Asymmetric Reactions of the U.S. Natural Gas Market and Economic Activity*

Bao H. Nguyen† and Tatsuyoshi Okimoto‡

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Abstract

This paper provides new empirical evidence on the asymmetric reactions of the U.S. natural gas market and U.S. economy to its market fundamental shocks in different phases of the business cycle. To this end, we employ a smooth-transition vector autoregression (STVAR) model to capture the asymmetric responses. Our results indicate that the STVAR model provides a plausible explanation to the behavior of the U.S. natural gas market, which asymmetrically reacts in bad times and good times. In addition, U.S. economic activity is found to be much more sensitive to energy price shocks occurring in recessions than in expansions.

JEL-codes: C32, E32, Q4

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†Lecturer, Development Policy Centre, Crawford, School of Public Policy, ANU College of Asia and the Pacific, Australia, and Lecturer, School of Economics, University of Economics Ho Chi Minh City (UEH), Vietnam. Email: bao.nguyen@anu.edu.au

‡Associate Professor, Crawford School of Public Policy, Australian National University, Australia, and Visiting Fellow, Research Institute of Economy, Trade, and Industry (RIETI), Japan. Email: tatsuyoshi.okimoto@anu.edu.au

1 Introduction

A large amount of empirical literature has been devoted to understanding the behavior of the US natural gas market, especially the relationship between the price of natural gas and crude oil. However, the literature has yet to show a consensus. Some studies, for example Pindyck (2004), Brown and Yücel (2008), Zamani (2016), and Jadidzadeh and Serletis (2017) find that movements in crude oil prices have a key role in shaping natural gas prices. In contrast, other studies conclude that there is a very weak or no connection between the two prices (Serletis and Rangel-Ruiz, 2004; Bachmeier and Griffin, 2006; Ramberg and Parsons, 2012). In fact, empirical results obtained from these previous studies rely on linear models that assumed that the price of oil and natural gas react indifferently over the business cycle. This contrasts with recent studies emphasizing that regime-switching exists in the relationship between the price of natural gas and crude oil (Brigida, 2014; Atil et al., 2014). As a consequence, studies that do not take economic conditions into account may yield a misleading understanding about the behavior of the two energy prices.

There is also a vast literature that investigates the effects of oil prices on the real economy, but there are relatively few studies that consider the effects of natural gas prices. Studies investigating the macroeconomic impacts of oil price shocks can be found in Hamilton (1983, 2003), Mork (1989), Rotemberg and Woodford (1996), Bernanke et al. (1997), Dhawan and Jeske (2008), Kilian (2009), Baumeister et al. (2010), Jo (2014), among others.[1] In addition, the nonlinear relationship between energy price shocks and economic activity has recently begun to emerge in the literature. For example, while Hamilton (2003) quantifies the different effects on economic activities between oil price increases and decreases, Baumeister and Peersman (2013) document the time-varying effects of oil supply shocks on the economy. Other studies include Huang et al. (2005), Rahman and Serletis (2011), Hamilton (2011), Katayama (2013), Baumeister and Kilian (2016b), and Cross and Nguyen (2017). Therefore, it is also crucial to consider possible nonlinear relationships between the energy prices and real economy.

In this chapter, we depart from the traditional literature by seeing if the US natural gas market behaves asymmetrically in different phases of the business cycle. In addition, we also examine the possible asymmetry in the responses of the US economy to shocks in oil and natural gas prices. More specifically, we address the following two questions:

[1] For comprehensive surveys of the relationship between oil prices and the macroeconomy, see Hamilton (2008) and Kilian (2008, 2014).

First, are the reactions of the U.S natural gas supply and price to its market fundamental shocks different in recessions and expansions? Next, are the responses of US economic activity to oil and natural gas prices different over its business cycle? Clearly, the answer to these questions is important to understanding not only the behavior of the natural gas markets, but also the reactions of the US economy to shocks on the oil and natural gas prices in the context of a nonlinear environment, something which has not been comprehensively investigated yet in the current literature.

We address these questions by modeling an augmented natural gas market with a smooth-transition vector autoregression (STVAR) model. Following the seminal work of Kilian (2009), we model the real natural gas price as endogenous and disentangle the causes underlying market fundamental shocks. In particular, there are three fundamental shocks stemming from the natural gas market: natural gas supply shocks, shocks to the US demand, and natural gas specific demand shocks. In addition, to account for the fact that the price of oil can influence the natural gas market as well as the US economy, we incorporate the world price of crude oil into the model and allow for shocks to the price of oil to have contemporaneous effects on the US natural gas market and economic activity. While the augmented natural gas market allows us to investigate how the US natural gas market and economic activity react to the fundamental shocks, the STVAR model provides a nonlinear framework that enables us to capture the possible state-dependent responses of the US natural gas market and economy.[2] In other words, the STVAR model is well suited to capturing a phenomenon that the responses of both energy markets and the economy would be asymmetric in bad times and good times. For example, the recent unexpected declines in the real oil price have not caused a strong economic expansion as one conjectured (Baumeister and Kilian, 2016b; Kilian, 2017). This suggests that a nonlinear framework, such as the STVAR model, that admits nonlinear interactions among variables could address well the research questions in this paper.

Our results indicate that in contrast to the prediction made by a linear VAR model, the STVAR model provides a plausible explanation to the behavior of the US natural gas market, reacting asymmetrically in bad times and good times. For example, the oil

[2]The STVAR model has been widely applied in macroeconomics and typically examined the effects of policy shocks in bad times and good times. For example, Auerbach and Gorodnichenko (2012), Berger and Vavra (2014), and Caggiano et al. (2015) find differences in the size of fiscal spending multiplier in the US economy over the business cycle. Similarly, Weise (1999) and Rahman and Serletis (2010) use the model to quantify the impact of monetary policy shocks. More recently, the STVAR model is also used to investigate the asymmetric effects of news shocks (Bolboaca and Fischer, 2016) and uncertainty shocks (Caggiano et al., 2014, 2017).

price shock is found to be an important factor driving the production of natural gas, however the directions of impact are totally different depending on the economic condition. During recession, a positive real oil price shock has a negative impact on natural gas production and the impact is still evident after a year. In contrast, during expansion, the responses of natural gas production to the same shock are significantly positive in the long-run. Similarly, in recessions, the real price of natural gas strongly responds to the global oil price shock with more than 6 percent rise in the short-run, but then the impact becomes insignificant in the long-run. In contrast, the oil price shock has significant positive impacts on the real price of natural gas even in the long-run, increasing it about 3 percent over expansion periods. The finding of positive relationship between the oil and natural gas prices is consistent with the findings in Jadidzadeh and Serletis (2017) and Zamani (2016), but our results suggest this relationship is more prominent in recessions in the short-run and in expansions in the long-run.

Furthermore, our empirical analysis shows more new evidence of asymmetric reactions regarding US economic activity. Specifically, the US economic activity is much more sensitive to shocks occurring in recessions than in expansions. In line with conventional evidence documented by, for example, Kilian (2009) and Baumeister and Peersman (2013), an unexpected increase in the real price of crude oil and natural gas has significant negative effects on the economy in recessions. However, in expansion, natural gas has essentially no impacts on the US economy, while oil price shocks still have significant effects, though the magnitude of the impacts is much less than that in recessions. Examining the impact of the natural gas supply shocks on the US economy, our results indicate that an unexpected decline in natural gas production has a negative effect on the economy only in expansions.

The remainder of the chapter is organized as follows: First, Section 2 outlines the econometric methodology, including the model specification and estimation. Next, Section 3 provides a brief overview of the pricing of the US natural gas market and the data used in the paper. Sections 4 then presents the results, including the estimated results of the linear setting and nonlinear setting. Section 5 reports the robustness check. Finally, Section 6 concludes the paper.

2 Empirical methodology

This section begins by describing our benchmark model, which is based on a traditional recursive VAR model. This linear setting enables us to understand the behavior of the

US natural gas market in a linear environment. Once established, the next step in our empirical analysis is to apply a nonlinear STVAR model to investigate the asymmetric reactions of the natural gas market and the response of US economic activity through impulse response functions (IRFs).

2.1 Benchmark model

To examine the reactions of the US natural gas market on its market fundamental shocks, including global oil price shocks, as well as demand and supply shocks, and the responses of the US economy to the associated shocks, our benchmark model is based on the models of Kilian (2009) and Jadidzadeh and Serletis (2017). Kilian (2009) employs the three-variable recursive VAR model consisting of global crude oil production, real global economic activity, and real oil price to examine the effects of demand and supply shocks in the crude oil market. Extending Kilian's model by adding real US natural gas prices, Jadidzadeh and Serletis (2017) investigate the impacts of demand and supply shocks in the global crude oil markets on the real price of natural gas in the US Departing from these studies, our focus is on the effects of oil prices, as well as demand and supply shocks in the US natural gas market on the US natural gas prices and production, and the US economy. Therefore, our benchmark model is a similar recursive VAR model consisting of four variables: real price of crude oil (rpo), the percentage change in US natural gas production ($\Delta prodg$), the percentage change in US real economic activity measured by US industrial production (Δip), and the real price of US natural gas (rpg).

Let $\mathbf{z}_t = (rpo_t, \Delta prodg_t, \Delta ip_t, rpg_t)'$. The structural representation of our benchmark VAR(p) model can be expressed as

$$\mathbf{B}\mathbf{z}_t = \boldsymbol{\gamma} + \sum_{i=1}^{p} \boldsymbol{\Gamma}_i \mathbf{z}_{t-i} + \boldsymbol{\varepsilon}_t, \tag{1}$$

where $\boldsymbol{\varepsilon}_t$ is assumed to independently follow a standard multivariate normal distribution.

Following Kilian (2009) and Jadidzadeh and Serletis (2017), we assume the recursive structure on $\mathbf{B}$, namely $\mathbf{B}$, is a lower-triangular matrix with 1 along the diagonal elements. The reduced form of VAR is obtained by premultiplying $\mathbf{B^{-1}}$ to both sides of (1) as

$$\mathbf{z}_t = \boldsymbol{\alpha} + \sum_{i=1}^{p} \mathbf{A_i z_{t-i}} + \mathbf{e_t}, \tag{2}$$

where $\boldsymbol{\alpha} = \boldsymbol{B}^{-1}\boldsymbol{\gamma}$, $\boldsymbol{A}_i = \boldsymbol{B}^{-1}\boldsymbol{\Gamma}_i$, and $\boldsymbol{e}_t = \boldsymbol{B}^{-1}\boldsymbol{\varepsilon}_t$. The reduced form can be easily estimated by the equation-by-equation ordinary least squares (OLS), which is equivalent to the maximum likelihood estimation (MLE) under the normality assumption of $\boldsymbol{\varepsilon}_t$.

2.2 STVAR model

In addition to the benchmark analysis, we also estimate the STVAR model to examine the possible asymmetric reactions of the US natural gas market to its market fundamental shocks, depending on the phases of the business cycle. This is relevant because recent studies, for example, Brigida (2014) and Atil et al. (2014), find the regime switching in the relationship between the oil and natural gas prices. It is also well-documented that the relationship between energy price shocks and economic activity is nonlinear, shown by, among others, Huang et al. (2005), Rahman and Serletis (2011), Hamilton (2011), Baumeister and Kilian (2016b), and Cross and Nguyen (2017). Therefore, it is very instructive to accommodate the nonlinearity in the relationship among the prices of natural gas and crude oil, as well as US economic activity, by introducing a regime-switching characterized by a smooth transition.

The smooth-transition autoregressive (STAR) model was developed by, among others, Chan and Tong (1986) and Granger and Teräsvirta (1993), and its statistical inference was established by Teräsvirta (1994). Since then, many types of the smooth-transition models have been considered. In particular, the STVAR model is an extension of the STAR model to a multivariate system of equations that can analyze the dynamic relations among several variables with taking a possible regime change or asymmetry into account (e.g., Weise (1999), Gefang and Strachan (2010), and Auerbach and Gorodnichenko (2012)). The same as these studies, we adopt a STVAR model to examine the asymmetric relationship among the prices of natural gas and crude oil, as well as US economic activity, with a possible regime change, depending on the phase of the business cycle.

Following Weise (1999) and Gefang and Strachan (2010), we accommodate the smooth transition into the reduced form equation (2) as

$$\mathbf{z}_t = (1 - F(s_{t-1})) \left(\boldsymbol{\alpha}^{(1)} + \sum_{i=1}^{p} \mathbf{A}_\mathbf{i}^{(\mathbf{1})} \mathbf{z}_{\mathbf{t-i}} \right) + F(s_{t-1}) \left(\boldsymbol{\alpha}^{(2)} + \sum_{i=1}^{p} \mathbf{A}_\mathbf{i}^{(\mathbf{2})} \mathbf{z}_{\mathbf{t-i}} \right) + \mathbf{e}_\mathbf{t}, \qquad (3)$$

where $\boldsymbol{\alpha}^{(j)}$ and $\mathbf{A}_\mathbf{i}^{(\mathbf{j})}$ are reduced form parameters for regime j, $F(\cdot)$ is a transition function taking the values between 0 and 1 with a transition variable s_t.

The transition function and transition variable are determined according to the purpose of the analysis. For example, to identify the differences in the size of the fiscal spending multiplier in the US economy over the business cycle, Auerbach and Gorodnichenko (2012) use a logistic transition function with a seven-quarter moving average of the output growth rate as a transition variable. Following a similar idea, we use a logistic transition function given as

$$F(s_{t-1}; c, \gamma) = \frac{1}{1 + \exp\big(-\gamma(s_{t-1} - c)\big)}, \quad \gamma > 0, \tag{4}$$

and an average growth rate of US industrial production over the last p-months as a transition variable s_t.[3] Adopting the convention, we date the index s by $t-1$ to avoid contemporaneous feedbacks. With this choice of transition function and variable, we can interpret regime 1, characterized by $\boldsymbol{\alpha}^{(1)}$ and $\mathbf{A}_\mathbf{i}^{(\mathbf{1})}$, as the recession regime with $F(s_{t-1}) \approx 0$ and regime 2, characterized by $\boldsymbol{\alpha}^{(2)}$ and $\mathbf{A}_\mathbf{i}^{(\mathbf{2})}$, as the expansion regime with $F(s_{t-1}) \approx 1$. The location parameter c determines the threshold between the recession and expansion. More specifically, if s_t is smaller (larger) than c, the VAR dynamics become closer to those in the recession (expansion) regime or regime 1 (regime 2). The smoothness parameter γ determines the speed of the transition from regime 1 to regime 2 as the past p-month economic growth rate increases. More specifically, when γ takes a large value, the transition is abrupt, whereas the transition is gradual for small values of γ.

One of the advantages of the logistic transition function (4) is that it can express various forms of transitions, depending on the values of c and γ. Additionally, c and γ can be estimated from the data, enabling the selection of the best asymmetric interdependence patterns among the prices of natural gas and crude oil and US economic activity based on data, which is very attractive for the purposes of this chapter.

In principle, we can estimate all the parameters of the STVAR model (3) simultaneously by MLE. However, it is challenging, if not impossible, to maximize the likelihood function with respect to all parameters because of a large number of parameters and the highly nonlinear structure of the STVAR model. For example, Weise (1999) fixes c at a predetermined value and estimates γ by the grid search while Auerbach and Gorodnichenko (2012) assume $c = 0$ and calibrate γ without any estimation. In contrast to these studies, we estimate both c and γ by the grid search.[4] Given the fixed values of c and γ, the STVAR model becomes a seemingly unrelated regression (SUR) model with

[3] We set the length of period to define the past economic performance as equal to the lag length for VAR model. This assumption is not necessary, but it is not unreasonable under the assumption that the current economic growth can be affected by past economic growth up to the pth lag. We also normalized s_t so that it has mean of 0 and standard deviation of 1.

[4] One cost to estimate c and γ with a grid search is that standard errors are not able to be evaluated for c and γ. Therefore, the standard errors for the impulse responses calculated below do not consider the effects of the estimation of c and γ. However, judging from the estimation results, this should not be a serious problem because the rest of parameter estimates seem to be insensitive to the small changes in the estimates of c and γ.

the same set of regressors. In this case, we can maximize the likelihood with the equation-by-equation OLS. Therefore, using the grid search we can find the ML estimates of c and γ relatively easily.

3 The pricing of natural gas in US markets and data selection

Because different types of natural gas prices are observed in different markets, the behavior of these prices may vary across suppliers and users and, thus, respond differently to shocks. We begin by briefly reviewing of the pricing of natural gas in US markets and then describe the data used in this paper.

The price of gas travels from wellheads (upstream markets) where natural gas is produced to the end users (downstream markets). According to Brown and Yucel (1993) and Mohammadi (2011), there are six separate segments, including wellhead, city gate, and four end-use nodes (e.g., commercial, industrial, residential, and electrical customers). It begins with *wellhead price*. The price of gas is first determined at the wellhead by independent brokers and pipeline companies. Therefore, the wellhead price often refers to the price of the upstream market. Pipeline companies and brokers then sell their natural gas to local distribution companies (LDCs) and some end users. The prices observed in this market refers to *city gate prices*. Generally, because industrial and electrical end users can switch easily between natural gas and other forms of energy to minimize their costs, these end users tend to purchase their natural gas directly from pipeline companies and brokers with competitive spot prices. For this reasons, prices paid by industrial and electrical users refer to *industrial prices* and *electric power prices*. In contrast, commercial and residential users normally cannot switch between different fuel forms; their energy expenditure is linked with a single fuel type. As a consequence, both commercial customers and residential customers purchase their natural gas from LCDs, and they are offered *commercial prices* and *residential prices*, respectively.

The above overview suggests that in nature, the wellhead price serves as a benchmark reference for downstream markets, including physical and spot markets.[5] Therefore, this paper utilizes the wellhead price as the benchmark price for the US market. Similar to Jadidzadeh and Serletis (2017), we divide the nominal price series sourced from the US

[5] An examination of the relationship between upstream and downstream prices can be found in Mohammadi (2011).

Department of Energy (EIA) by the US CPI to obtain the real price of natural gas. The natural gas price series is 100 times the monthly logarithm of the real price. We also note that the set of available data of the wellhead price is only from January 1980 to December 2012. Thus, we extend the data to the latest date by using natural gas import prices from January 2013 onward. That being said, because the domestic natural gas market is a competition market, the movements of the wellhead price and the import price (in log levels) are almost identical, as can be seen from Figure 1. Regarding natural gas production, we use monthly U.S natural gas gross withdrawals, also complied by EIA, as a proxy for natural gas supply. The variable is seasonally adjusted and then enters to the model by taking the first difference of the natural logarithm. To capture the US economic activity, that drives demand for natural gas in the US market, we utilize the US monthly industrial production index, seasonally adjusted, retrieved from Federal Reserve Bank of St. Louis and then transform the index to growth rate by taking the first difference of the natural logarithm. Finally, we use the US refiners' acquisition cost for imported crude oil (IRAC), published by the EIA, to compute the real price of crude oil with the same method used to calculate for the real natural gas price.[6]

Figure 1 plots the historical evolution of our series from February 1980 to November 2016, as well as series used for robustness exercises presenting in Section 5. This sample period is the longest set of available data for monthly US natural gas production.

4 Empirical results

We begin our analysis by considering the reactions of the US natural gas market and economic activity to fundamental shocks in the linear model with no regime shifts. Having established this result, we then discuss the significance of allowing for possible state dependence in investigating the reactions of the natural gas market and the different responses of the US economy over the business cycle.

[6] A discussion on whether or not we should consistently use the price of oil and natural gas in percent change (first differences of the natural logs of the variables), along with other variables, can be found, for example, in Kilian (2009), Kilian and Park (2009), Kilian and Murphy (2014), Lütkepohl and Netšunajev (2014), and Jadidzadeh and Serletis (2017). According to these empirical works, it is not clear whether the real price of crude oil, and hence the natural gas price in this paper, should be modeled in log levels or log differences. The level specification is preferred because it produces consistent impulse response estimates, regardless of the assumption of unit root.

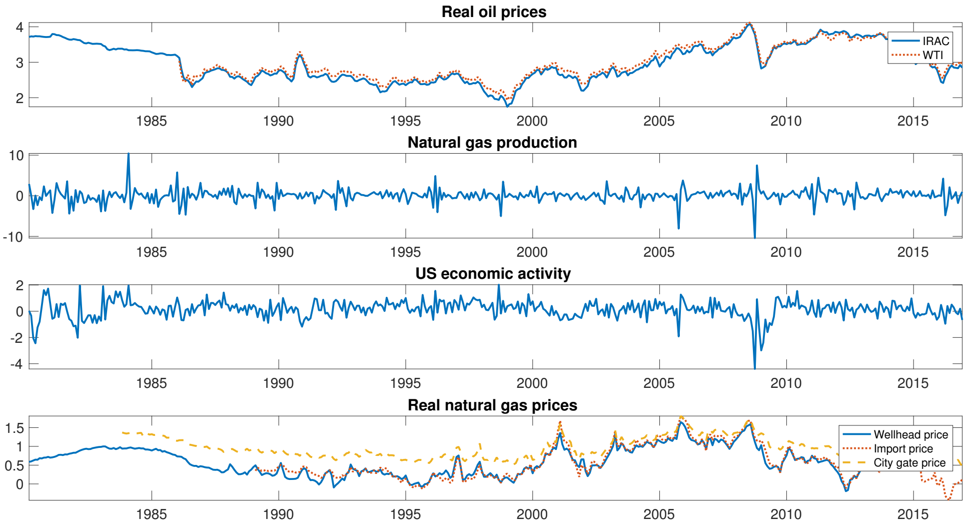


Figure 1: Historical evolution of the series (1980M2-2016M11)

Note: The monthly raw data of crude oil prices, natural gas prices and production collected from EIA. US monthly industrial production index (US economic activity) is sourced from Fed of St. Louis. WTI, wellhead price, city gate price and import price series span from 1986M1 to 2016M11, 1980M1 to 2012M12, 1983M10 to 2016M11, and from 1989M1 to 2016M11 respectively. Natural gas production, US economic activity are in percent changes, remaining series are in log-levels.

4.1 Results based on the VAR model

In this subsection, we document the results of a linear VAR model as a benchmark. To this end, we estimate its reduced form (2) by MLE and use it to construct the structural VAR representation (1).[7] Following Kilian (2009), our impulse response analysis is based on a recursive-design wild bootstrap with 2,000 replications. For the details of the method, see Gonçalves and Kilian (2004).

Figures 2, 3, and 4 plot the estimated dynamic responses to a one-standard-deviation shock to market fundamentals together with one standard error bands. These shocks include the natural gas supply, US economic activity, natural gas price (or specific demand shock), and the world price of crude oil shocks. Following the standard literature on energy markets, such as Kilian (2009) and Jadidzadeh and Serletis (2017), we define the natural gas supply shock as a negative shock while other shocks are positive shocks. Therefore, all shocks will tend to raise the price of natural gas.

As can be seen from Figure 2, we find that natural gas production is not sensitive to the fluctuations of the price of crude oil. Similarly, although the price of natural gas positively affects natural gas production in the short term, it does not have any significant effects on the natural gas supply in the long term. In contrast, US demand shock brings a positive effect on the supply of natural gas, increasing it more than 0.2 percent in the long run.

Regarding the reactions of the natural gas price reported in Figure 3, we observe that the real oil price and natural gas supply shocks are considered relatively strong drivers of natural gas price movements. In other words, an increase in the real oil price leads to a higher natural gas price, and a decrease in natural gas production also increases the natural gas price significantly. More specifically, a one-standard-deviation oil price shock could lead to the real price of natural gas consistently increasing about 3 percent, while a one-standard-deviation negative supply shock could increase the real natural gas price persistently by 1 percent. The former finding is in line with Jadidzadeh and Serletis

[7] For the analyses of this and the next subsections, we use $p = 6$ as a lag length of the VAR and STVAR models. Although Jadidzadeh and Serletis (2017) and Kilian (2009) assume $p = 24$, it is not reasonable to use the same lag length for the STVAR model, given the nonlinear nature of the system and that the effective number of observations for each regime, particularly for recessions, is small. Thus, $p = 6$ is a reasonable choice for maintaining the estimation plausibility and capturing enough interactions among variables. We conducted a sensitivity analysis of our benchmark results, estimated with the linear VAR model, by assuming $p = 24$ as in previous studies, which will be provided upon request. The main results still hold under this alternative lag length.

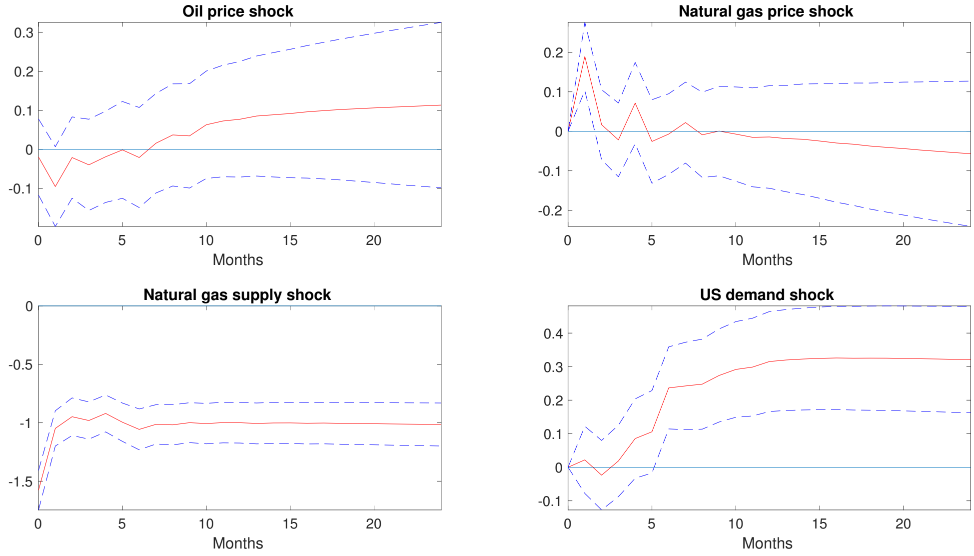


Figure 2: Natural gas production responses to one-standard-deviation structural shocks
Note: The Figures show impulse responses based on model 1. The confidence intervals were constructed using a recursive-design wild bootstrap. The natural gas supply shock is normalized to disrupt US natural gas production.

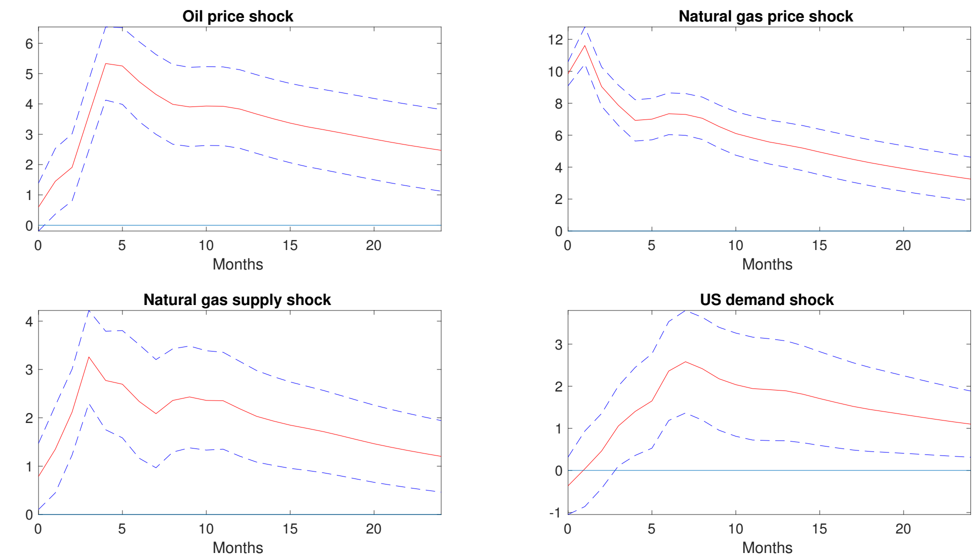


Figure 3: Natural gas price responses to one-standard-deviation structural shocks
Note: See Figure 2.

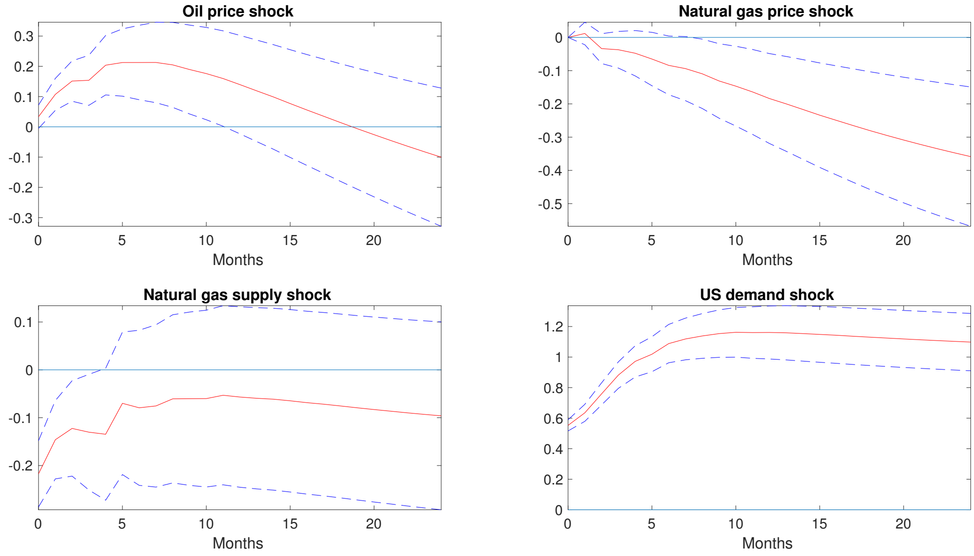


Figure 4: US economy responses to one-standard-deviation structural shocks
Note: See Figure 2.

(2017), who also conclude that crude oil market fundamentals are an important determinant of natural gas price. Similarly, the US demand shock is found to be another significant factor for natural gas price, particularly in the long run, increasing the natural gas price by 2 percent. Thus, US strong demands push up the natural gas price eventually, even though these demands also lead to more natural gas supply. In addition, the specific natural gas demand shock has a strong effect that immediately leads to a surge in the natural gas price; however, the impact becomes weaker in the long run. This is partly because the increase in natural gas price induces more supply in the short run, as we discussed above. Thus, we observe that more natural gas is produced in response to higher economic activity, but at the same time, we also find the price of natural gas increased.

Finally, evidence obtained from the linear framework provides contrasting results to the conventional literature regarding the macroeconomic effects of energy market shocks, such as Kilian (2009) and Baumeister and Peersman (2013). As can be seen from Figure 4, we find that US economic activity responds negatively to the natural gas supply shock but temporarily increases in response to a positive shock of oil price. US economic activity also is found to not be sensitive to an unexpected increase in the price of natural gas in the short run, but there is evidence that the economy is slightly negatively affected in the long run. In other words, the US economic activity is found to be positively affected by oil price shock and insensitive to shocks in natural gas prices in the short run. In addition, US economic activity is not affected by the oil price shock in the long run. These findings contradict previous studies, such as Kilian (2009) and Baumeister and Peersman (2013). However, our findings based on the SVAR model might be a result of the ignorance of possible nonlinearity. We will examine this possibility by estimating the STVAR model in next subsection.

4.2 Results based on the STVAR model

Although the estimated results obtained with the standard linear VAR model provide some interesting findings on how the US natural gas market and economic activity react to different structural shocks, they are fully silent on the propagation dynamics over the business cycle. However, the recent studies, for example, Brigida (2014) and Atil et al. (2014), find there is regime switching in the relationship between the oil and natural gas prices. In addition, other recent studies, such as Huang et al. (2005), Rahman and Serletis (2011), and Hamilton (2011), indicate that the relationship between energy price shocks and economic activities is asymmetric and depends on the phase of business cycle. Following these studies, we introduce regime switching to play a role in the system and take the US business cycle into account. More specifically, we document in this subsection the results based on the STVAR model (3) to better understand the asymmetric reactions of the U.S natural gas market and economy in bad and good times.

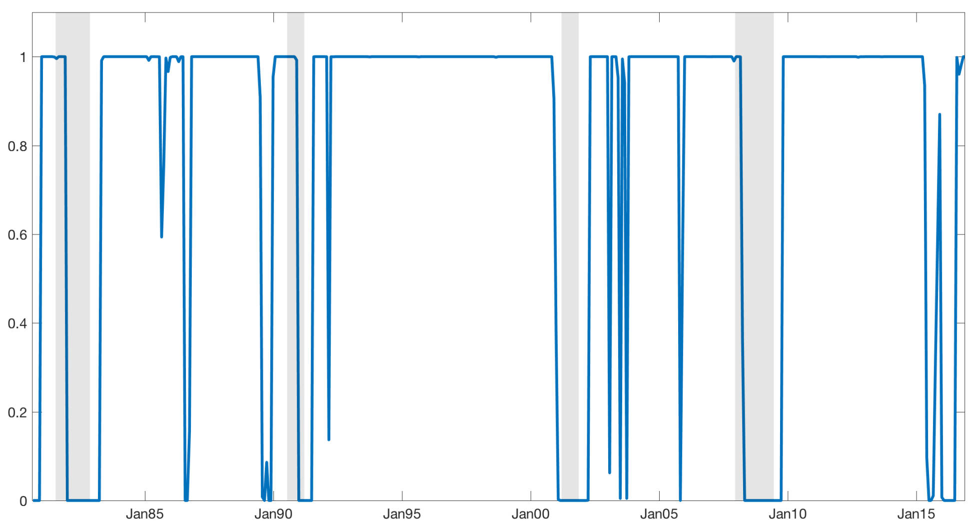


Figure 5: NBER dates and weight on recession regime $F(s_t)$

Note: The shaded region shows recessions as defined by the NBER. The solid line shows the weight on recession regime $F(s_t)$.

We estimate c and γ by the grid search, and their estimates are given by -0.036 and 106.8, respectively. This means that if the average growth rates over the last six months is lower than -0.036 percent or -0.434 percent per year, the regime would become closer to the recession regime. In addition, the relatively large estimate of γ indicates that this transition from the expansion regime to the recession regime is rather rapid. This can be also be confirmed from Figure 5, plotting the estimated dynamics of transition function (4) or the weight on the expansion regime along with recessions identified by the NBER. The estimated regime dynamics reasonably correspond to the business cycle. More specifically, the weight on the expansion regime is almost zero during the NBER recession dates and nearly one for most of other dates. Thus, our estimation result of transition function (4) strongly indicates that the dynamic relationship among the prices of natural gas and crude oil, as well as US economic activity could be different depending on the phase of the business cycle, which can be examined more formally by comparing the impulse response functions of each regime.

4.2.1 Asymmetric reactions of natural gas markets

Having discovered that the STVAR model provides evidence that the dynamic relationship among the prices of natural gas and crude oil and US economic activity could be different depending on the phase of the business cycle, we now examine the asymmetric responses over the business cycle in more details to answer whether the US natural gas market reacts differently to market fundamental shocks in recessions and expansions.

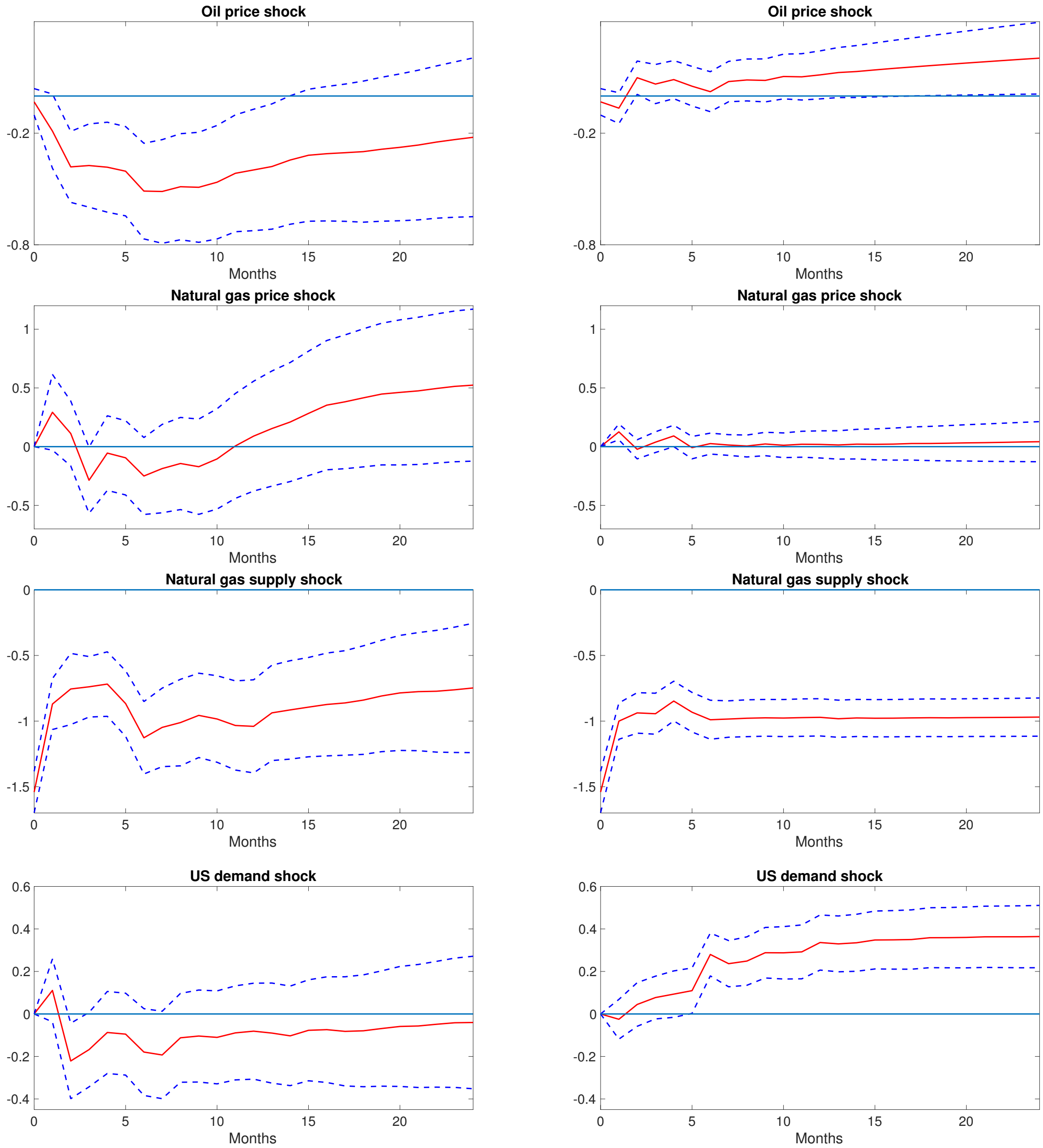
Figures 6 presents the dynamic responses of natural gas production conditional on a recessionary and expansionary phase of the economy, showing the quantitatively different pictures between bad and good times. For example, in contrast to the prediction made by the linear VAR, the STVAR reveals that the reactions of natural gas production to the real oil price shock are statistically significant, with remarkable differences between recessions and expansions. During a recession, a positive real oil price shock has a negative impact on natural gas production, and the impact is still evident after a year. In contrast, during an expansion, the responses of natural gas production to the same shock are positive, particularly in the long run. Similarly, in response to the demand shock, we also find the opposite. During periods of slack economic activity, even if the US demand for natural gas suddenly increases, the supply of natural gas is not very responsive to the shock. However, we find strong positive responses of natural gas supply to the US demand in the long run during an expansion.

Another interesting difference can be seen from the reactions of natural gas production to the specific natural gas demand shock. The specific demand shock is defined as an unexpected increase in natural gas prices that is not related to changes in natural gas production or US economic activity. Although the reactions of natural gas production to the natural gas price shock are insignificant in the long run for both regimes, there is a significant positive response in the short run only when in a period of expansion.

Turning to the responses of natural gas price, we find that the responses in recessions and expansions are also very different, as can be seen in Figure 7. In recessions, the real price of natural gas strongly responds to the global oil price shock in the short run, but then the impact becomes insignificant in the long run. In contrast, the oil price shock has significant positive impacts on the real price of natural gas even in the long run during expansions. The finding of positive relationship between the oil and natural gas prices is consistent with the findings in Atil et al. (2014), Zamani (2016), and Jadidzadeh and Serletis (2017), but our results demonstrate this relationship is more prominent in recessions in the short run and in expansions in the long run. For example, although this study does not distinguish between the underlying sources of the oil price shocks, Jadidzadeh and Serletis (2017) apply a VAR model and identify different shocks stemming from the global oil market, namely oil supply shock, aggregate demand shock, and oil-specific demand shock. Their results indicate that although different oil price shocks have different time-varying impacts on the natural gas price, the overall impact is about 2-4 percent, which is consistent with our findings. More precisely, our results further highlight that, in the short run, the reaction of the natural gas price is stronger in recessions, about 6.5 percent, when compared to those in expansions, about 4 percent. But in the long run, the effects found in expansions are 2.6 percent and larger compared to recessions, with no significant effects found.

The real natural gas price also evidently reacts to the unanticipated changes in natural gas production. Specifically, the negative supply shock induces higher natural gas prices in the short run in both recessions and expansions, but only the reaction in expansions is statistically significant in the long run. Interestingly, the estimation results from the STVAR model reveal that the natural gas price is not sensitive much to the US demand shock, which generally contrasts with evidence found in oil markets.[8] We see that, during a recession, an increase in the demand for natural gas leads to no significant changes in the natural gas price. On the other hand, and somewhat surprisingly, the US demand shock

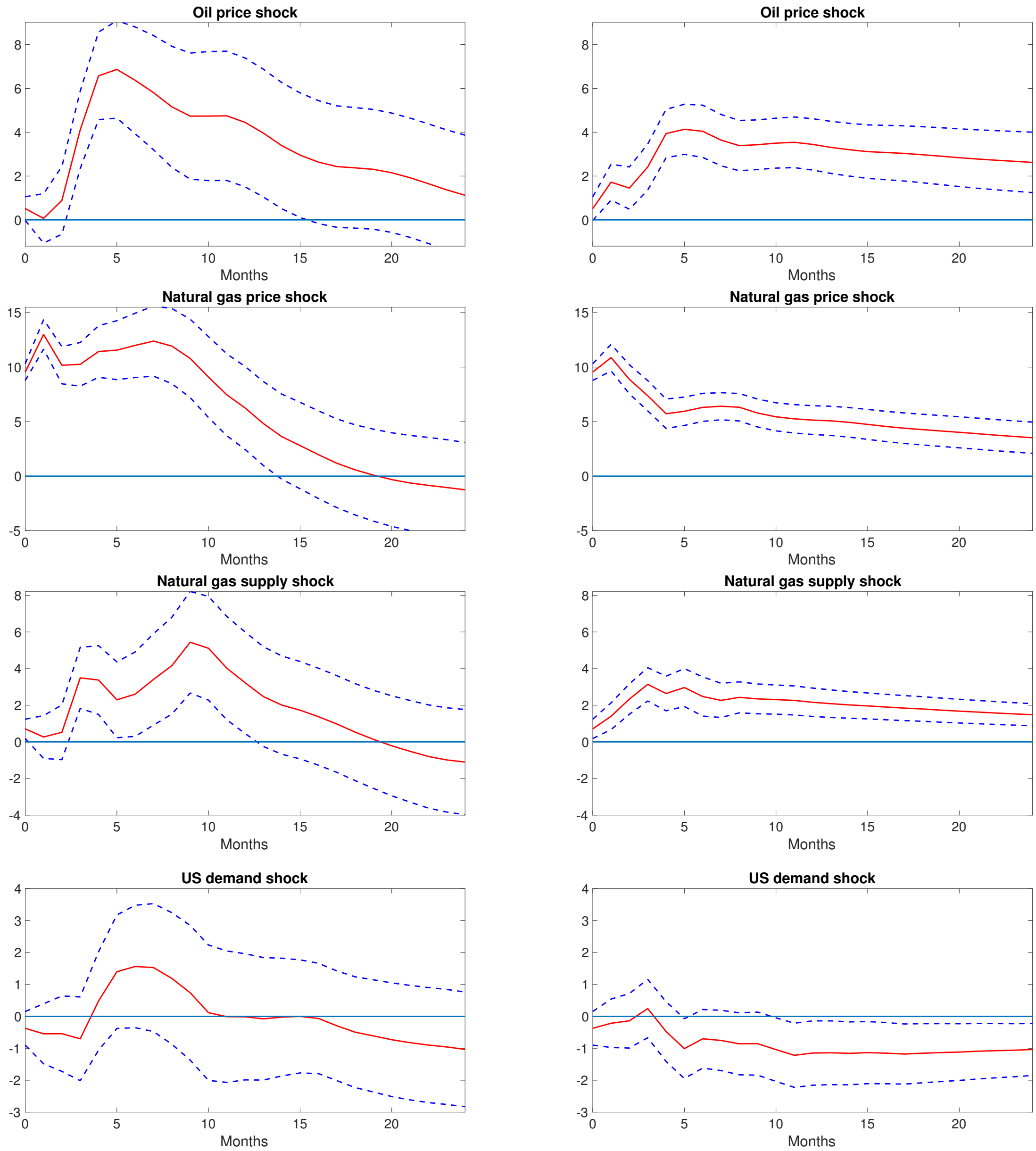
[8]We note one reason for this is that over the past three decades, the price of oil was led by factors related to the global demand rather than the supply side. See Baumeister and Kilian (2016a) for a nice survey.



(a) Recession

(b) Expansion

Figure 6: Natural gas production responses to one-standard-deviation structural shocks *Notes* The Figures show impulse responses based on model 3. The confidence intervals were constructed using a recursive-design wild bootstrap. The natural gas supply shock is normalized to disrupt US natural gas production.



(a) Recession (b) Expansion

Figure 7: Natural gas price responses to one-standard-deviation structural shocks

Note: See Figure 6.

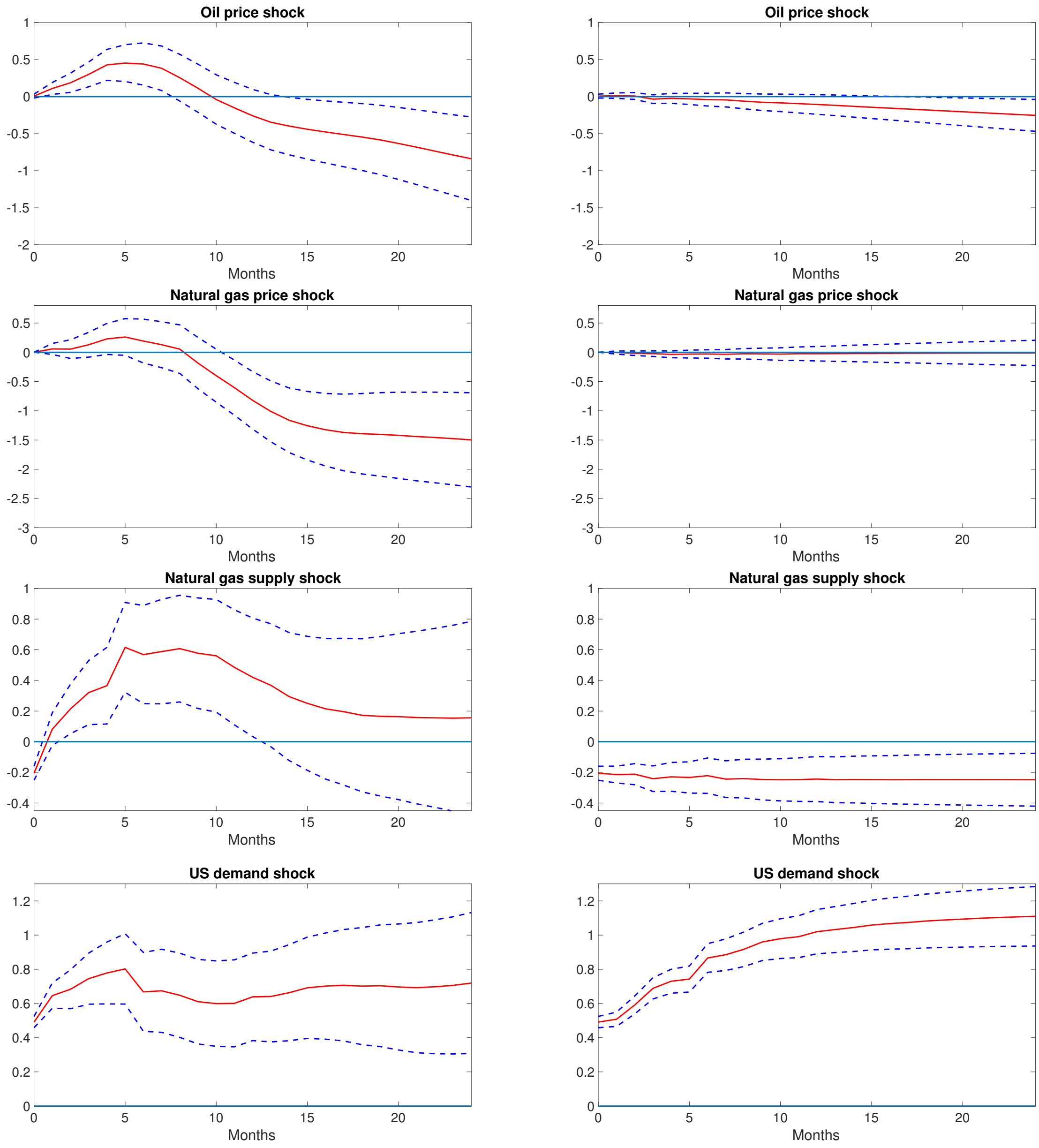
negatively affects the natural gas price in the long run during expansions. Given that the natural gas supply responds significantly and positively to the US demand shock, the real natural gas price falls permanently, but the magnitude is quite small at about 1 percent. At the same time, we observe from Figure 7 that the specific demand shock is considered as a relatively stronger factor that affects the natural gas price. More specifically, the results indicate that the price of natural gas consistently increases, but the impact in a recession dies out after about a year while the associated impact is more permanent, with more than a 3 percent rise during expansions.

4.2.2 Asymmetric reactions of US economic activity

We find empirical evidence that US economic activity responds asymmetrically to shocks stemming from the natural gas and oil markets. In general, as can be seen in Figure 8, economic activity is much more sensitive to the shocks occurring in recession periods compared to the responses to the same shocks occurring in expansion periods. Specifically, an unexpected increase in the real price of crude oil and natural gas has significant negative effects on the economy during recessions. This finding is consistent with previous evidence for oil prices, for example Kilian (2009) and Baumeister and Peersman (2013), but it provides new evidence for the natural gas prices.

However, during an expansion, the oil price shocks are found to be more important than the natural gas price shocks. More precisely, natural gas shocks have essentially no impacts on the US economy while oil price shocks still have significant negative effects in the long run; although, the magnitude of the impacts is much less than in recessions. In addition, when examining the impact of the natural gas supply shocks, we observe that in recessions, the associate shock induces a hump-shaped response from the US economy, but the effect is not statistically significant in the long run. In expansions, our results show strong evidence that an unexpected decline in natural gas production has a negative effect of -0.2 percent on the economy, which is small but persistent. This is partly because in good times, the natural gas price is found to increase in response to the natural gas supply shock.

Although this study is the first, at least best of our knowledge, to estimate the asymmetric reactions of the responses of the US economy to natural gas and oil price shocks, taking the business cycle into consideration, it is nonetheless interesting to compare the results with related studies. Regarding the magnitude of the responses of US economic activity to an oil price shock, our results are more in line with recent empirical studies, such as Hamilton (2003), Hamilton and Herrera (2004), and Bjørnland et al. (2016).



(a) Recession

(b) Expansion

Figure 8: US economic activity responses to one-standard-deviation structural shocks

Note: See Figure 6.

Depending on the sample and model specification, these studies show that following a one-standard-deviation shock to the price of crude oil, which is roughly 10-15 percent, US GDP declines by 0.4-0.8 percent within two years.[9] Our results are not only in line with these previous results, but also provide richer insights. We find that in response to the oil price shocks, US economic activity declines gradually, about 0.8 percent during recessions but only 0.25 percent during expansions. Interestingly, the impact of the natural gas price shock is found to be larger than that of the oil price shock during a recession, about 1.5 percents, but during expansions, the impacts of the natural gas price shock are negligible.

5 Robustness

In this section, we perform additional exercises that examine the robustness of our findings. The main conclusions of the paper remain unchanged after all these robustness checks. Below, we provide a short summary.

First, as we mentioned in Section 3, the price of natural gas is observed in different nodes, from the upstream to downstream markets. We have used the upstream price (wellhead price) as a benchmark price in our model. To address concerns regarding the sensitivity of the selection of the natural gas price, we also estimated the model by using the city gate price. We observed that the main results remained unchanged when using this alternative natural gas price metric, but natural gas production is found to react differently to the city gate price shocks during expansion periods. Although the relationship between natural gas production and the wellhead price shock is not statistically significant, we found a small disruption in natural gas production in response to an unexpected higher city gate price.

Second, in Section 3, we noted that the wellhead price of natural gas data ends in 2012M12; therefore, we extend the series by using the import price of natural gas from 2013M1. We also investigated the sensitivity of our results to this extension. To this end, we estimated the model using a truncated estimation sample, ending in 2012M12. Given that the effective number of observations is smaller, the confidence bounds are greater for the IRFs, particularly in the recession regime. We found that the estimated results were not sensitive to this alternative estimation sample.

[9] We note that, although these studies do not disentangle shocks attributed to driving oil price fluctuations, recent studies, for example Kilian (2009), Aastveit et al. (2015), and Caldara et al. (2016), show that when controlling the underlying sources of crude oil price shocks, the effects are much smaller.

Finally, regarding the series of oil prices, there are two main alternative oil price metrics that have been widely used in the literature: the US refiners' acquisition cost for imported crude oil (IRAC) and the West Texas Intermediate (WTI) price of crude oil. Because it is generally considered to be the best proxy for the free global oil price market (Baumeister et al., 2010), the present paper has used the former price for the benchmark model. When WTI is used, however, we found that the main results based on the VAR model are not sensitive to the change. However, in a nonlinear environment, the IRFs estimated with WTI are less stable during recessions, particularly for the response of natural gas production while the estimated impulse responses in expansions are almost identical to those presented in Section 4.2.

6 Conclusion

In this chapter, we examined the reactions of the US natural gas market to market fundamental shocks in both linear and nonlinear environments. These shocks include the following: the global real oil price shock, the natural gas supply shock, US economic activity shock, and the specific demand shock. We also addressed the important question that whether the US economy responds asymmetrically to the shocks during periods of recession and expansion. We began the analysis by examining the impulse response of the natural gas market and the US economy to these shocks in the linear VAR model. Although the estimated results provide interesting findings, they do not show much regarding the propagation dynamics over the business cycle. We then re-estimated the model by admitting different phases of the US business cycle, that is, recessions and expansions, to see what role they play in the system. We found that the nonlinear setting provides sensible responses as compared to their linear counterparts.

We showed novel evidence that in contrast to the prediction made by conventional VAR models, the STVAR model provides a plausible explanation to the behavior of the US natural gas market, asymmetrically reacting in bad and good times. In particular, the finding of a positive relationship between the oil and natural gas prices is consistent with the findings in Atil et al. (2014), Zamani (2016), and Jadidzadeh and Serletis (2017), but our results indicate this relationship is more prominent in recessions in the short run and in expansions in the long run. Specifically, during recessions, the real price of natural gas strongly responds to the global oil price shock with a more than 6 percent rise in the short run, but then, the impact becomes insignificant in the long run. In contrast, over expansion periods, the oil price shock has significant positive impacts on the price of natural gas even in the long run, increasing it about 3 percent. We further showed that the oil price shock is an important factor driving the production of natural gas; however, the directions of the impact are totally different, depending on economic conditions. More precisely, during a recession, a positive real oil price shock has a negative impact on natural gas production, and the impact is still evident after a year. In contrast, during an expansion, the responses of natural gas production to the same shock are significantly positive in the long run.

In addition, our analysis contributes to the growing literature on the asymmetric impacts of energy price shocks on the US economy. Studies characterizing the nonlinear macroeconomic effects of oil price changes and the US economy can be found in work conducted by, for example, Hamilton (2003) and Baumeister and Peersman (2013). In this paper, we demonstrate that US economic activity is much more sensitive to oil and natural gas price shocks during recessions rather than expansions. An unexpected increase in the real price of crude oil and natural gas have negative effects on the economy during recessions. However, during expansions, natural gas shock have essentially no impacts on the US economy while oil price shocks still have a significant negative effect in the long run; although, the magnitude of the impacts is much less than during recessions. Furthermore, examining the impacts of the natural gas supply shocks, our results provide new evidence that an unexpected decline in natural gas production has a negative effect on the US economy only during expansions.

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