of natural gas? The effect of an unanticipated oil-specific demand expansion on the real price of oil is the same as our main results. Similar to the main results, an aggregate demand shock causes the real price of natural gas to increase but, in this case, with a 2-month delay; it then decreases and ultimately remains at a higher price.

These results show that the oil market affects the natural gas market mainly through demand shocks rather than through oil supply shocks; we can conclude that our main results are robust.

As another check of the robustness of our results, we run our programs for a period in which there is no significant departure between the price of natural gas and that of crude oil in the U.S natural gas price data. These results also confirm that the previous results are robust.

2.4 Conclusion

Some researchers have found evidence for a long-term relationship between the prices of crude oil and natural gas and have shown that their prices are cointegrated. Most of them concentrate on the WTI crude oil price and the Henry Hub natural gas price of the United States. In this paper, we attempt to take a different view on the global relationship between natural gas and crude oil prices to investigate how oil market affects natural gas prices which produce similar fluctuations in their prices. We use a structural VAR model and decompose the price of oil into three components by applying Kilian's new index for real activity to investigate the relationship between oil and natural gas markets. For this purpose, we use U.S imported crude oil and natural gas prices as an index for world crude oil and natural gas prices.

The main point of the paper is that there is an indirect relationship between the oil market and the natural gas market that arises from precautionary demand shocks for oil. We interpret this as indicating that the precautionary demand shocks for oil create precautionary demand shocks for its main substitute, natural gas. It causes the prices of crude oil and natural gas to change in similar directions. Global aggregate demand shocks are the second factor in similarly changing crude oil and natural gas prices. Consequently, demand shocks are the main factors that indirectly connect the global crude oil and natural gas markets.

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Chapter 3

The Relationship between Crude Oil and Coal Markets: A New Approach

Abstract

Two main parts of global energy basket are crude oil and coal that their level of substitutability in production and consumption sides may relate their markets. The purpose of this paper is investigating the relationships between crude oil and coal markets using a structural vector autoregressive model (SVAR). We use the Kilian (2009) index as an indicator of global real activity to distinguish between the effects of oil market and global aggregate demand shocks. The empirical results suggest that coal prices are affected by both supply and demand shocks of oil market, while oil supply shocks has no effect on the oil prices. This shows the high amount of interactions between their markets which mainly arises due to substitution role. Meanwhile, the effect of global aggregate demand on the price of coal is higher than on the price of oil and fear of future oil supply just temporary affect the coal market. (JEL Q41, Q43)

Keywords: Crude oil price, Coal price, Oil supply shock, Aggregate demand shock, Precautionary demand shock, Structural Vector Autoregression (SVAR)

3.1 Introduction

Coal and oil are the two most important sources of primary energy in the world, for example the first fuel that households began to burn for heat was coal. After that coal have been used as a fuel for thousands of years and as the nation became industrialized coal cause the rapid growth of factories. After discovering of oil, coal was overtaken by oil. Coal fueled steam engines in trains long before the liquid fuel-powered engines of today's cars were in use. The main factors that cause countries replace oil with coal in some sectors were the environmental pollution and transportation. Coal has caused substantial air pollution as well as ground and surface water pollution in mining, transportation and consumption. The coal pollution is much higher than oil pollution. Coal is steady supply of greenhouse gases that cause many countries attempt to restrict its consumption in the world. For example, before the second oil shock, U.S and some other countries had established coal production ceiling rules. Although, they had to remove these rules gradually after second oil shock to compensate the decline of oil production. **Figure 3.1** shows the amount of fossil fuels CO2 emissions into Earth's atmosphere. We see that the air pollution of coal is significantly higher than oil and natural gas.

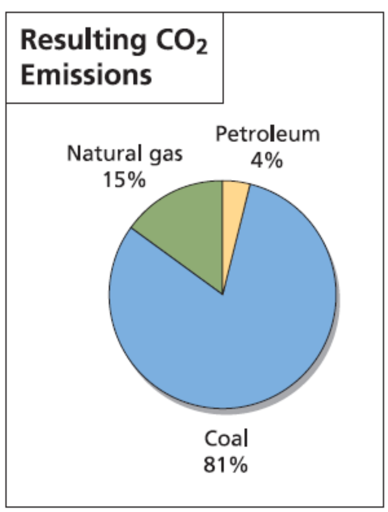

Figure 3.1 Coal, the greatest source of carbon dioxide emissions between fossil fuels. Source: EIA.

Transportation is second issue that cause countries try to replace oil with coal after discovery of oil. Coal is the second largest product traded internationally. The transportation of coal is expensive and needs infrastructures such as rail which limit the trade of coal to regionally exports and imports. On the other hand, oil can transport to all regions of the world which cause oil has a global market. Thus, coal markets are much less global than oil, having instead a domestic or regional orientation. Although, with progressing in technology and improving transportation for coal, the small, segmented and domestic coal markets have moved toward global market, for example increasing in seaborne trade for coal has unified segmented coal markets into a global market (see e.g. Ellerman (1996)).

Consequently, environmental pollution and transportation are two main issues that cause consumers replace coal with oil. However, during last centuries, the amounts of oil in some periods had sudden decline which produce high interactions between oil and coal productions and consumptions. After the 1973 oil price shock, electric utilities saw a need to reduce reliance on petroleum. Most of the new utility plants built after 1975 were coal and nuclear facilities. As a result, a large portion of the oil-fired capacity in the late 1970's and early 1980's was reserved for peak load periods or for emergencies and routine maintenance periods. Due to new plant construction and higher oil prices in the late 1970s and early 1980s, the use of residual fuel oil at electric utilities declined substantially. From a peak of 1.7 million barrels per day in 1978, oil consumption at electric utilities fell to 475,000 barrels per day in 1985. In this period, the production of coal had started to increase. In the late of nineteenth century by increasing in the use of electricity, coal became a mainstay in electric power plants. Therefore, the use of coal has shifted primarily to the electricity generation, while oil and natural gas compete in several residential and commercial end user markets. **Figure 3.2** illustrates 40.2% of world electricity was produced by coal in 2012, while this amount was less than 7.4% for oil.

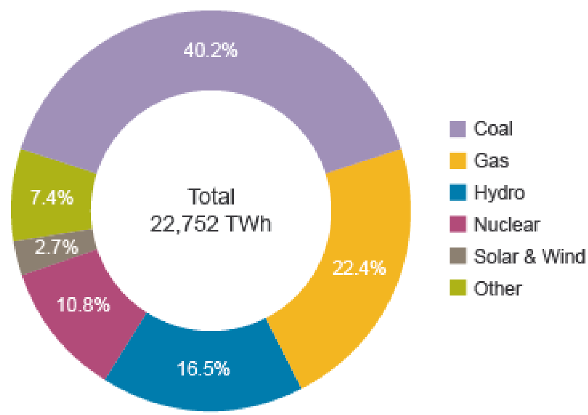

Figure 3.2 World electricity production 2012. Source: IEA electricity information 2014.

As a result, from many years ago, there has been high level of substitutability between coal and oil that may relate their markets.

For coal, factors such as alternative fossil fuel markets, changes in environmental laws, changing of weather, labor issues and technological innovations impact pricing volatility. In the last decade, because of high regulatory restrictions and reserve depletion that led to significant supply inelasticity and increased the price volatility, the story of coal prices changed substantially. We see that, the coal prices suddenly increased by 200% in 2001and by 300% in 2008.

For oil, factors which produce volatility in its prices are similar to other fossil fuels. There is an important factor that is special to fossil fuels markets, policy. In the oil market, oil cartels such as OPEC and oil exporters countries as the members of oil cartels could change the oil prices by changing their policies. This can affect the relationship between oil and coal markets.

Meanwhile, policy has important role in the coal market, but weaker than crude oil market. After first oil shock and second oil shock that origin from Middle East, policymakers began to change their policies about coal. They decide to shift the usage of energy toward greater coal consumption. Coal in some countries similar to U.S. or South Africa was domestic energy resources. Therefore, after increasing the consumption of coal and decreasing the share of crude oil in the energy basket of countries, they decrease their dependence on the oil market. They shift the share of crude oil to coal market by prohibiting the use of oil and natural gas in the electric utilities which could use coal. In the 1975, policy makers extended this rule for two years. Furthermore, they attempt via loan for new coal mines increase the coal production to can offset the decline of crude oil.

Another policy that helps to shifting crude oil market share towards coal market was removing the production ceiling of coal.

All of these policies lead to increasing the production of coal, consumption of oil and shifting coal consumption into electricity generation industries. **Figure 3.3** demonstrates the world coal consumption that increased highly around 1985, after second oil shock, and removing the ceiling production of coal by policy makers. After that it declined a little but again increased.

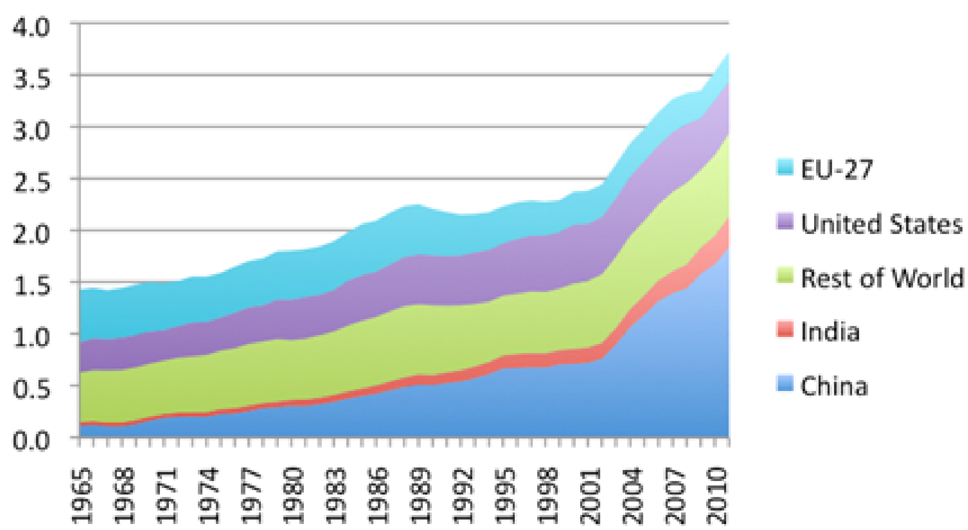

Figure 3.3 World coal consumption, Billion of metric tons of oil equivalent.

After 1985, coal has not been subjected to explicit regulations. However, for the high pollution of coal countries established new regulations for coal market but they were mainly about coal consumption, rather than coal production.

Some researchers have studied the long- run and short-run relationships between crude oil and coal markets. Emami and Foroughi (2011) find some evidence that the coal prices are sensitive to rises and declines of crude oil prices, while crude oil prices are sensitive just to coal price increases. Zellou and Cuddington (2012) studied trends and supper cycles in crude oil and coal prices. His said: there appear to be four super cycles in coal prices over the period 1800- 2009 and three super cycles in oil prices over the period 1861- 2010. These coal super cycles roughly match the timing of those for oil and metals prices after World War II but not in the pre-World War II period.

Li et al (2010) investigate the long-run relationship between international steam coal prices. According to their cointegration tests results they find some evidence that international steam coal market in generally integrated. Some researchers find evidence that "the world oil market, like the ocean, is one great pool," (Adelman (1984)). Some studies investigate the short-run and long-run relationships between crude oil, coal and natural gas. Therefore, the lack of studies on the relationships between crude oil and coal causes we decide to investigate on this issue, to find evidence on the relationships between coal and crude oil.

In this chapter, we investigate the structural relationships between coal and oil markets, to understand how coal market affects oil market and its price in the short run. Meanwhile, as in recent years the high fluctuations of coal prices is approximately similar to oil prices, find evidence that how oil market impact the coal price volatility in the short run.

The rest of the paper is organized as follows. In the next section, we describe the data, then in the next subsection we explain our model, and we show our empirical results and our interpretations in next subsection. In the last section of this chapter, we conclude our results.

3.2 Empirical Analysis and Results

3.2.1. Data

Our data set is monthly data from January 1989 to December 2013, consist of four variables: the percent change in global crude oil production, the new index of real economic activity (Kilian's Index), the real price of oil, and the real price of coal.

The percent change in global crude oil production is the log differences of average monthly crude oil production in millions of barrels pumped per day from the U.S. Energy Information Administration (EIA). The index of real economic activity is the monthly index of global real economic activity based on dry cargo bulk freight rates, as Kilian (2009) demonstrated. The real oil price is the monthly imported crude oil price of the United States that obtained from the EIA. The real coal price is the monthly Australian coal price, as the biggest exporter coal country from World Bank Cross Country Data in dollars per million ton. The prices of oil and coal are expressed in log units and have been deflated by the U.S. CPI.

Table 3.1 illustrates that Indonesia is the biggest coal exporter country, and Australia is in second grade in 2012, while the amount of coking coal export of Indonesia is negligible in comparison with this amount for Australia.

Table 3.1 Top coal exporters (2012e). Source: EIA.

	Total of which	**Steam**	**Coking**
Indonesia	383Mt	380Mt	3Mt
Australia	301Mt	159Mt	142Mt
Russia	134Mt	116Mt	18Mt
USA	114Mt	51Mt	63Mt
Colombia	82Mt	82Mt	0Mt
South Africa	74Mt	74Mt	0Mt
Canada	35Mt	4Mt	31Mt

On the other hand **Table 3.2** shows that for many years the total amount of Australia's coal exports was bigger than Indonesia and just in 2012 Indonesia gained the first place. In early 2011, Australian coal producing regions had affected largely by Australia's typhoon season which recovery of huge damages to infrastructures has taken months and lead to slow production and decreasing in the amount of export. According to these reasons, we choose Australia's coal price as the price of biggest coal exporter country in our period.

Table 3.2 Production of Indonesia and Australia from 2003 to 2012

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Australia	350.4	364.3	375.4	382.2	392.7	399.2	413.2	424.0	415.5	301
Indonesia	114.3	132.4	152.7	193.8	216.9	240.2	256.2	275.2	324.9	383

3.2.2 Model

To investigating the relationship between crude oil and coal, we apply a four variable structural vector autoregression (SVAR) model. Our data set consist of four variables: the percent change in global crude oil production, $\Delta prod_t$, the new index of real economic activity (Kilian's Index), rea_t, the real price of oil, rpo_t, and the real price of coal, rpc_t.

$$z_t = (\Delta prod_t,\ rea_t, rpo_t, rpc_t) \qquad \textbf{(3.1)}$$

The model in its structural VAR representation is written as

$$A_0 z_t = \alpha + \sum_{i=1}^{p} A_i z_{t-i} + \varepsilon_t \qquad \mathbf{(3.2)}$$

where ε_t is the vector of serially and mutually uncorrelated structural errors. We postulate a recursive structure for our model, A_0^{-1}, such that the reduced form errors e_t can be written according to $e_t = A_0^{-1}\varepsilon_t$:

$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \\ e_t^{rpc} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \\ \varepsilon_t^{Coal\ \ price\ shock} \end{pmatrix} \qquad \mathbf{(3.3)}$$

In this model, we have six restrictions. The first five restrictions are based on Kilian (2009) assumptions in his model. Similar to him, we define unpredictable innovations of global crude oil production as oil supply shocks. Our fourth and fifth restrictions for global real economic activity are explained base on the oil supply shocks and aggregate demand shocks. Innovations of real economic activity that cannot be explained based on oil supply shocks are explained based on global demand for industrial commodities (aggregate demand shocks).

Oil specific-demand shocks reflect fluctuations that arise from fear about future oil supply shortfalls. Our last restriction is explained innovations to the real price of oil are based on oil supply shocks, aggregate demand shocks and oil specific-demand shocks.

The last assumption, explain that innovations of coal price are based on all of our shocks, consist of oil supply shock, aggregate demand shock, oil specific-demand shock and coal price shock.

As we mentioned before, the coal market was small and segmented markets (Zellou and Cuddington (2012)) that with progressing in technology it goes toward a global market in recent year, slowly. It is while; the oil market has some main cartels, the most important one, the Organization of Petroleum Exporting Countries (OPEC), which organize the amount of crude oil supply to control its prices. These cartels power lead to a highly integrated economic market for crude oil (see Bachmeier and Griffin (2006)). As a result, oil market is more powerful than coal market, and we assume that it can affect coal market as a main substitute fossil fuel in the world until today.

3.2.3 Empirical Results

We generate Impulse responses of oil supply shock, aggregate demand shock, oil-specific demand shock, and coal price shock on oil production, real activity, the real price of oil, and the real price of coal. All of our shocks are normalized. The error of reduced-form VAR of the model is based on a recursive-design wild bootstrap with 2000 replications (Goncalves and Kilian (2004)). The reduced-form VAR model is estimated by the least-squares method. The results are in the **Figure 3.4**.

In response to oil supply shock, the global oil production decreases significantly to a lower amount. As oil is critical fuel in some fields, countries attempt to increase their production in order to compensate this decline in the global oil production. Therefore the production of oil slightly increases, but remain in an amount less than primary amount. **Figure 3.4** shows that the oil supply shock has no significant effect on the real activity and real price of oil, but it has statistically significant effect on the real price of coal for approximately 7 months.

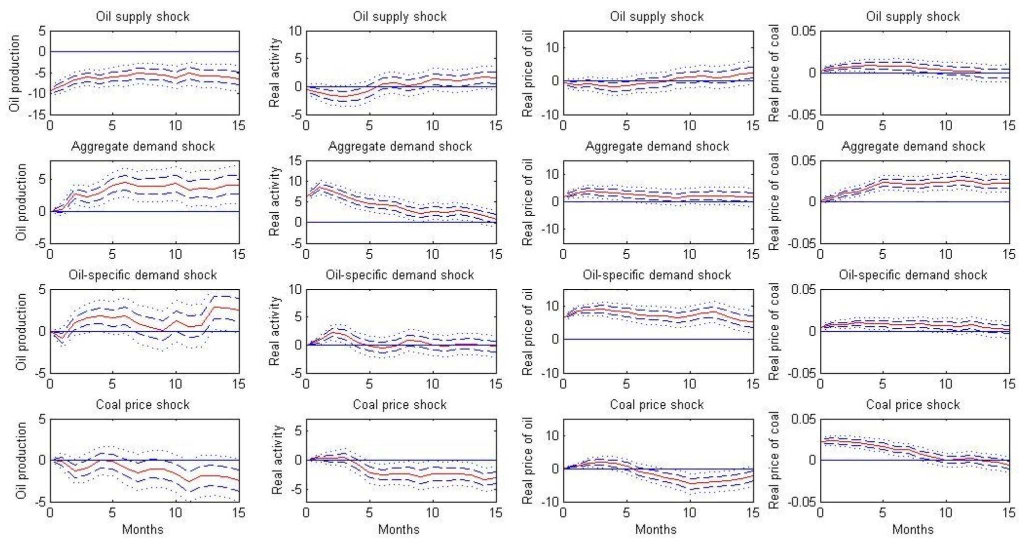

Figure 3.4 Impulse responses of structural shocks.

The main reason that causes oil supply shock has significant effect on the coal prices is economic substitution. When the price of crude oil goes up, the demand for coal as the substitution of crude oil has increased. It leads to increase in the prices of coal, as **Figure 3.5** shows.

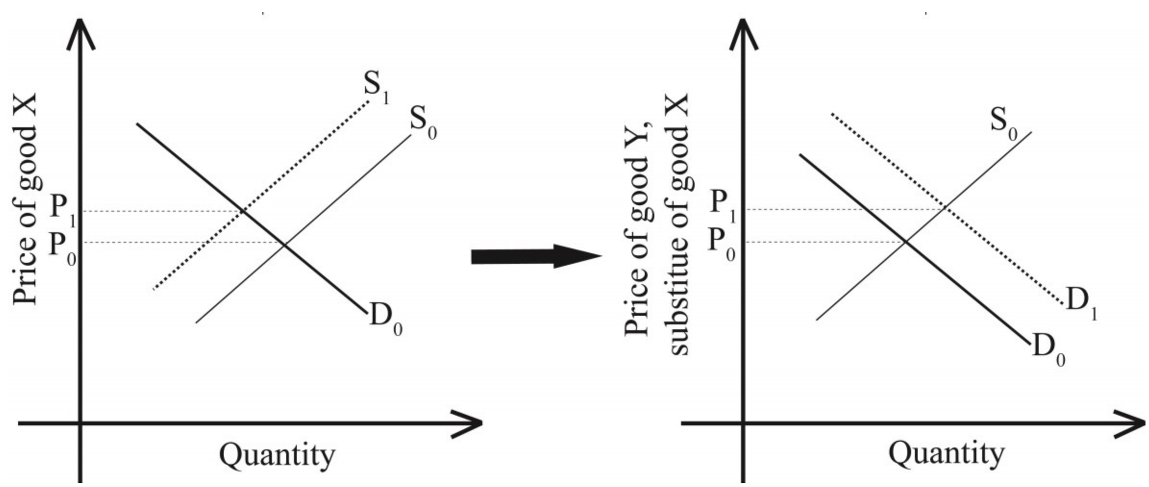

Figure 3.5 The relationship between price and demand of two substitute goods.

In ordinary goods, the decrease of supply causes the price goes up, therefore the demand for substitution goods goes up, but for crude oil even our results show that the oil supply decline has no significant effect on the oil prices, the decrease of oil production lead to increase of coal prices. It shows that on the back of oil production, there is a power that reflects the effect of oil supply decline to the coal market, which is policy, and policy makers attempt to compensate oil supply decline by increasing the coal demand. It was happened especially after oil shocks, first and second oil shocks.

What about the effects of aggregate demand shock on the oil production, oil price and coal price? **Figure 3.4** illustrates that an unanticipated aggregate demand increase has positive and significant effect on the real activity.

The results show that a positive aggregate demand shock has a positive and significant effect on the oil price, and coal price. When global demands for industrial goods increase, lead to demand increase for energy which mainly lead to increase in the demand of crude oil and coal. Because crude oil is used for transportation and coal is used for generating electricity mainly after oil shocks.

In response to the global aggregate demand shocks, **Figure 3.4** demonstrate that oil production rapidly increase to higher amount and this rises continue until around 7 month, then remain approximately in the same amount until the end of our horizon. As a result, we see that similar to our previous results in the Zamani (2016), "how the crude oil market affects the natural gas market: demand and supply shocks", an unanticipated aggregate demand increase has a positive and significant effect on the production of oil. These results are different from Kilian (2009)'s result. He finds some evidence that global aggregate demand shock has no significant effect on the oil production. However, our results of the effects of aggregate demand shock on the oil prices is similar to Kilian (2009)'s result.

In response to the oil-specific demand shock, the results illustrates that a positive oil specific demand shock causes an increase in the prices of crude oil and coal. An unanticipated increase in the oil specific demand causes an increase in the price of crude oil immediately after occurring of shock and then it rise to higher amount after 1 months. The result show that it decline and again increase, but at the end of our horizon it still remain in the price that is higher than the primary price.

This is while coal prices in response to the oil specific demand shock, gradually increase to the higher price and remain nearly in the same price until 8 months statistically significant. After that the price of coal decreases to the initial price. Consequently, the precautionary demand of crude oil has significant effect on the oil and coal prices, and as we shows in the second chapter, furthermore, it has significant effect on the price of natural gas. The uncertainty about the future price of oil, produce a fear between the crude oil consumers. Therefore, they attempt to compensate the future shortfalls of oil with substitute fuels of oil, which are mainly coal and natural gas. The price of oil increase immediately after occurring oil specific demand shock while for coal is gradually, thus show that this specific demand slowly and weaker than oil market transfer to other fossil fuels market. We can interpret that oil specific demand shock is fossil fuels specific demand shock, which we will show it in the future.

Meanwhile, results show that oil specific demand shock has no significant effect on the oil production. And it has significant effect on the real activity. An unanticipated increase in the specific demand of oil leads to increase in the real activity for approximately three month and after that fluctuate until receive to the primary amount after 10 month.

The important point here is the amount of effect of demand shocks on the coal prices. According to **Figure 3.4** the effect of oil specific demand shock on the coal prices is smaller than the effect of global aggregate demand shock on the coal prices. While oil specific demand shock increase coal prices just for some months, aggregate demand shock increase the coal prices until 5 month, and then it fluctuate approximately around it until 15 months. In other words, it shows an unanticipated increase in the global aggregate demand change the coal prices substantially for a long time, and it is possible that it remains in this amount, while oil specific demand effect is transitory and small just for some months.

At the end, **Figure 3.4** demonstrates that coal price shock increases the real price of coal immediately for about 10 months, while decrease the real activity statistically significant after about 3 months. As are data for world coal production is limited, we are not able to show that coal supply or coal demand have suddenly decreased or increased, respectively, and lead to coal price shock. However according to the results in **Figure 3.4** as with increasing in the real price of coal, real activity decreased substantially, so we suppose coal price shock, here, happened because of sudden decrease in the coal supply. Coal is one important part of industrial commodities which its supply decline can has significant effect on the real activity, as our results show.

Thus, if we suppose during our period, coal supply shock leads to coal price shock, coal as a main substitute of oil causes oil demand increase, as a result, oil price increase to higher amount. We can see in the **Figure 3.4** that in response to coal price shock, oil price increase statistically significant to higher amount.

Totally, **Figure 3.4** illustrates that oil supply and demand shocks have significant effect on the coal prices, while just oil demand shocks have significant effect on the oil prices. Meanwhile, coal price shock has significant effect on the real price of coal and crude oil.

3.3 Conclusion

The long run relationship between crude oil and coal markets have investigated and researchers find some evidence that there is a cointegration relationship between coal and oil markets in some regions of the world and there is not in some other regions. In this research, we study the short- run relationship between coal and crude oil prices in the world using the SVAR model and new index of Kilian (2009) to investigate the effect of high fluctuations of coal and crude oil prices.

Our results suggest that all shocks of crude oil market, including oil supply shock and oil specific demand shock, meanwhile, aggregate demand shock affect coal prices and the effects of aggregate demand shock on the coal prices are higher than other shocks. Furthermore, coal price shocks have significant effect on the price of crude oil which shows the effect of substitute goods on each other. As crude oil market is more powerful than coal prices, the substitute effect of coal shows the high amount of substitution between the markets of coal and crude oil.

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Chapter 4

Aggregate Demand Change and Oil Production: Reconsideration

Abstract

We examine the relationship between the oil market and global aggregate demand in different oil crisis periods, using the new index for global aggregate demand that Kilian (2009) introduced. Because of the importance of the second oil crisis, we first concentrate on the subsample period of the second oil crisis and the subsequent decade, and applies Kilian's structural vector autoregressive (SVAR) model to this subsample period. Here, we encounter an empirical puzzle: we obtain a statistically significant *negative* effect of a positive aggregate demand shock on oil production even though Kilian's result for the full sample for his study shows statistically insignificant effect. A solution to this puzzle is the main finding of this paper: when we add coal and natural gas prices to Kilian's SVAR system, we have a statistically significant *positive* effect both for the subsample and for our full sample periods. We also find that aggregate demand shocks have significant effects on the prices of oil, coal, and natural gas. Our results suggest that oil, coal, and natural gas prices interact with each other as responses to aggregate demand shocks, and ignoring these interactions can result in misleading results for the relationship between the oil market and global aggregate demand. (JEL Q43, E32)

Keywords: Aggregate Demand Shock, Oil Production, Crude Oil Price, Natural Gas Price, Coal Price, Structural Vector Autoregression (SVAR)

4.1 Introduction

The relationship between oil market and macroeconomy is an intricate issue in Economics. The traditional main view had been that oil price shocks caused macroeconomic variables to fluctuate especially in the 1970s. However, a recent challenge is that the reverse causation direction of the world aggregate shocks to affect the oil market may be more important as Barsky and Kilian (2002) argued. Kilian (2009) showed important piece of evidence for this reverse causality by constructing a new measure of global real economic activity based on dry cargo single voyage ocean freight rates. Kilian applied a three-variable structural vector autoregressive (SVAR) model to oil production, this new monthly index of global activity, and oil price.

In this debate of the causality direction, coal and natural gas markets have been ignored in the literature as we explain in the next section. However, crude oil, coal and natural gas are the main fuels in the world from many years ago until now which cover more than 80 percent of world fuels production, for example the world production of oil, coal and natural gas at 2012 are 31.4, 29 and 21.3, respectively, as **Figure 4.1** shows.

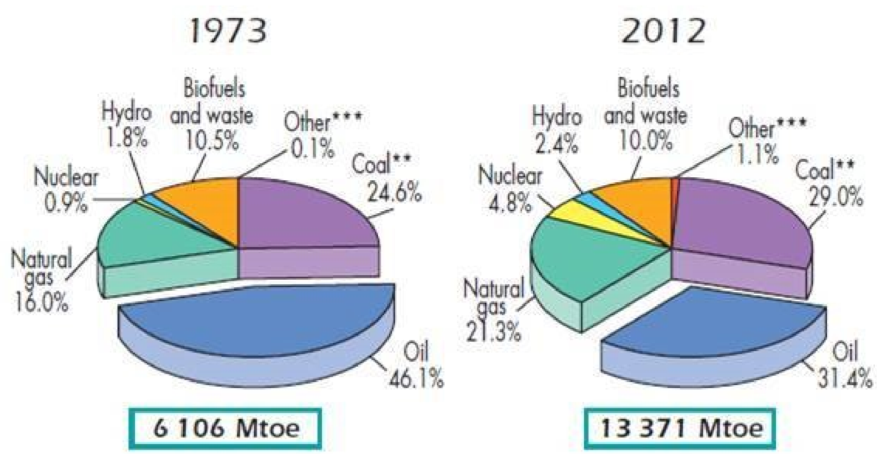

Figure 4.1 1973 and 2012 fuel shares of total primary energy supply (Mtoe). Source: Key World Energy Statistics 2014.

We see in the figure 1 that other fuels such as nuclear power has been playing a much smaller role in the world energy basket in comparison with fossil fuels. It illustrates in 2012 the world production of nuclear power is 4.8 percent. In consumption side, **Figure 4.2** shows that the share of different kinds of fossil fuels changed from 1973 to 2012. Meanwhile, during this period, these percent change many times, especially after first and second oil shocks.

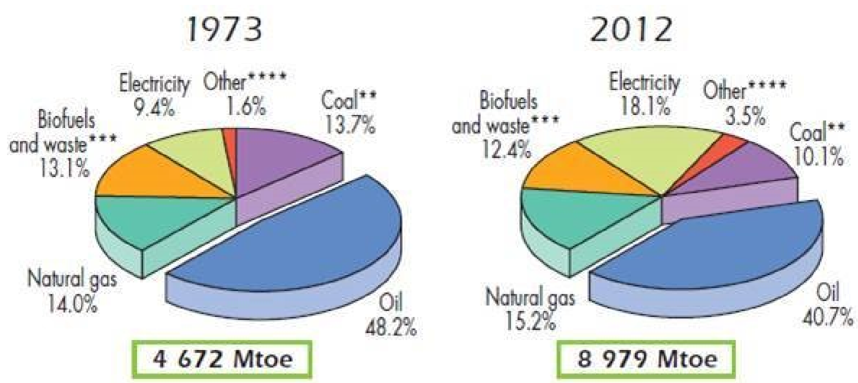

Figure 4.2 1973 and 2012 fuel shares of total final consumption. Source: Key World Energy Statistics 2014.

As a result, fossil fuels still constitute a large portion of world energy with high-interactions between their markets in both demand and supply sides, from amount of production and investment for mining activities to consumption sectors and determining their prices. Consequently, ignoring the coal and gas markets may result in biased results for the debate.

The first and second oil crises are two important periods in which some of the main oil producers in the world changed their policies to suddenly decrease their oil production mainly because of political issues. The debate on the causality direction between the oil market and aggregate demand often has focused on these two periods (e.g. Burbidge and

Harrison (1984), Kilian (2009)). However, the world gas price data are not available for the first oil crisis period. Consequently, we start our investigation to add coal and gas market considerations for the debate by focusing on the second oil shock and the sequent decade.

For this purpose we first apply Kilian's three-variable SVAR model to his data in this sub-sample period in order to see if ignoring the coal and gas markets may results in counter-intuitive results. This analysis yields a puzzle: the result of second oil shocks and subsequent decade shows an unanticipated *positive* aggregate demand shock has statistically significant *negative* effect on the oil production. In Kilian (2009), for his full sample period, he finds this effect to be insignificant, small, positive and temporary, just for 8 months with a delay of half a year. Our analysis shows that Kilian's result is not robust in the sub-sample period with a puzzling result: How can a positive aggregate demand shock have negative effect on oil production?

We think that this puzzle may be caused by ignoring the coal and gas markets. Hence, we add the real prices of coal and natural gas as the fourth and fifth variables to Kilian's three-variable SAVAR model. The results of our five-variable SVAR model for the subsample period of the second oil and the subsequent decade show that a *positive* aggregate demand shock has *positive* significant effect on the oil production. Thus, we solve the puzzle by this five-variable SVAR model. For our full sample period from 1976/1 to 2012/12, we find that these results are robust for our five-variable SVAR model. These results indicate that ignoring coal and natural gas markets can lead to misleading results for the investigation of the relationship between aggregate demand and the oil market.

Our overall results for the five-variable SVAR model strengthen the importance of the reverse causality argument of Barsky and Kilian (2012). We find that our results are consistent with those of Kilian (2009) in that the aggregate demand shock has positive significant effect on the oil price. In Kilian (2009), the aggregate demand shock does not have a significant effect on oil production, while we find it has a significant effect on oil production.

The rest of the paper is organized as follows. In the section, we have a review of the literature. The structural VAR frameworks and the identification of our models are given in section II. Section III reports the empirical results which contain the results of Kilian's model and the results of our new model as puzzle's solution. Meanwhile, we test the robustness of our key solution at the end of this section. Finally, section IV provides the concluding remarks.

4.2 Literature

Many researchers have investigated the relationship of oil market and macroeconomy. They focused on macroeconomic performance before, during and after oil shocks. For this purpose, they measured many factors similar to GNP, CPI, unemployment, some other macroeconomic indicators, and recently world economic activity.

Researchers argue that oil price shocks substantially affect the important macroeconomic variables and there is a negative correlation between oil prices and macroeconomy. Hamilton (1983, 1988 a, b, 1996) finds some evidences that there is a historical correlation between oil shocks and recessions which oil price shocks play a contributing factor role in some U.S. recessions. Hamilton (1988 a, b) discussed macroeconomy is affected by oil shocks through decreasing the demand for consumption and investment goods. Gisser and Goodwin (1986) examined the relationship of oil and macroeconomy and found crude oil prices have significant effects on the broad range of macroeconomic variables.

The significant impact of changes in the price of oil on the world macroeconomy also had reported by Mork (1989), Mork, Mysen and Olsen (1994), Burbidge and Harrison (1984) and Bjornland (2000).

Some of studies had cast doubt on the results of Hamilton and some other researchers which they argue that there is causation from oil price shocks to output (e.g., Hooker (1996)).

The main challengeable issue has started with the Barsky and Kilian (2002) which they discussed on causality from aggregate demand to oil prices in contrast with previous studies. At the first, with a monetary model they show the supply shocks, such as oil supply shock are not necessary for stagflation, and stagflation may happen in the absence of supply shock, ,for example in 1970s, a considerable amount of stagflation could have been avoided by appropriate monetary policy. Then they show that the effect of oil supply shock on the GDP deflator seems small in practice and it cannot reasonably explain the inflation of GDP deflator. Their find some evidence that in the 1970s the increase of oil price accompany with increase of other commodity prices were a response to the macroeconomic changes.

Barsky and Kilian (2004) said: Economists have long been intrigued by empirical evidence that suggests that oil price shocks may be closely related to macroeconomic performance. They investigated critically the evidence of many studies which argue oil price shocks affect macroeconomic variables and provide arguments in favor of reverse causality from macroeconomic variables to oil prices.

In addition to Barskey and Kilian (2004), Kilian (2008) also said that exogenous oil supply shocks made little difference on average for the evolution of U.S. real economic growth and inflation since the 1970s, although they did matter for particular episodes, especially for U.S. real growth.

After them, Kilian (2009) tried to measure global real economic activity to investigate the relationship of world aggregate demand as a factor of macroeconomy and oil market via this new index. In his results there is no significant effect from oil supply shocks to real activity, but also there is a positive and significant effect from aggregate demand shock to oil prices.

Therefore, some researchers believe oil supply shocks are big matter for macroeconomy and new researchers said there is a reverse effect from macroeconomy to oil price. How about oil production? Kilian (2009) find some evidences that there is no significant effect from aggregate demand shock to oil production. With causation from aggregate demand to oil market, how oil demand increase does not increase oil production?

Some of researchers when refer the relationship between energy markets and macroeconomy, they just investigate the relations between oil prices and macroeconomy without using coal and natural gas prices (see, e.g., Bjornland (2000), Rotemberg and Woodford (1996)). As we discuss in the introduction, adding the prices of coal and natural gas may affect the results.

On the other hand, several papers have investigated the relationships between oil, coal and natural gas prices without looking at macroeconomic variables.

Oil and natural gas have common wells that cause some of researchers just have studied the relationships between them (see, e.g., Brigida (2014), Brown and Yücel (2008), Hartley, Medlock III, and Rosthal (2008)). Some other researchers also have studied the relationships between oil and coal (e.g., Zellou and Cuddington). Meanwhile, the relationships between all of fossil fuels have investigated, too (see, e.g., Manzoor and Seiflou (2011)).

What are the relations between production and consumption of fossil fuels? Villar and Joutz (2006) said oil and natural gas through both supply and demand are linked to each other. They argue oil demand increase or oil supply decrease which leads to increase in oil prices may have different effects on natural gas market and raise or decrease its price. They also explained natural gas and crude oil operators compete for similar economic resources such as labor and drilling rigs.

The main factors which determine the relations between production and consumption of fuels are technology and the amount of production that lead to fuel switching. Fuel switching is important factor that affect both production and consumption sides of fuels. . It happened in some special events during time and the main reasons were political issues or technological progresses. For example, Kenneth and Peach (1992) mentioned a fuel switching had occurred from 1970 to 1989 because of instability of oil sources which cover first and second oil shocks.

4.3 The Structural Vector Autoregressive (SVAR) Models

In this chapter, we employ two structural vector autoregressive models. The first model is same as Kilian (2009)'s SVAR model and the second one is our new SVAR model as key solution of the puzzle.

4.3.1 First model

We apply a structural vector autoregressive model same as Kilian (2009)'s structural model. Our full sample comprises monthly data from January 1976 to December 2012. We use Kilian's data from 1976/1 to 2007/12 and add new data after that from 2008/1 to 2012/12 for our full sample period. Our data consist of $z_t = (\Delta prod_t\ , rea_t, rpo_t)$ where $\Delta prod_t$ defers the percent change in global crude oil production, , rea_t is the index of real economic activity and rpo_t denotes to the real price of oil.

The percent change in global crude oil production is average monthly data in millions of barrels per day from the U.S. Energy Information administration (EIA) which is the log differences of world crude oil production. The Index of real economic activity is monthly index of global real economic activity based on dry cargo bulk ocean freight rates which Kilian (2009) demonstrated it. The real price of oil is the log of monthly imported crude oil price of United States, dollars per barrel which have been deflated by the U.S. CPI. The price of oil and CPI are obtained from EIA.

In the reduced-form representation our model is displayed as

$$z_t = \delta + \sum_{i=1}^{p} B_i z_{t-i} + e_t \qquad (\mathbf{4.1})$$

where e_t is the vector of the reduced-form errors.

The model in its structural VAR representation is written as

$$A_0 z_t = \alpha + \sum_{i=1}^{p} A_i z_{t-i} + \varepsilon_t \qquad (\mathbf{4.2})$$

where ε_t is the vector of serially and mutually uncorrelated structural errors. We postulate a recursive structure for our model, A_0^{-1}, such that the reduced form errors e_t can be written according to $e_t = A_0^{-1}\varepsilon_t$:

$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \end{pmatrix} \qquad (\mathbf{4.3})$$

The restrictions of A_0^{-1} are based on the Kilian's assumptions in his paper.

4.3.2 Second Model

Our second model is a five variable structural vector autoregressive model based on monthly data for $z_t = (\Delta prod_t\ , rea_t, rpo_t, rpc_t, rpg_t)$ where the first three variables are same as the first model variables, rpc_t denotes the real price of coal and rpg_t is the real price of natural gas. The coal price is monthly Australian coal price, as the biggest exporter coal country from World Bank Cross Country Data in dollars per million ton. The real price of natural gas is the U.S. natural gas wellhead price in dollars per thousand cubic feet which is obtained from EIA. The prices of coal and natural gas are expressed in logs and have been deflated by the U.S. CPI from EIA. Our full sample similar to first model is from 1976/1 to 2012/12.

In the reduced-form representation, our second model is similar to first model. In the structural VAR representation, we hypothesize a block recursive structure for our second model, A_0^{-1} , such that the reduced form errors e_t can be written according to $e_t = A_0^{-1}\varepsilon_t$:

$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \\ e_t^{rpc} \\ e_t^{rpg} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \\ \varepsilon_t^{Coal\ price\ shock} \\ \varepsilon_t^{Natural\ gas\ price\ shock} \end{pmatrix} \quad \mathbf{(4.4)}$$

In this model, we plan to solve the puzzle and identification of coal and natural gas shocks are not important for our purpose, therefore, we block the fourth and fifth rows of A_0^{-1}.

4.4 Empirical Results:

Our empirical results consist of three sections. First, we show the puzzle of Kilian's model with his data. Then, we explain the key solution of this puzzle by the results of our new model in the second section. At last, in the third section, we check the robustness of our solution.

4.4.1 The Puzzle

First, we generate the responses of oil production, real activity and real price of oil on impulses of oil supply shock, aggregate demand shock, and oil-specific demand shock. All of our shocks are normalized. The error of reduced-form VAR of the model is based on a recursive-design wild bootstrap with 2000 replications (Goncalves and Kilian, 2004). The two important oil shocks that studies focus on these shocks and their results on the macroeconomy, as important evidences, are oil price shocks at 1978 and 1980. We focus at the first on this period, and our result is in **Figure 4.3**.

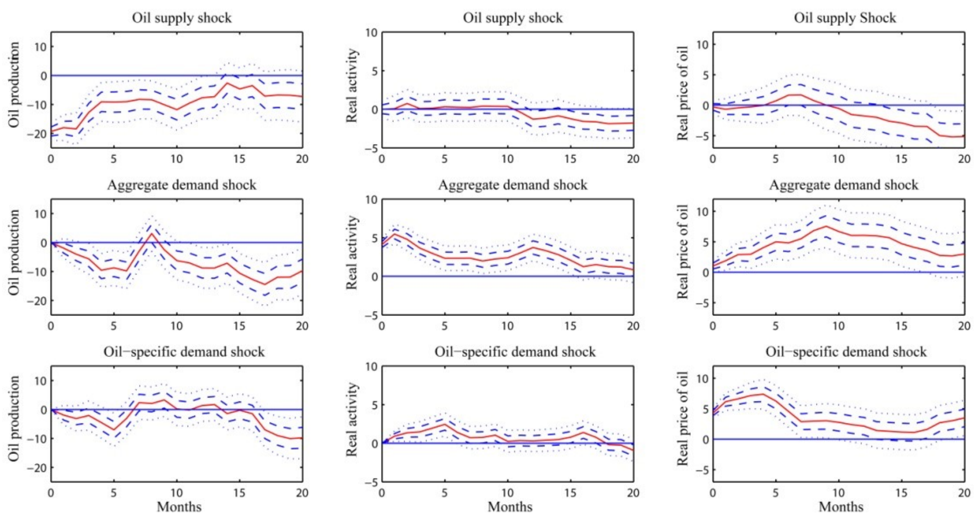

Figure 4.3 Responses to Structural Shocks, from 1978/1 to 1989/12.

The result show that an unanticipated aggregate demand increase has statistically significant and positive effect on the real activity, which remain until the 16 months, but with a decline in the middle. From the first month, the aggregate demand shock starts to increase the real price of oil, until 9 months and after that decrease to the first price until the end of our horizon.

The results illustrates that aggregate demand shock not only has highly significant effect on the real price of oil, but also it has *negative* effect on the oil production which is statistically significant. In other words, a *positive* aggregate demand shock causes oil production sharply decrease. **Figure 4.4** shows why aggregate demand increase should increase the production of oil. When aggregate demand increases, it leads to the demand for oil as one of main fuels for production and transportation increase, as a result the production of oil should increase which leads to increase in the price of oil.

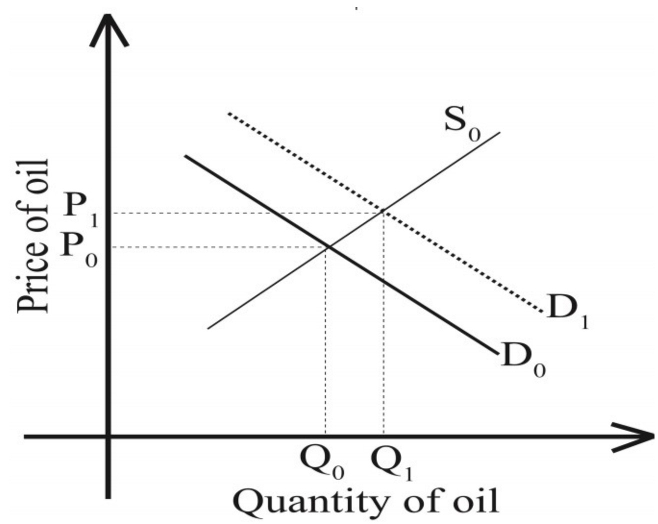

Figure 4.4 Aggregate demand increase should increase the production of oil.

As a result, we encounter with a puzzle: a *positive* aggregate demand shock which *decrease* the production of oil from the first month. Although in the middle it rises but after that it decrease more than before.

On the other hand, Kilian's result in his paper shows aggregate demand shock has a statistically insignificant effect on the oil production which increased temporary after half a year and remained for 8 months.

4.4.2 The Solution of the Puzzle

To investigating the reason, we add the price of coal and natural gas in our new model, as we explain before. In this stage we run our model in the second oil crisis period and subsequent decade, from 1978/1 to 1989/12. **Figure 4.5** illustrates the effect of oil supply shock, aggregate demand shock, oil-specific demand shock, on the oil production, global real activity, real price of oil, real price of coal and real price of natural gas.

Similar to first model, all of our shocks are normalized and the error of reduced-form VAR of the model is based on a recursive-design wild bootstrap with 2000 replications.

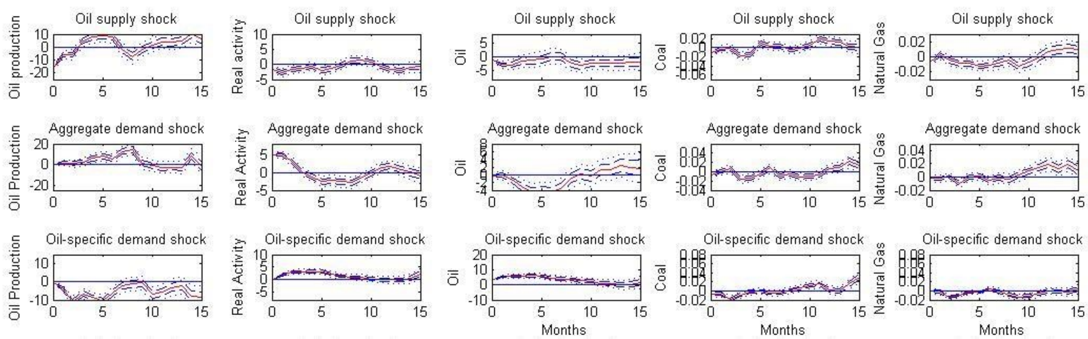

Figure 4.5 The solution of the puzzle, responses to structural shocks, from 1978/1 to 1989/12.

The first result of our second model from 1978/1 to 1989/12 in figure 5 shows a positive aggregate demand shock increase the amount of production with about 3 months delay, and after that a negative aggregate demand shock decrease the oil production from the previous amount.

This result shows that with applying the role of coal and natural gas extra to crude oil, as the main fuels in the word until now, an unanticipated aggregate demand expansion has positive significant effect on the oil production with a delay while without considering the coal and natural gas, there is statistically significant and negative effect on the oil production from 1978/1 to 1989/12.

There are two reasons that considering coal and natural gas markets changes the effect of an unanticipated aggregate demand increase on the oil production. One is related to the interactions between fossil fuels markets in all periods and the next one is related to this special period, second oil shock and subsequent decade, which could occur in some other periods, too.

The first reason is the substitutability of oil, coal, and natural gas especially in the short–run due to labor input substitutability. Increasing the price of oil because of shortage of oil supply which raises the demand for oil caused the prices of coal and natural gas as substitutions fuel increased. Therefore, coal and natural gas companies employed more labor to increase their production. Increasing the production of coal and natural gas decreased the production of oil.

The second reason is changing policy of coal and natural gas markets just before and during second oil shock. With the Middle East oil crisis at 1973 which world economy experienced a crisis, industrial countries decide to decline the share of oil in their energy basket to the extent possible, to prevent some possible problems in the future in another oil shock. It caused policymakers try to shift their energy towards coal and natural gas which were their domestic energy resource, but actually it change substantially after second oil shock, which countries totally change their regulations. Kenneth and Peach (1992) said that during this time consumption of petroleum products grew 13 percent, while for coal was 54 percent and for natural gas were 9 percent in US.

Regarding to coal, they passed the production ceiling, loaned money for new underground coal mines and established the IEA Coal Industry Advisory Board (CIAB) from 19 countries to contributing valuable experience in the fields of coal production, trading and transportation at July 1979 to increase the production of coal. As a result, the price of coal increased after this time, too.

In addition to coal market, natural gas market also experienced new policies after second oil shock. Policymakers had established price control rules for natural gas during many years which yield to serious distortions including, ultimately, natural gas shortages in the 1970s, even at 1976 and 1977 many factories and institutions had to close from lack of natural gas. To economists, the obvious reform to natural gas shortages in the 1970s was to decontrol prices. They start to change the price controls by increasing the ceiling price of gas to the higher price at 1978 that it finally completed at 1989 and they removed ceiling price of natural gas. Removing ceiling price and increasing the price of natural gas caused many producers arrived in this industry, the shortage of gas vanished, and its production rose dramatically during 1978 to 1989.

Figure 4.6 illustrates that from 1984 to 1989 the production of gas increased as much as they extract 75 percent of all gas reserve at 1984, while the amount of demand increased to 25 percent of 1984. This shift in production, caused even with growing demand, the price of natural gas until 1998 almost steadily fell and reached to the 46 percent of the 1984 price level.

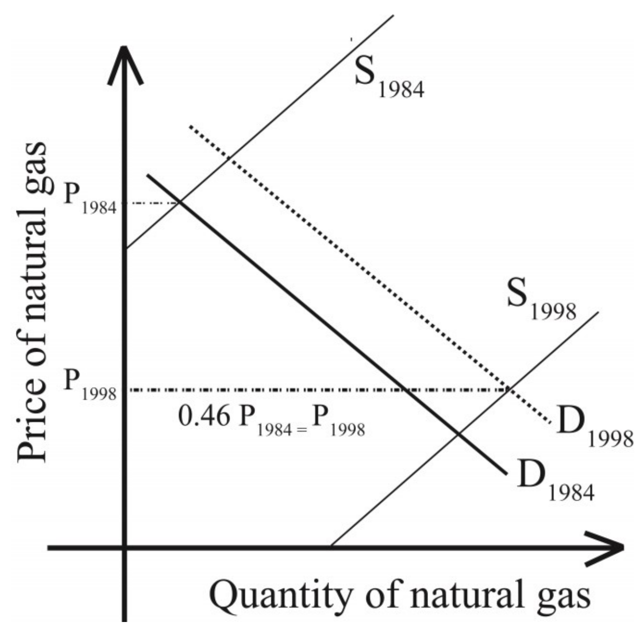

Figure 4.6 Decreasing the price of natural gas to less than half from 1984 to 1989.

Consequently, Because of new policies in the coal and natural gas markets, just before and during second oil shock, the price of coal and natural gas, also their production increased.

The first and second reasons caused the oil supply curve to shift to the left. When these effects are ignored in Kilian's SVAR model, it misinterpreted such a shift as a negative effect of aggregate demand shock on the oil production during this period. How about our full period, from 1976/1 to 2012/12?

4.4.3 Robustness Check

For robustness check, we run our first model in the full period from 1976/1 to 2012/12. Figure 7 illustrates that an unanticipated aggregate demand increase has positive and significant effect on the oil production, just after about 7 months, and remain statistically significant for approximately 2 months that is highly different from our result in the figure 1, from 1978/1 to 1989/12. Consequently, the first model is not robust; while the results of our second model in both periods in **Figure 4.5** and **4.7** show an unanticipated aggregate demand expansion increases the production of oil with a delay.

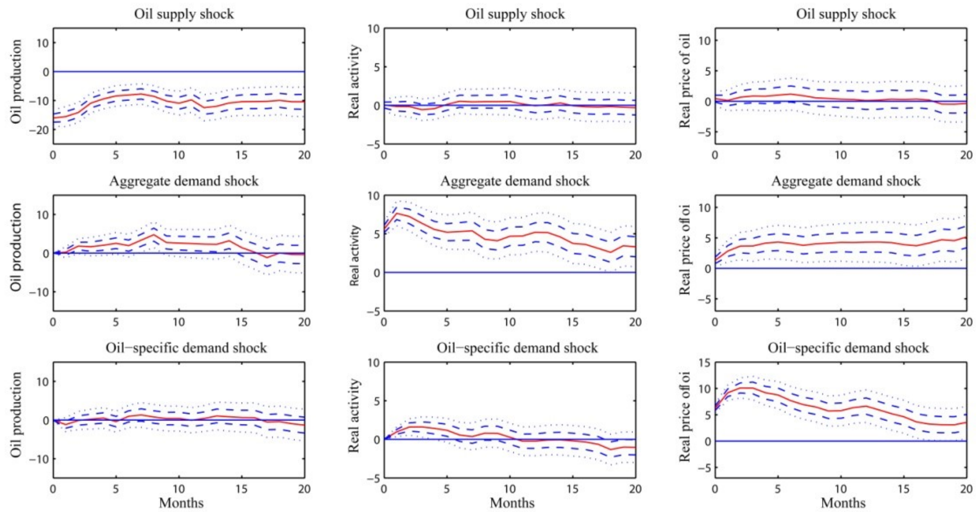

Figure 4.7 Responses to Structural Shocks, from 1976/1 to 2012/12.

In **Figure 4.8**, we see a positive aggregate demand shock has positive effect on the oil production with nearly 2 months delay. Meanwhile the decline of positive aggregate demand shock until the end of our horizon has a decreasing effect on the oil production after around 9 months. In addition to this effect, this figure shows aggregate demand shock increased the price of oil, coal and natural gas. The results of other periods also are robust.

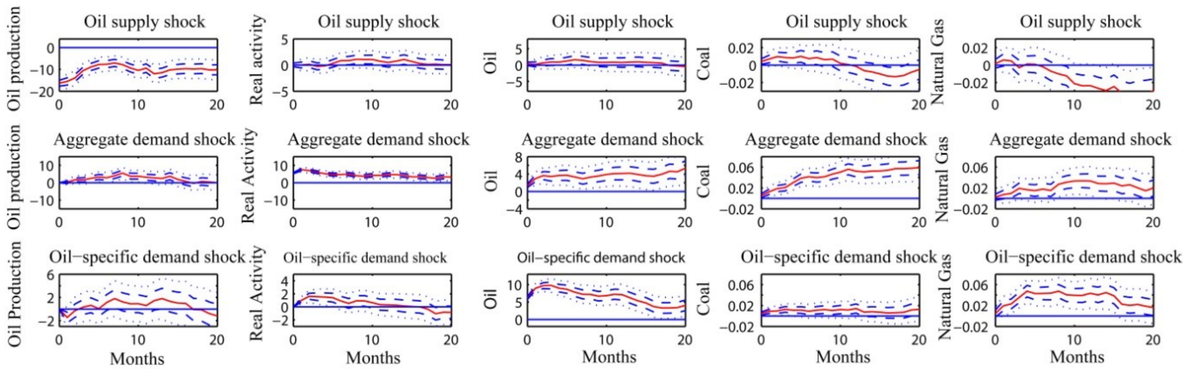

Figure 4.8 Responses to Structural Shocks, from 1976/1 to 2012/12.

4.5 Conclusion

Kilian (2009) illustrates that a positive global aggregate demand shock has insignificant effect on the oil production and positive significant effect on the price of oil. In his paper, he introduced a new index to measure the global aggregate demand and determine its shocks .In this paper, we examine this relationship via Kilian's SVAR system and his data which find a puzzle: a *positive* global aggregate demand shock has *negative* significant effect on oil production. To solve the puzzle, we pay attention to the high interactions of oil, coal and natural gas markets, and include the prices of coal and natural gas to Kilian's SVAR model. The results of our five-variable SVAR model show *positive* aggregate demand shock has *positive* significant effect on oil production. Thus, adding coal and natural gas prices solve our puzzle.

Our empirical results suggest the following interpretation. Partly as a result of policy changes for coal and natural gas mentioned above, both prices and production amounts of coal and natural gas tended to increase during the second oil shock and the subsequent decade. Because of the substitutability of oil, coal, and natural gas especially in the short–run due to labor input substitutability, these policy changes caused the oil supply curve to shift to the left. When these effects are ignored in Kilian's SVAR model, it misinterpreted such a shift as a negative effect of aggregate demand shock on the oil production during this period. Our results suggest that oil, coal, and natural gas prices interact with each other as responses to aggregate demand shocks, and ignoring these interactions can result in misleading results for the relationship between the oil market and global aggregate demand.

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4.7 Appendix 1

For robustness check, we run our first and second model in a different sub-sample. Figure 9 and 10 show the results of our models from 1989/1 to 2014/2.

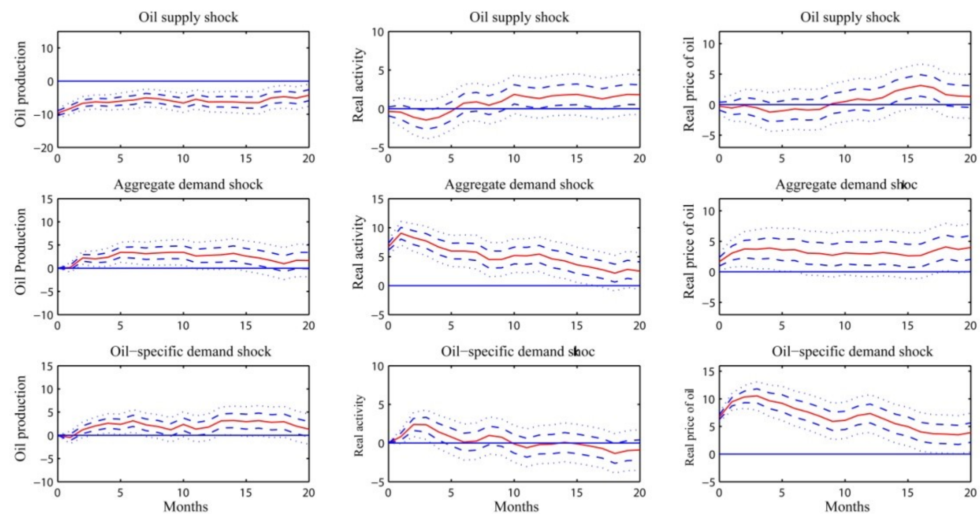

Figure 4.9 Responses to Structural Shocks, from 1989/1 to 2014/2, First Model.

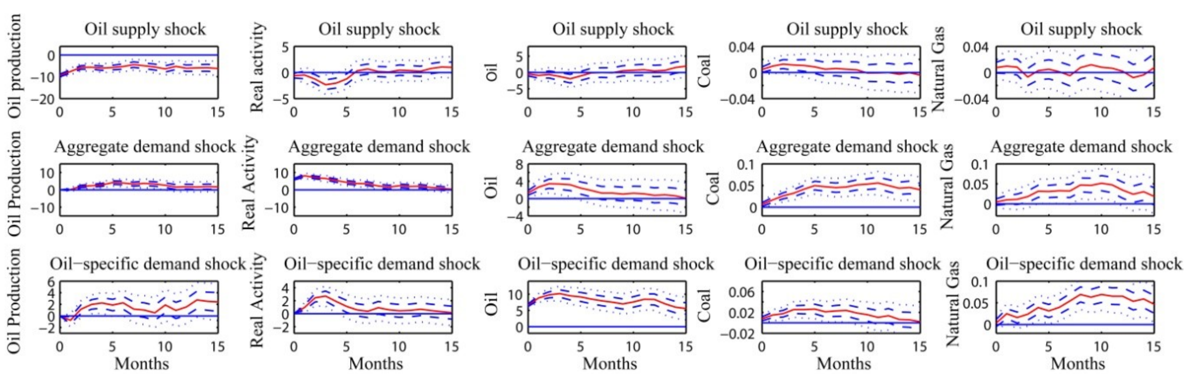

Figure 10: Responses to Structural Shocks, from 1989/1 to 2014/2, Second Model.

In this period, in the first model, an unanticipated aggregate demand increases have statistically significant effect on the oil production with a 1 month delay. Furthermore, it increases the oil price immediately, which receives to higher amount after about 2 months, and remains nearly constant until the end of our period. After adding coal and natural gas prices, a positive aggregate demand shock increases the oil production with approximately 2 months delay. Meanwhile, figure 6 illustrates a positive aggregate demand shock increase the price of oil, coal and natural gas. Consequently, our five variable SVAR model is robust in this period.

Chapter 5

Long-Run Relationship of Crude Oil, Coal and Natural Gas Prices

Abstract

In this study, we investigate the long-run relationships between three primary energy prices: crude oil, coal, and natural gas. For this purpose, it employs two different types of tests: first, the Johansen's tests based on his maximum likelihood estimation method and second, the Park (1990)'s tests based on Park (1992)'s Canonical Cointegration Regression. Johanesen test results suggest that the no cointegration hypothesis can be rejected, but one cointegraion relationship or two cointegrataion relationship hypotheses are not rejected. Park's tests show some evidence that there is a cointgration relationship between natural gas/crude oil and a cointegration relationship between natural gas/coal. The evidence for coal/crude oil is somewhat mixed. Overall, the results are consistent with the view that at least, there are two cointegration relationships among the three energy prices. (JEL C12, Q40, Q43)

Keywords: Crude oil price, Coal price, Natural gas price, Cointegration, Johansen test, CCR test

5.1 Introduction

Crude oil, coal, and natural gas are three primary energies in the world that until these days countries mainly provide their energy from them. Fossil fuels have especial market for themselves from aspect of production, transportation and consumption depending on the types of technology which leads to different prices for fossil fuels. The main theory that could connect the markets of fossil fuels is economic substitution.

In our chapter 2 and 3, we investigate the short run relationships between the prices of crude oil and natural gas, and between crude oil and coal. As changing the amount of production, the amount of export and import of fossil fuels and also changing technology for consumption may take more than one month time, it is more plausible that these energies have long run relationships rather than short run relationships; however we show before that there are significant relationships between crude oil with coal and natural gas in short run. In the long run, these fuels become much closer economic substitutes depending on their respective costs of conversion technologies (Griffin (1979)).

In this study, we investigate the existence of long run co-integration relationships between the prices of crude oil, coal and natural gas. As a prerequisite for the cointegration test, the unit root tests in order to determine the integration degrees of the data are tested. Then, we test the cointegration relationships between fossil fuels by two different tests, the Johansen (1988-1991)'s integration test and the Park (1990)'s tests based on Park (1992)'s Canonical Cointegration Regressoin (CCR). The first and important difference between these two tests is the null hypothesis of them. In the Johansen test, the null hypothesis is no cointegararion relationship that can have fault to reject it and illustrates false result but in the CCR test the null hypothesis is cointegration. Meanwhile, they have some other differences that we will explain in next section. These differences cause we choose the Johansen and CCR tests to investigate on the cointegration relationships between fossil fuels.

Many researchers study the long run relationships of the oil markets, for example study the cointegration relationships between four different oil benchmark prices that have different physical properties, West Texas Intermediate, Brent, Dubai, and Maya (Hammoudeh et al (2008)). Most of their results suggest that "the world oil market, like the ocean, is one great pool," (Adelman (1984))

Some researchers study the long run relationships between natural gas markets, for example various natural gas markets in U.S. (e.g., see King and Cuc (1996)) or various natural gas markets in European countries (e.g., see Asche et al (2000)), and various regions of the world between Europe, North America, and Japan (Hirschhausen et al (2004)). The results of these researchers show that natural gas market in some regions of world is integrated, and there are long run relationships between their prices. They mostly used Johansen likelihood-based cointegration test.

Meanwhile, some other researchers investigate the long run relationships between coal markets (e.g., see Warell (2006)).

How about the long run relationships between crude oil, coal and natural gas markets?

Some few researchers study the long run relationships of fossil fuels market, and their results are not same. Bachmeier and Griffin (2006) evaluated the degree of market integration both within and between crude oil, coal, and natural gas markets. They show that crude oil, coal, and natural gas markets are only very weakly integrated. They focus on the world oil market and conclude that it is highly integrated. Regarding to coal market,, they study the U.S. market and showed that the coal market in the U.S is integrated, but weaker than world oil market.

Mohammadi (2011) study the long run and short run relationships among coal, natural gas, and oil prices of U.S from 1976 to 2008. They used Johansen test to investigate the cointegration relationships between fossil fuels in U.S. They provide a week support for an integrated energy market.

Manzoor and Seiflou (2011) , investigate on the existence of long run relation between crude oil, natural gas and coal pricesin U.S. They used Error Correction Model (ECM) and their data was from 1983 to 2008. They confirm in their study the existence of long run relationship between coal, natural gas and crude oil prices.

In this study by using two different cointegration tests, our results show some evidence that there are at least two cointegration relationships between fossil fuels markets.

This chapter is developed in four sections. Section two describes our two tests, Johansen test, and CCR test, for cointegration. Section three at the first explains our data and the results of Augmented Dickey Fuller (ADF) test for our three data series. Then, the empirical results of two tests are described. The last section reports the main conclusions.

5.2 Test for Cointegration

Cointegration is a statistical property of time series variables, in the simple case: We have two time series Xt and Yt, that both are integrated of order one, I(1),in other words they have unit root, if a linear combination of this series is integrated of order zero, then two series are co-integrated. It means Xt and Yt are co-integrated if there exists a parameter b such that

$$U_t = Y_t - bX_t \tag{5.1}$$

is a stationary process. Campbell and Perron (1991) defined cointegration with more details in their paper.

In this research, we use two different cointegration tests. At the first, we use the Johansen test and estimation strategy, maximum likelihood estimator. With this test estimating all cointegrating vectors when there are more than two variables is possible. The second test is Park (1992)'s canonical cointegration regressions(CCR). The Johansen test use VAR system, therefore, all variables are treated symmetrically, as opposed with some models that have a clear interpretations of exogenous and endogenous variables. In the CCR model, the base idea is estimating long-run covariance and to transform the regressand and the regressors in order to remove the endogeneity problem while maintaining the cointegration relationship (Ogaki and Park (1997)).

5.2.1 The Johansen Test for Cointegration

The Johansen test is a test for cointegration of several I (1) time series. Generally, if there are n variables which all have unit roots, there are at most n-1 cointegrating vectors that Johansen test can estimate all of them. Against some tests that permit for single cointegration vector, for example the Engle-Granger (1987) test, Johansen test permits for more than one cointegration relationship.

There are two types of Johansen test, first, the maximum eigenvalue test, second, the trace test. Johansen tests are likelihood-ratio tests. Meanwhile, in the Johansen test no cointegration is the null hypothesis for both tests. The alternative hypothesis of cointegration is different in trace and eigenvalue tests.

The starting point of Johansen's test, a vector autoregression (VAR) of order p given by

$$X_t = \mu + \sum_{i=1}^{p} A_i X_{t-i} + \varepsilon_t \qquad \mathbf{(5.2)}$$

where X_t is an vector of variables which are integrated of order one, I(1), and ε_t is an vector of innovations.

The VAR formula can be rewritten as

$$\Delta X_t = \mu + \Pi X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + \varepsilon_t \qquad (5.3)$$

where

$\Pi = \sum_{i=1}^{p} A_i - I$ and $\Gamma_i = -\sum_{j=i+1}^{p} A_j$.

The coefficient matrix Π can be written in terms of the vector or matrix of adjustment parameters α and the vector or matrix of cointegrating vectors β as

$$\Pi = \alpha\beta' \qquad (5.4)$$

It can be shown that for a given r (the reduced rank of coefficient matrix Π), the maximum likelihood estimator of β defines the combination of X_{t-1} that yields the r largest canonical correlations of ΔX_t with X_{t-1} after correcting for lagged differences and deterministic variables when present.

The trace and eigenvalue tests of Johansen are proposed by two different likelihood ratio tests of the significance of canonical correlations (maximum correlation):

$$J_{trace} = -T \sum_{i=r+1}^{n} \ln(1 - \widehat{\lambda_i}) \qquad (5.5)$$

$$J_{eigenvalue} = -T \ln(1 - \widehat{\lambda_{r+1}}) \qquad (5.6)$$

T is the sample size and $\widehat{\lambda_i}$ is the i^th^ largest canonical correlation. The trace test tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of n cointegrating vectors. The maximum eigenvalue test, on the other hand, tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of 1+r cointegrating vectors (Hjalmarsson and Österholm(2007)).

5.2.2 Canonical Cointegration Regression (CCR)

The Park (1992)'s Canonical Cointegration Regression (CCR) is a test to estimate cointegration vectors. As OLS estimator is not asymptotically efficient, it use OLS residuals to estimate the long-run covariance parameters. As strict erogeneity is a problem in some test, in CCR test, the transform of the regressand and the regressors due to remove this problem while maintain the cointegration relationship is possible. One reason that we use CCR test as Ogaki and Park (1997) said: Monte Carlo simulations in Park and Ogaki (199lb) have shown that the CCR estimators have better small sample properties than Johansen's (1988) ML estimators in terms of the mean square error even when the Gaussian VAR structure assumed by Johansen is true. Another difference of CCR test with Johansen test is that the null hypothesis of CCR is the deterministic cointegration restriction by testing that is there is any significant linear trend in a cointegrating regression to control the probability of rejecting a valid economic model while in Johansen test the null hypothesis is no cointegration. The null hypothesis of no cointegration may fail to reject in the cointegration tests (see, e.g., Engle and Granger (1987)). Meanwhile, Park's tests are based on the Wald tests rather than VAR tests.

For CCR model, we consider a cointegrated system

$$y_t = h' d_t + c' X_t + \varepsilon_t \qquad \textbf{(5.7)}$$

$$\Delta X_t = v_t \quad \textbf{(5.8)}$$

where d_t is a deterministic term that are usually constant, time trends, or both, y_t and X_t are I (1) and difference stationary, and ε_t and v_t are stationary with zero mean. Here y_t is a scalar and X_t is a (n-1)x1 random vector. Let

$$w_t = (\varepsilon_t, v_t')' \quad \textbf{(5.9)}$$

It is assumed that w_t is stationary with zero mean and the long run covariance matrix Ω. As OLS is asymptotically inefficient, to removing that in the CCR, Park (1992) consider transformations

$$y_t^* = y_t + \pi_y' w_t \quad \textbf{(5.10)}$$

$$X_t^* = X_t + \pi_x' w_t \quad \textbf{(5.11)}$$

The base idea of CCR is to choose π_y and π_x , so that the OLS estimator is asymptotically efficient when y_t^* is regressed on X_t^*(Ogaki et al (2001)).

In the CCR test, chi-square tests in a regression with spurious deterministic trends are used to test the stochastic and deterministic cointegration. For this purpose, the CCR procedure is applied to a regression

$$X_1(t) = \theta_c + \sum_{i=1}^{q} \eta_i t^i + \gamma X_2(t) + \varepsilon(t) \qquad \mathbf{(5.12)}$$

The Park's(1990) H(p,q) denotes the standard Wald statistics to test the hypothesis $\eta_p=\eta_{p+1}=\ldots=\eta_q=0$. Then H(p,q) converges in distribution to a χ^2_{p-q} random variable under the null hypothesis of cointegration.

5.3 The Cointegration Analysis

In this section, first we explain our data. Then in the subsection two and three we describe our results of the Johansen and CCR tests.

5.3.1 Data

Our data set is monthly data consist of three variables: the nominal price of oil, the nominal price of coal and the nominal price of natural gas, from January 1976 to December 2012. The natural gas data availability limit our data until December 2012. In the Johansen test we employ ln real prices of crude oil, coal and natural gas and ln nominal prices of crude oil, coal and natural gas. We deflated the nominal prices of fossil fuels by U.S. CPI, and then take natural logarithm. The CPI is obtained from EIA.

The price of oil is the monthly imported crude oil price of United States, dollars per barrel. **Figure 5.1** shows the nominal and real prices of crude oil that we use in two tests.

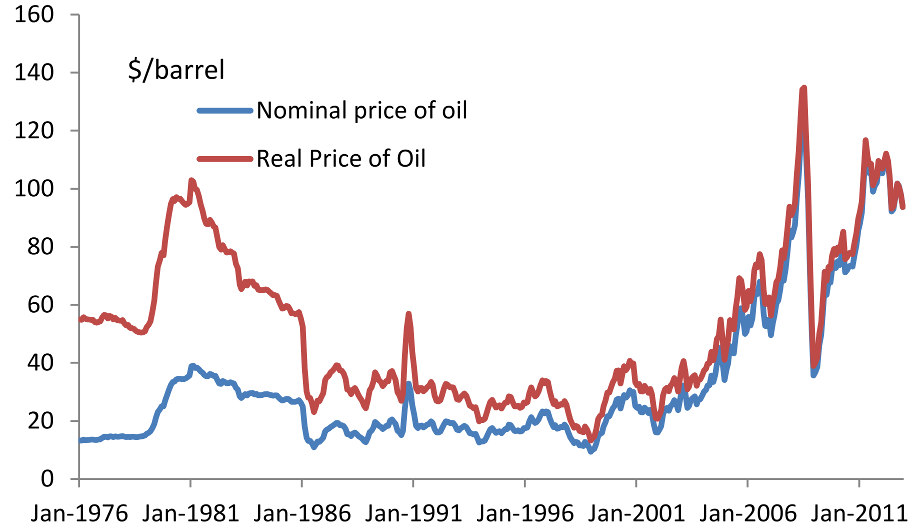

Figure 5.1 The nominal and real prices of crude oil from January 1976 to December 2012.

The coal price is monthly Australian coal price, as the biggest exporter coal country from World Bank Cross Country Data in dollars per million ton. The price of natural gas is the U.S. natural gas wellhead price in dollars per thousand cubic feet which is obtained from EIA. **Figures 5.2** and **5.3** demonstrate the nominal and real prices of coal and natural gas, respectively.

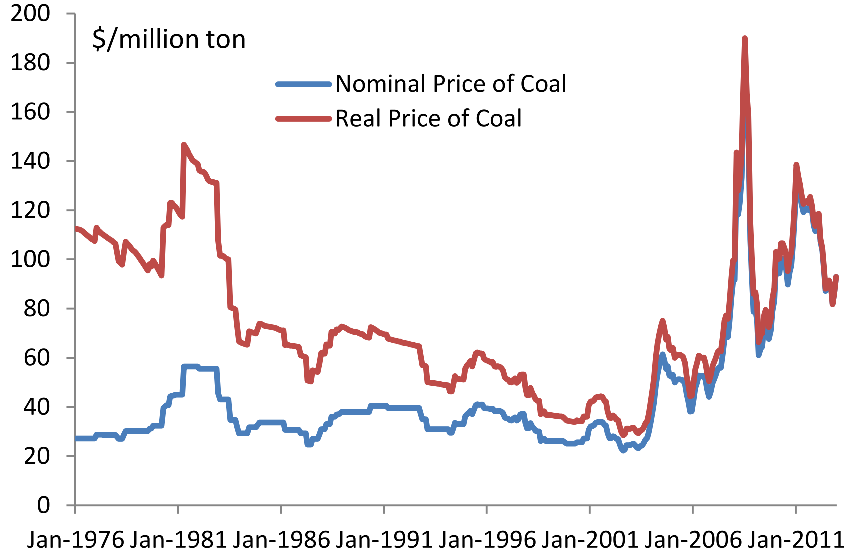

Figure 5.2 The nominal and real prices of coal from January 1976 to December 2012.

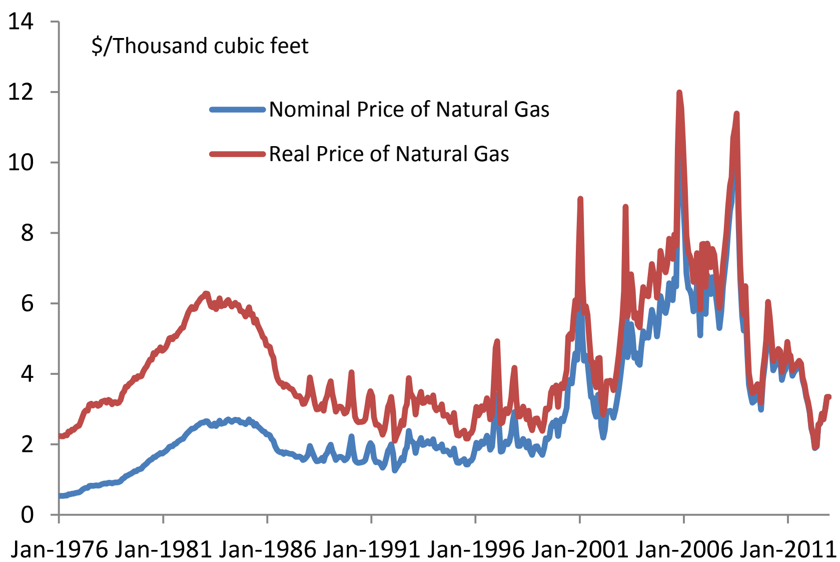

Figure 5.3 The nominal and real prices of natural gas from January 1976 to December 2012.

To do cointegration tests, at the first we check the order of integration of our data series. For this purpose, we employ Augmented dickey Fuller (ADF) test for series and for their first differences. Test of unit roots in individual energy prices are reported in **Table 5.1**.

Table 5.1 Results ADF test for Unit-Roots, Critical values: 1%: -3.444923, 5%: -2.8678, 10%: -2.570200

	ADF Test on Price	**ADF Test on First Differences**
Crude oil Price	-2.051941	-11.45925***
Coal Price	-1.630305	-8.526885***
Natural Gas Price	-2.797718*	-15.47981***

The results of table 1 show that unit roots for none of the price series can be rejected but are all easily rejected for their first differences at a 1% significance level. Thus, we conclude that all variables are first difference stationary, I (1) and proceed to test of cointegration.

5.3.2 Results of Johansen Test for Cointegration

As the base of Johansen test is VAR model, our tests of cointegraton with monthly data appear to be sensitive to the choice of lag lengths. As a result, at the first we choose the best lag length of our data. For this purpose, we apply the Akaike Information Criterion (AIC). The smallest amount of AIC shows the best lag length for our data. As in Johansen test we work with two data series, first: ln nominal prices of crude oil, coal and natural gas and second ln real prices of crude oil, coal and natural gas, we employ AIC test for both data sets. The results are illustrated in **Table 5.2**.

Table 5.2 The amount of AIC to choosing the best number of lags for the data

	The Amount of AIC	
Number of Lags	**Ln Real Prices of Oil, Coal and Gas**	**Ln Nominal Prices of Oil, Coal and Gas**
1	-7.555078	-7.484517
2	-7.864312	-7.807338
3	-7.875742	-7.827425
4	-7.856283	-7.809567
5	-7.838380	-7.794865
6	-7.831575	-7.785680
7	-7.840697	-7.79328
8	-7.820357	-7.771748
9	-7.823804	-7.787806
10	-7.781396	-7.750050

Table 5.2 shows in both data sets, 3 lags are the best lag length for our three-variable VAR model (crude oil, coal and natural gas data) in this study. On the other hand AIC is not a perfect measure for the best lag length. Thus, we report the Johansen test results of a specification which includes three lags and some lags before and after three lags that their AIC results are near to three lags result, from two lags to nine lags. Table **5.3** and **5.4** illustrates the results of Johansen tests for both in real and nominal prices of fossil fuels.

Table 5.3 The results of Johansen tests for cointegration, using ln real prices of crude oil, coal and natural gas

Lags	H_0	Trace Test Statistic [a]	Maximum Eigenvalue Test Statistic [b]
2	r = 0	37.2*	24.17*
	r <= 1	13.06	9.40
	r <= 2	3.67	3.67
3	r = 0	33.23*	20.57
	r <= 1	12.66	9.60
	r <= 2	3.06	3.06
4	r = 0	33.63*	22.69*
	r <= 1	10.94	8.61
	r <= 2	2.33	2.33
5	r = 0	39.07*	28.78*
	r <= 1	10.28	8.17
	r <= 2	2.11	2.11
6	r = 0	39.39*	30.29*
	r <= 1	9.10	7.59
	r <= 2	1.51	1.51
7	r = 0	39.11*	29.89*
	r <= 1	9.21	7.45
	r <= 2	1.77	1.77
8	r = 0	3.179*	23.95*
	r <= 1	7.83	6.33
	r <= 2	1.50	1.51
9	r = 0	28.44	28.44
	r <= 1	7.58	7.58
	r <= 2	1.63	1.63

[a] Critical values: r =0 : 29.80, r <= 1: 15.49 , r <= 2 : 3.84. [b] Critical values: r =0 : 21.13, r <= 1: 14.26 , r <= 2 : 3.84.

Table 5.4 The results of Johansen tests for cointegration, using ln nominal prices of crude oil, coal and natural gas

Lags	H_0	Trace Test Statistic [a]	Maximum Eigenvalue Test Statistic [b]
2	r = 0	35.93*	25.71*
	r <= 1	10.21	7.73
	r <= 2	2.48	2.48
3	r = 0	32.01*	21.97*
	r <= 1	10.04	8.11
	r <= 2	1.93	1.93
4	r = 0	34.04*	25.14*
	r <= 1	8.91	7.68
	r <= 2	1.22	1.202
5	r = 0	37.55*	29.22*
	r <= 1	8.33	7.25
	r <= 2	1.08	1.08
6	r = 0	36.24*	27.94*
	r <= 1	8.30	7.62
	r <= 2	0.68	0.69
7	r = 0	36.74*	28.07*
	r <= 1	8.70	7.67
	r <= 2	0.99	0.99
8	r = 0	34.42*	25.808
	r <= 1	8.61	7.93
	r <= 2	0.68	0.68
9	r = 0	33.38*	24.66*
	r <= 1	0.72	7.92
	r <= 2	0.79	0.79

[a] Critical values: r =0 : 29.80, r <= 1: 15.49 , r <= 2 : 3.84. [b] Critical values: r =0 : 21.13, r <= 1: 14.26 , r <= 2 : 3.84.

According to the Johansen tests, trace test and maximum eigenvalue test, results for cointegration for all lag numbers from 2 to 9, reject the H_0 of there is no cointegration vector among three variables, and the next steps r <= 1 and r <= 2, fails to reject the H_0. These results are same for natural logarithm of real prices of crude oil, coal, and natural gas, and for natural logarithm of nominal prices of crude oil, coal, and natural gas, except for ln real prices of crude oil for three lags of the maximum eigenvalue test and nine lags of both tests.

Thus the results suggest that the no cointegration hypothesis can be rejected, but one cointegraion relationship or two cointegrataion relationship hypotheses are not rejected.

5.3.3 Results of CCR Test for Cointegration

In this subsection, we discuss on our empirical results of Park (1992)'s Canonical Cointegration Regressoin (CCR). In the CCR tests, we utilize the natural logarithm of real prices of crude oil, coal, and natural gas.

Following the recommendation of Park and Ogaki (1991b), we report the CCR estimator based on the third stage. The data do not show signs of deterministic trends, therefore we do not test for the deterministic cointegration restriction. Meanwhile, it causes we use spurious trends starting from the linear trend rather than the quadratic trend. In this case, we choose order zero for the maintained trend in the test, p=0. Thus, H (0, q) statistics test the null hypothesis of cointegration. The H (0, q) results are reported from fourth stage of the CCR. As the CCR tests the cointegration relationship between two data series, therefore we report its results for 3 pairs of data, first oil and natural gas, second coal and natural gas, and last pair oil and coal. In this test, it is important that which data series will be choose as regressand and which will be choose as regressor. **Table 5.5** illustrates the results of the three pairs of data in which each data plays the role of regressand and regressor.

Table 5.5 The CCR results for the ln real prices of crude oil, coal and natural gas

Sample	$b^{a}_{1,CCR}$	$b^{a}_{2,CCR}$	H(0,1)[b]	H(0,2)[b]	H(0,3)[b]
Natural Gas/Crude Oil	-0.38366512 (0.78231693)	0.46781851 (0.20289184)	0.93751427 (0.33291793)	3.2219802 (0.19968980)	4.9690977 (0.17407400)
Crude Oil/Natural Gas	0.13361423 (1.1427969)	2.6267424 (0.80309668)	0.81939258 (0.36535782)	27.541577 (1.0457369e-006)	28.505082 (2.8451536e-006)
Coal/Natural Gas	3.9644412 (0.79104377)	0.19040424 (0.52125192)	0.46615399 (0.49476185)	1.6122438 (0.44658662)	1.6728644 (0.64298341)
Natural Gas/Coal	1.2785802 (1.0646154)	0.029502466 (0.25012017)	0.15183331 (0.69678951)	0.17880216 (0.91447872)	0.27698945 (0.96429641)
Crude Oil/Coal	-1.3191777 (0.83305724)	1.2144709 (0.19538971)	1.3709001 (0.24165729)	1.4676903 (0.48005954)	1.4692385 (0.68938805)
Coal/Crude Oil	0.56883287 (0.59925416)	0.95884271 (0.15534978)	8.1104294 (0.00440113)	8.3202732 (0.01560543)	8.6975626 (0.03359431)

[a] Standard errors are in parentheses. [b] P- values are in parentheses.

In the first row of **Table 5.5** natural gas is chosen as endogenous variable (regressand) and crude oil is selected as exogenous variable (regressor) and the second row of the table shows the results of choosing crude oil as regressand and natural gas as regressor. According to our previous studies in this thesis, and some other studies on the relationship between oil and natural gas prices, natural gas has not significant effect on the prices of crude oil and the crude oil market shocks change the natural gas prices statistically significant. As a result, the results of first row of the table are more reliable for us to the results of second row. It shows that none of the H(0, 1), H(0, 2), and H(0, 3) statistics are significant and we accept the null hypothesis of cointegration between the prices of natural gas and crude oil. Furthermore, the H(0, 1) statistic of second row fail to reject the null hypothesis of cointegration (crude oil as exougenous variable) , while H(0, 2), and H(0, 3) statistics reject the null hypothesis.

Regarding to coal and natural gas prices, the H(0, 1), H(0, 2), and H(0, 3) statistics all accept the null hypothesis of cointegration between their prices, coal as regressor or natural gas as regressor. Therefore, it suggests that there is a cointegration relationship between the prices of coal and natural gas from 1976 to 2012.

In this thesis, we study the relationship between crude oil and coal prices, too. According to our results in the third chapter, oil price shocks have significant effects on the coal prices, and coal prices shock has significant effect on the oil price, however these results are for short time. In the long time, policy makers attempt to control the oil prices via changing the rules of coal market, therefore it can be acceptable that in the long run oil is more endogenous than coal. The results suggest that if crude oil be regressand and coal be regressor, H(0, 1), H(0, 2), and H(0, 3) statistics are not reject the null hypothesis, as a result crude oil prices and coal prices are cointegrated. However, if we choose coal as regressand and oil as regressor, H(0, 1), H(0, 2), and H(0, 3)statistics, all, reject the null hypothesis of cointegration.

Consequently, these results suggest that there are at least two cointegration relationships between the crude oil, coal and natural gas prices. It is important to note that two cointegration relationships between three variables means all three variables have cointegration relationships. As our results are mixed for crude oil and coal cointegration relationships, we interpret it first as low power of test and second for size distortion of our data.

5.3.3.1 Robustness check

For robustness check we change the beginning of our sample periods to one year later, and report the results in **Table 5.6**. The new results similar to our main results suggest that there are cointegration relationships between natural gas /crude oil (crude oil as endougenous variable), natural gas /coal, coal /natural gas, crude oil /coal. The H(0,1) statistic of crude oil /natural gas relationship accept the cointegration hypothesis, while H(0, 2), and H(0, 3) reject the null hypothesis. Regarding to relationship between coal/ crude oil, while H(0,1) and H(0,2) reject the null hypothesis of cointegration, H(0, 3) fail to reject.

Table 5.6 The CCR results for the ln real prices of crude oil, coal and natural gas with changing the start of the sample period to one year later

Sample	$b^{a}_{1,CCR}$	$b^{a}_{2,CCR}$	H(0,1)[b]	H(0,2)[b]	H(0,3)[b]
Natural Gas/Crude Oil	-0.46333268 (0.76861616)	0.49321903 (0.19955613)	0.51453866 (0.47318068)	2.7845346 (0.24851122)	4.8324314 (0.18448068)
Crude Oil/Natural Gas	0.038782184 (1.15809741)	2.6625077 (0.80595350)	0.45468268 (0.50011957)	29.243297 (4.4657953 e-007)	29.652508 (1.6329718e-006)
Coal/Natural Gas	3.5947432 (0.068159923)	0.43981733 (0.43973570)	0.45693092 (0.49906182)	1.3776233 (0.50217246)	1.5048718 (0.68114638)
Natural Gas/Coal	0.94920777 (1.0626866)	0.11119341 (0.25042285)	0.060836237 (0.80517908)	0.16728580 (0.91975964)	0.18919613 (0.97931427)
Crude Oil/Coal	-1.4534892 (0.83906496)	1.2488833 (0.19744968)	1.0745462 (0.29992081)	1.1008310 (0.57671014)	1.1248322 (0.77108312)
Coal/Crude Oil	0.64667024 (0.58624525)	0.93627542 (0.15214208)	6.2120031 (0.01268869)	6.2128638 (0.04476038)	6.5456028 (0.08788128)

[a]Standard errors are in parentheses. [b]P- values are in parentheses.

5.4 Conclusion

The long run relationship between the prices of crude oil, coal and natural gas is investigated in this study. Our data set is before the second oil shock until 2012, which during this period the amount of production and consumption of fossil fuels have changed many times. In order to study the cointegration relationship between fossil fuels prices, we use two tests, with different null hypothesis, the Johansen test with null hypothesis of no cointegration and the CCR test with null hypothesis of cointegration. The results of Johansen tests for both nominal and real prices show some evidence that no cointegration hypothesis can be rejected; however the results of one and two cointegration relationship hypotheses cannot be rejected. CCR test results suggest that there is a cointegration relationship between natural gas and crude oil, while natural gas price is endogenous variable and crude oil price is exogenous variable, and between natural gas and coal. The evidence between coal and crude oil is somewhat mixed depend on the choosing regressand and regressor variables in the CCR. Thus, we conclude that at least, there are two cointegration relationships among three fossil fuels prices.

5.5 References

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Chapter 6

Conclusion

The relationships between crude oil, coal and natural gas markets are intricate issues. These relationships assist macroeconomists and policymakers to think correctly about current and future of fossil fuels markets and their relationships with macroeconomy. For this reason, many researchers study the relationships between crude oil, coal and natural gas markets in one side, and the relationships between macroeconomy and crude oil market in another side.

In this thesis, we study the short-run and the long-run relationships between fossil fuels markets and macroeconomy. We investigate the answers of the questions that are there any relation between crude oil, coal and natural gas markets in the short-run and long-run? Have the natural gas and coal markets any significant effect on the macroeconomy? The macroeconomy affects only crude oil market, or affect all fossil fuels markets?

For this purpose, we concentrate on the new approach of Barsky and Kilian (2002) which they discuss on the causality from aggregate demand to oil prices in contrast with traditional approach. Kilian (2009) construct a new index of global real economic activity to show this reverse causality which is based on the on dry cargo single voyage ocean freight rates and is explicitly designed to capture shifts in the demand for industrial commodities in global business markets.

For our purpose, we employ this index to distinguish between three shocks of crude oil market, oil supply shocks, aggregate demand shocks and oil-specific demand shocks. Oil-specific demand shocks arise from uncertainty about future supply of crude oil.

The highest fluctuations of fossil fuels markets were occurred during first and second oil shocks. Meanwhile, most of researchers focused on these periods to report their results on the relationships between crude oil market and macroeconomy. In this research, we concentrate on the relationships of fossil fuels and macroeconomy at same time, but there are some limitations for data of natural gas and coal during first oil shocks. As a result, we concentrate on the second oil shock and subsequent years.

In the chapter two, we investigate the relationships between crude oil and natural gas prices. The results provide some evidence that natural gas price shocks have no significant effect on the oil prices and oil production, while it has significant effect on the real activity. On the other side, aggregate demand shocks, and oil- specific demand shocks have significant effect on the natural gas prices. Furthermore, oil supply shocks have no effect on the oil and natural gas prices.

In the chapter three, we study the relationships between crude oil and coal markets. In contrast with the effect of natural gas price shocks on the oil prices, the results show that coal price shocks have significant effect on the crude oil prices. It can arise from the substitute relationships between crude oil and coal markets, which is more powerful than the substitute relationships between crude oil and natural gas markets. Meanwhile, the results show oil supply shocks, aggregate demand shocks and oil-specific demand shocks have significant effect on the coal prices.

Global aggregate demand shocks increase the demand for energy which increases the price of all fossil fuels. Another oil demand shocks, oil specific demand shocks, transfer the uncertainty of future supply of oil gradually to other fossil fuels markets, as the main substitutes of crude oil to producing enough energy. This demand increase of coal and natural gas increase their prices. We can interpret it as energy-specific demand shocks, which we will illustrate in the future.

The global aggregate demand shocks have positive and significant effect on the oil production; this is obvious in the results of chapter two and three which is in contrast with Kilian (2009) results. Therefore, in our next chapter, we investigate the relationship between global aggregate demand and oil production. For this purpose, we develop a five-variable structural vector autoregressive model (SVAR). The results suggest that ignoring the relationships between crude oil, coal and natural gas which their markets have high interactions may lead to incorrect results.

In the chapter five, we study the long-run relationships between fossil fuels market. Are there any cointegration relationships between the crude oil, coal and natural gas markets? For this purpose, we use two different cointegration tests, first Johansen cointegration test, with no cointegration null hypothesis, and second Park (1992)'s Canonical Cointegration Regression (CCR) with cointegration null hypothesis.

The results of the Johansen cointegration test reject no cointegration relationships, but one ar two ccointegration relationships are not rejected. The results of CCR test suggest that there are cointegration relationships between natural gas/crude oil and natural gas/coal, while the results of cointegration between coal/crude oil is somewhat mixed. Generally, the results suggest that there are at least two cointegration relationships between fossil fuels markets; consequently fossil fuels markets are cointegrated.

We can conclude that there are short-run and long-run relationships between crude oil, coal and natural gas markets which lead to high intractions between them. Therefore, we suggest that to investigate the relationships between macroeconomy and oil market, we should consider coal and natural gas markets and ignoring the main substitutes of crude oil may lead to incorrect answers.

List of Publications

Papers

1. **Narjes Zamani, Masao Ogaki,** “Aggregate Demand Change and Oil Production: Reconsideration”, under preparation.

2. **Narjes Zamani,** “The Relationship between Crude Oil and Coal Markets: A New Approach”, Under Preparation.

3. **Narjes Zamani**, “How the Crude Oil Market Affects the Natural Gas Market? Demand and Supply Shocks”, International Journal of Energy Economics and Policy, Vol 6, No 2(2016), 217-221.

Conferences

1. **Narjes Zamani, Masao Ogaki**, “Aggregate Demand Change and Oil Production: Reconsideration”, 33RD USAEE, North American Conference, Oct 25-28, 2015, Pittsburgh.

2. **Narjes Zamani**, “How the Crude Oil Market Affects the Natural Gas Market: Demand and Supply Shocks”, International Conference on Economics, Business and management, ICEBM 2015, December 30-31, Tokyo, Japan.

3. **Narjes Zamani,** “The Relationships between Crude Oil and Coal Markets: A New Approach”, International Conference on “Business, Economics, and Social Science &Humanities- BESSH-2016, February 05-06, Seoul, South Korea.

4. **Narjes Zamani, Masao Ogaki**, “Aggregate Demand Change and Oil Production: Reconsideration”, Japanese Economic Association, June 18-19, 2016, Nagoya, Japan.

5. **Narjes Zamani,** “Long-Run Relationship of Crude Oil, Coal and Natural Gas Prices”, Japanese Economic Association, September 10-11, 2016, Tokyo, Japan.