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How the Crude Oil Market Affects the Natural Gas Market? Demand and Supply Shocks

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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). 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 to the natural gas market and increases the natural gas price as the primary substitute for oil. Meanwhile, 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, demand shocks link oil and natural gas markets and produce similar changes in their prices.

Keywords: Crude Oil Price, Natural Gas Price, Aggregate Demand Shock
JEL Classifications: Q41, Q43

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 Yucel (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% of natural gas usage can be switched to petroleum products. 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. As a result, natural gas and oil are close substitutes in the electric generation, industrial and residential sectors.

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.

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 (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., Hartley 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. However, some researchers believe the ratio of oil price to natural gas price has decreased in recent years.

Recently, some researchers have also discussed the decoupling of crude oil and natural gas prices (e.g., Bock and Gijón, 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. THE STRUCTURAL RELATIONSHIP BETWEEN PRICES OF CRUDE OIL AND NATURAL GAS

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.

2.2. The Structural Vector Autoregressive (SVAR) Model

We employ SVAR 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

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

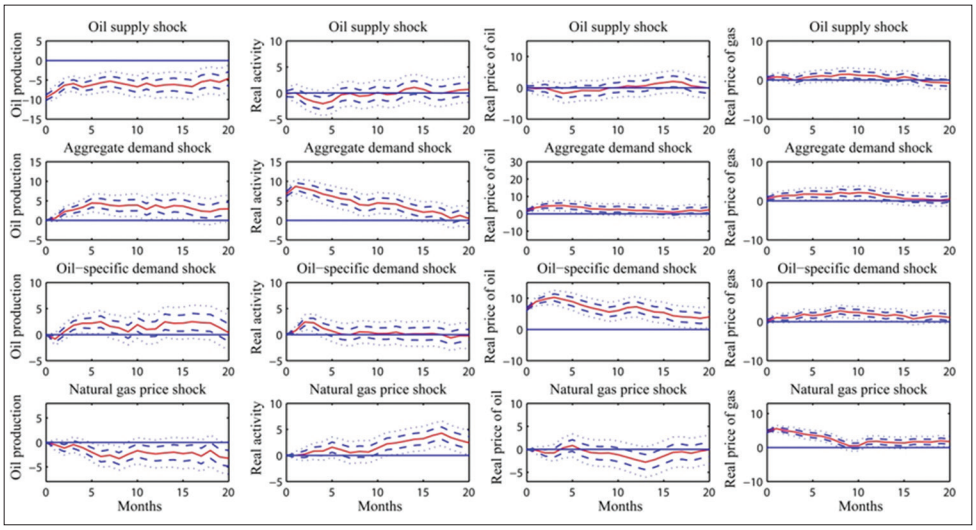
where e_t is the vector of reduced-form errors. We estimate the reduced-form VAR model using the least-square method, which is used in the structural VAR model.

The model in its structural VAR representation is written as

$$A_0 z_t = \alpha + \sum_{i=1}^{p} A_i z_{t-i} + \varepsilon_t \quad (2)$$

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: $e_t = A_0^{-1}\varepsilon_t$

Figure 1: Impulse responses of structural shocks



$$e_t = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \\ e_t^{rpg} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \\ \varepsilon_t^{Natural\ gas\ price\ shock} \end{pmatrix} \quad (3)$$

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, 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.

2.3. Results

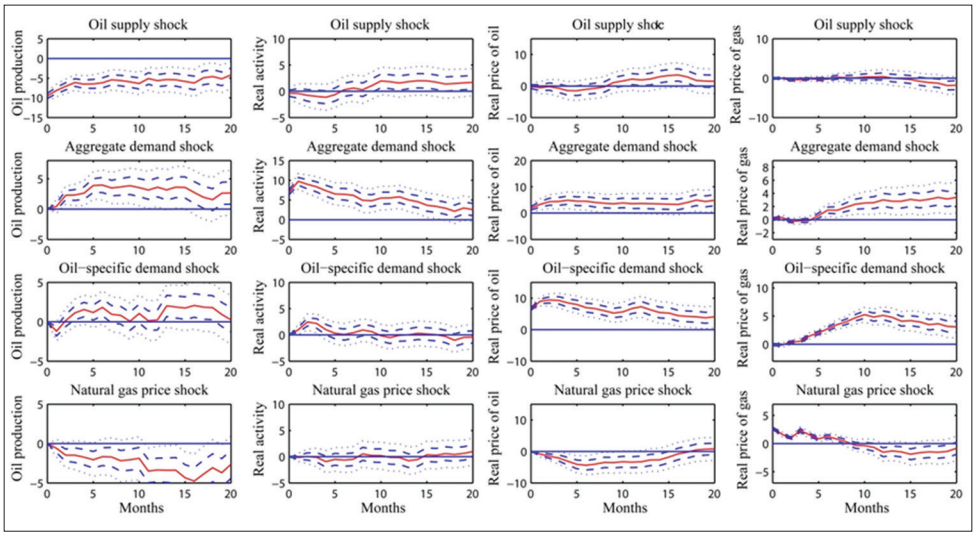
We generate Impulse responses of oil supply shock, aggregate demand shock, oil-specific demand shock, and natural gas price shock on oil production, real activity, the real price of oil, and the real price of natural gas. All of our shocks are normalized. The error of reduced-form VAR of the model is 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 1 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 offset the initial production shortfalls, as Figure 1 shows. It is obvious from Figure 1 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 3 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 2 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 1 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-month and then decreases it until the 20th month.

Figure 2: Impulse responses of structural shocks for robustness check



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 1 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-month, 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 1 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.

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

Our new data for natural gas prices can be based on the natural gas price of Russia. Figure 2 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.

Similar to our main results, Figure 2 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 1st 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 months 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.

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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