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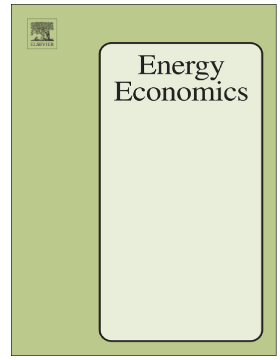

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PII: S0140-9883(20)30421-7

DOI: https://doi.org/10.1016/j.eneco.2020.105081

Reference: ENEECO 105081

To appear in: *Energy Economics*

Received date: 10 June 2020

Revised date: 3 December 2020

Accepted date: 17 December 2020

Please cite this article as: X. Shi and Y. Shen, Macroeconomic uncertainty and natural gas prices: Revisiting the Asian Premium, *Energy Economics* (2018), https://doi.org/10.1016/j.eneco.2020.105081

Macroeconomic uncertainty and natural gas prices: Revisiting the Asian Premium

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This Version： 2020.12.03

Abstract: While macroeconomic uncertainty and its impact on commodity, mainly oil prices, have been frequently studied, there is no study investigating the role of macroeconomic uncertainty in natural gas pricing. To fill this gap, we construct homogeneous macroeconomic uncertainty measures for three major natural gas markets and investigate the dynamic causal effects of macroeconomic uncertainty shocks on the formation of natural gas prices. We show that macroeconomic uncertainty plays a vital role in determining natural gas price variations, in addition to driving business cycle fluctuations in these economies. Compared to oil price, the uncertainty impact on gas pricing is relatively moderate but significant. Market-specific supply and demand analysis shows the drivers of gas prices are substantially different in three different markets, which helps to understand the "Asian Premium" phenomenon in the natural gas trade.

Keywords: Macroeconomic Uncertainty; Drivers of Commodity Prices; Natural Gas; Oil; Asian Premium

Highlights:

- While macroeconomic uncertainty may influence natural gas prices, there is no investigation in the literature.
- Studying of uncertainty and natural gas pricing can inform the ongoing gas pricing transition.
- Macroeconomic uncertainty plays a vital role in determining natural gas prices.
- Decomposition of gas price by supply and demand factors help to understand the "Asian Premium" phenomenon.

1 Introduction

Macroeconomic uncertainty as an essential source of business cycle fluctuations has been intensively studied in the literature since the seminal work of Bloom (2009). Along with the increasing popularity, the impact of uncertainty on commodity, mainly oil prices, has been frequently studied. However, while natural gas is increasingly being commoditized, there is no study investigating the influencing roles of macroeconomic uncertainty on natural gas prices. In this study, we construct homogeneous macroeconomic uncertainty measures for three major natural gas markets and investigate dynamic causal effects of the macroeconomic uncertainty on the formation of natural gas prices, which contribute to understand the "Asian Premium" phenomenon in the natural gas trade.

The diversified natural gas pricing mechanisms provide an excellent case to study the heterogeneous roles of uncertainty in determining gas price variations. Compared with oil pricing, natural gas does not have a single global market. However, the development of liquefied natural gas (LNG) markets and ongoing gas market liberalization make the gas market increasingly integrated (Avalos et al., 2016; Shi et al., 2019b). Due to the fragmentation, natural gas pricing has various forms, and the pricing mechanisms are in transition in many parts of the world. The majority of global traded natural gas was priced on oil prices, that is, oil linkage, or oil indexation. Such oil indexation, however, was replaced by hub prices in the U.S., U.K., and Northwest Europe in the 1980s, 1990s, and 2010s, respectively (EIA, 2017). The pricing transition from oil-indexation to hub prices is on the way in Germany and about to start in East Asia (EIA, 2017; Shi and Variam, 2016).

To fill the gaps, following Jurado et al. (2015), we construct forecast-error-based uncertainty measures for three major natural gas markets (the U.S., Japan, and Germany), and investigate dynamic causal effects of macroeconomic uncertainty shocks on natural gas pricing in these different markets. Three markets represent three different gas pricing mechanisms: the U.S. market for hub pricing, the Japanese market for oil indexation, while the German market for transition between the two pricing regimes. For the baseline results, we set up a structural vector autoregressive model

(SVAR) that incorporates fundamentals, non-fundamentals, and uncertainty, together with gas prices change in an endogenous system. This econometric model is an extension of the framework in Bloom (2009) for investigating uncertainty shocks. We quantify how much these macroecnomic factors contribute to the movements of natural gas prices. Moreover, as pointed out by Kilian (2009), it is crucial to separate the supply and demand factors in investigating the commodity price. Therefore, we also conduct further analysis with the gas market-specific supply and demand framework introduced by Zhang et al. (2018a) to decompose the historical variations in gas prices into different supply and demand components. Our baseline results show that macroeconomic uncertainty plays a vital role in determining commodity prices, along with driving business cycle fluctuations in a particular economy. Our market-specific supply and demand analysis shows the drivers of gas prices are substantially different in three distinct markets, which helps to understand the "Asian Premium" phenomenon in natural gas trade.

Our research contributes to the literature in three ways. First, we fill the research gap by investigating the role of macroeconomic uncertainty in driving natural gas prices movements. While the existing literature on studying the roots of energy price movements focuses on the determinants of oil price movements (e.g. Kilian, 2009; Kilian and Murphy, 2014; Herrera and Rangaraju, 2020), this study extends the literature to cover the natural gas market and hence fills the gap in the literature. Our examination leads to a better understanding of the price formation mechanism of natural gas. Second, we reveal the potential heterogeneity in uncertainty's role in natural gas pricing. Our market-specific supply and demand analysis shows the drivers of gas prices are substantially different in three different markets, which helps to understand the "Asian Premium" phenomenon in natural gas trade. Third, this study constructs homogenous macroeconomic uncertainty indicators for three major industrial countries. More specifically, we extend the forecast-error-based uncertainty measure by Jurado et al. (2015) to build a country-specific uncertainty index for three major gas market players. These measures are applicable in other studies that intend to shed light on the recent fast developing topic of measuring and examining the impacts of uncertainty.

Further investigation of how uncertainty and market fundamentals determine gas prices under different mechanisms can also inform policy development to ensure a smooth transition of the gas pricing mechanisms. An investigation of the role of uncertainty on gas prices can inform the debates about whether uncertainty will play a more important role in the hub pricing regime than the oil indexation regime (Zhang et al., 2018b). One major concern that makes policymakers hesitate to promote the price transition is that hub indexation could be more likely subject to market abuse than oil indexation while the large size of the oil market is less likely to be affected by manipulation and speculations (Komlev, 2016), and the participation of powerful financial players could make gas prices fail to reflect market fundamentals (Shi and Variam, 2016). Although understanding the role of non-market fundamentals in gas pricing mechanisms is essential to make decisions during the pricing transition, there is no study to investigate how macroeconomic uncertainty may have different impacts in different pricing mechanisms.

The paper proceeds as below. The next section briefly summarises the literature. Section three explains the data and empirical strategies. Section four presents the empirical results. The last section concludes the paper with policy implications.

2 Literature review

The relationship between oil price and economic activity is a fundamental issue in macroeconomics. Although findings in the literature show significant variations, it is generally documented that oil price has a significant relationship with real activity in the U.S. and other countries. At least since the first oil crisis in 1973, the macroeconomic effects of oil price fluctuations have been studied extensively (e.g. Barsky and Kilian, 2004; Baumeister and Kilian, 2017; Kilian, 2008, 2014). The impact of oil prices has been extended to diversified categories, notably financial markets, for example, Baumeister and Kilian, (2017), Kilian and Park (2009), Zhang and Ma (2019) and Zhao et al., (2019). At the same time, investigating the determinants of oil price movements has become a popular topic since Barsky and Kilian (2002). Baumeister and Kilian (2016) surveys relevant studies and Kilian and Zhou (2020) surveys the econometrics of oil market models. In the 2000s, substantial oil price volatilities triggered intensive debates in the literature on the possible drivers of oil prices and the role of non-fundamental factors, such as speculation and uncertainty (Fattouh et al., 2013).

Past studies have suggested that uncertainty has played an essential role in determining oil price fluctuations. Some empirical studies suggest that when fundamentals drive price volatility, uncertainty magnifies the price impact of oil supply and demand shocks (Van Robays, 2016; Joëts et al., 2017). One widely discussed channel is that uncertainty changes the decision-making behavior of economic agents (Bernanke, 1983; Litzenberger and Rabinowitz, 1995; Bloom et al., 2007; Miles, 2009), such as production decision delays by oil firms (Favero et al., 1994; Elder and Serletis, 2010; Bredin et al., 2011; Kellogg, 2014). Kilian (2009) was the first study to model precautionary demand based on uncertainty shifts. The study shows that increased precautionary demand for oil triggered by increased uncertainty about future oil supply shortfalls play an important role in the crude oil market. Alquist and Kilian (2010) provides a theoretical model of precautionary demand.

The determinants of natural gas prices are also increasingly been studied. Crude oil price, climate factor, the volume of the natural gas supply, demand, and storage are the main determinants of natural gas prices (Brown and Yücel, 2008; Caporin and Fontini, 2017; Ramberg and Parsons, 2012). In North America, where there is a well-established hub pricing regime, the determinants of natural gas prices have gradually diversified: the role of oil price has been weakened while the prices of alternative energy have become important (Ji et al., 2018). The shale gas revolution, enabled by horizontal drilling and hydraulic fracturing technologies, changes the U.S. and global natural gas markets (Hausman and Kellogg, 2015; Kilian, 2016). The U.S.'s changing role from LNG importer to exporter has extended the influence of Henry Hub prices to the international LNG trade. However, oil prices still have a significant influence on gas hub prices in the European gas markets (Asche et al., 2013). Comparative studies of different gas pricing regimes found that the influence of oil prices on natural gas prices delines when the gas markets become more competitive and over time (Zhang et al., 2018a).

Investigation of the determinants of natural gas prices is increasingly important and has practical implications due to the developing feature of the natural gas markets and gas pricing. Currently, much of the natural gas prices in the world, except North America, Northwest Europe, and Britain, are not pricing by the markets, and in Asia they are predominantly linked to oil prices, that is, oil indexation. Natural gas prices in North America, Northwest Europe, and Britain, are determined by supply and demand fundamentals in the markets, or hub prices. Gas market liberalization and thus the transition from the oil indexation to hub prices is processed in Northeast Asia and a large part of Europe (EIA, 2017; Wang et al., 2020). However, in Asia, the oil linked prices gained a share from 35% in 2005 to 67% in 2018 (IGU, 2019). One issue on the transition from oil indexation to hub prices is "Asian Premium", referring to higher prices in Asia than elsewhere in the natural gas trade. Zhang et al. (2018a) found that oil indexation did contribute to the Asian Premium in natural gas trade, that is, East Asian LNG buyers pay higher prices than the market fundamentals would suggest. Another study argued that the oil indexation would generate abnormal price dynamics, or bubbles since the real fundamental value of natural gas are unknown (Zhang et al., 2018b). However, even in the most competitive gas market, the U.S. gas market, the production and consumption factors only explain less than 15% of gas price variations (Zhang et al., 2018a). Therefore, further investigation on the determinants of natural gas prices is necessary, and the results can inform the gas market liberalization and pricing transition.

Many policymakers are also interested in evaluating the impact of various kinds of uncertainty on natural gas prices. For one reason, producers and consumers will be less assured about prices as hub prices are more volatile than the oil-indexed prices (Shen et al., 2018; Zhang et al., 2018b). These financial uncertainties will affect the whole natural gas supply chain, including production, investment, shipping, financing, and key market players (e.g., producers, consumers, shippers, traders, and financial market players). Another reason is that the gas markets will be gradually financialised in the hub prices pricing (Shi et al., 2019a; Zhang et al., 2017). In these financialised energy markets, speculative trading can cause extreme price movements, or price bubbles (e.g., Hache and Lantz, 2013). This potential negative impact of financialization casts doubt on the pricing transition in the natural gas sector.

Informed by oil price studies, uncertainty may play a significant role in determining natural gas prices. The limited studies of gas pricing reveal a similar pattern in gas and oil markets. For example, a unidirectional linkage from policy uncertainty to commodity returns exists for both crude oil and natural gas (Andreasson et al., 2016). Although all energy commodities are affected by a broad range of uncertainties, the existing literature on uncertainty focuses mostly on the oil market. There is no study investigating the role of macroeconomic uncertainty in determining natural gas prices.

3 Data and Method

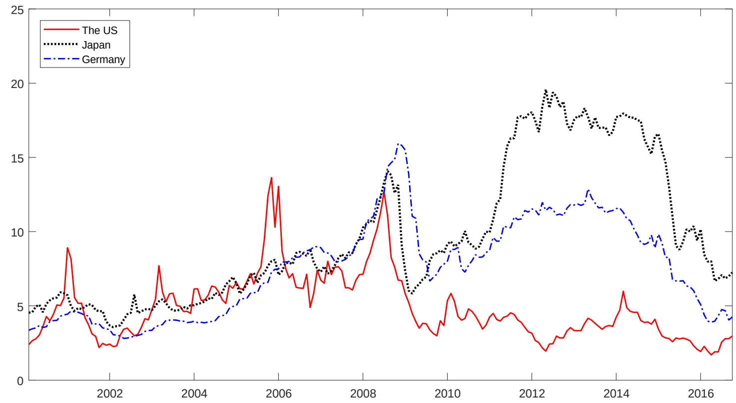
3.1 Data

This paper uses time-series data for the United States, Japan and Germany, which are three major gas consumers in the world and represent three different pricing regimes.The U.S. market is a competitive gas market where gas prices are formulated in gas hubs, while gas prices in the Japanese gas market are mainly indexed to oil prices, and the Geman gas market is a mix of both. See EIA (2017), Shen et al. (2018) and Zhang et al. (2018a) for a review of these different market characteristics.

To construct the country-specific uncertainty measure, we utilize major macroeconomic indicators for each country, which is listed in Table A1 in the appendix. Table A1 also reports the sources and transformation for each series. The series of GDP growth, unemployment rate, inflation rates, and short-term interest rate are also used in the baseline results in Section 4.3 as controls, which follows Bloom (2009). For natural gas prices, the U.S. Henry Hub spot price is used, and Japan's data are Indonesian LNG prices delivered in Japan. These data series were collected from the International Monetary Fund Primary Commodity Prices. The German natural gas price was collected from the World Bank Pick Sheet. The three prices represent different structures of gas markets. The data is in a monthly frequency, from 2000 to 2016.

Fig. 1 plots our sample data of gas prices in different markets. The figure shows that, although prices are not always the same, the pricing patterns are generally consistent before the 2008 Global Finance Crisis (GFC). However, after the crisis, clear departures from these patterns emerge. The departure of the U.S. gas price is likely due to the shale gas revolution (EIA, 2017). The early similarities in pricing patterns in Japan and Germany reflects the fact that natural gas prices are largely indexed to oil prices in these two markets before 2008. After oil indexation was gradually phased out in Europe (e.g., Erdos, 2012; Lin and Li, 2015; Ramberg and Parsons, 2012), the price divergence becomes more obvious. The overshot of the Japanese price may also be related to the 2011 Fukushima nuclear accident that boosted Japan's demand for LNG. The obvious divergence of gas price after 2008 are argued by many as the "Asian Premium" phenomenon (Zhang et al., 2018a), which we will revisit in this study.

Figure 1: Gas price in the U.S., German and Japanese markets



In the market-specific supply and demand analysis of Section 4.4, we follow Zhang et al. (2018a) and include three country-specific demand factors: the constructed macroeconomic uncertainty, the growth rate of natural gas consumption and the growth rate of the gross domestic product (GDP). We also include two country-specific supply factors: the growth rate of net natural gas imports and the growth rate of indigenous production of natural gas in each country. The global real acticity index developed in Kilian (2009) is also used as a proxy for global economic conditions. Oil prices include three benchmark prices: WTI prices in the U.S. market, Brent prices in the German market, and Dubai prices for Japanese LNG. The sources and types of all series are given in detail in Table 1. All variables are converted into growth rates to ensure stationarity conditions for the VAR modelm, expect for Kilian's index.

Table 1. Variables of interest and sources

Notations	Details	Data resource	Factor categories
GAS	Growth rate of gas prices	IMF Primary Commodity Prices & Pink Sheet	NA
OIL	Growth rate of oil prices	IMF Primary Commodity Prices	Market factor
REA	Global real economic activity	Kilian (2009)	General economic condition
PRO	Growth rate of indigenous production of natural gas	IEA monthly statistics	Supply factor
IMP	Growth rate of net import of natural gas	IEA monthly statistics	Supply factor
CON	Growth rate of gas consumption	IEA monthly statistics	Demand factor
UNC	Uncertainty index	Constructed by Authors	Demand factor
GRO	GDP growth	OECD Data: Industrial Production	Demand factor

Notes: All variables are seasonally adjusted with the monthly frequency from 2000 to 2016.

3.2 Construction of macroeconomic uncertainty measure

For the key variable of interest, the macroeconomic uncertainty, we adopt Jurado et al. (2015) 's forecast-error-based uncertainty measure and construct homogeneous macroeconomic uncertainty measures for three major natural gas markets. Based on this, we assess how much the uncertainties contribute to natural gas prices in the three representative pricing regimes, including the U.S., Europe, and East Asia.

A challenge in empirically investigating the behavior of uncertainty and its relation to macroeconomic activities is that there is no objective measure of uncertainty. While most existing uncertainty proxies have the advantage of being directly observable, their adequacy relies on how strongly they are correlated with the latent stochastic process of uncertainty. Jurado et al. (2015) propose a method that measures macroeconomic uncertainty as the conditional variance of the unforecastable component common to a set of macroeconomic variables. This method ensures the econometric estimates of uncertainty as free as possible, both from the structure of specific theoretical models and from dependencies on any single (or small number) of observable economic indicators.

To investigate the dynamic causal effects of macroeconomic uncertainty on the formation of natural gas prices, we simply follow Jurado et al. (2015) to construct the homogeneous macroeconomic uncertainty measures for three major natural gas markets. More specifically, let y_{jt} genetically denote a series that we wish to compute the macroeconomic uncertainty in and whose value in period $h \geq 1$ is estimated from the factor augmented forecasting model,

$$y_{jt+1} = \emptyset_j^y(L)y_{jt} + \gamma_j^F(L)\widehat{F}_t + \gamma_j^W(L)W_t + v_{jt+1}^y, \quad (1)$$

Where $\widehat{F}_t$ is a set of estimated country factors common to all variables in a particular country, and W_t is a set of additional predictors, $\emptyset_j^y(L)$, $\gamma_j^F(L)$, and $\gamma_j^W(L)$ are finite-order polynomials in the lag operator L of orders p_y, p_F and p_W, respectively, and v_{jt+1}^y is an idiosyncratic prediction-error for the series.[1] An important feature of our analysis is that the one-step-ahead prediction error of y_{jt+1}, and of each factor in F_t and W_t is permitted to have time-varying volatility σ_{jt+1}^{y}, σ_{t+1}^{F}, σ_{jt+1}^{W}, respectively. This feature generates time-varying macroeconomic uncertainty in series y_{jt}.[2] The macroeconomic uncertainty, denoted as $\mathcal{U}_{jt}^{y}(h)$, is then the conditional expectation of this time-varying squared forecast error, which is computed using a stochastic volatility model.[3] This model allows for shocks to the second moment of a variable to be independent of the first moment, ensuring that these estimates capture a mean preserving increase in volatility rather than a rise in volatility that accompanies a deterioration in the mean.

To estimate macroeconomic uncertainty for each country, we form weighted averages of individuals uncertainty estimates for each series:

$$\mathbb{U}_t(h) = \sum_{j=1}^{N_y} w_j \mathcal{U}_{jt}^{y}(h). \tag{2}$$

[1] The factors are also allowed to have autoregressive dynamics so that the whole system could be written as a more compact factor augmented vector autoregression (FAVAR) model. For more details, see Jurado et al. (2015).

[2] We follow Jurado et al. (2015) to allow for stochastic volatility in both the estimates of the factors used to augment the VAR and the variables included in the VAR. This results in four sources of time variation in the forecast errors due to the stochastic volatility of the VAR shocks, the factors, the covariance between these two, and an autoregressive term due persistence in the volatility of the VAR shocks. Without stochastic volatility the forecast error would not vary with t but only with h.

[3] We use the STOCHVOL package in R as in Jurado et al. (2015)to estimate the volatilities by which uses Markov Chain Monte Carlo (MCMC) methods. The forecasting residuals are estimated with least squares and those residuals are used to estimate stochastic volatility model where volatility follows an AR(1) process with an intercept term.

A simple weighting scheme is to give each series the same weight. As an alternative, we also adopt a statistical method and construct a latent common factor estimate of macro uncertainty as the first principal component of the covariance matrix of individual uncertainties.[4]

In the empirical section below, the number of $\widehat{F}_t$ is selected by the information criteria proposed in Bai and Ng (2003). Note that our empirical results are robust to the reasonable change of number for these factors. As in Jurado et al. (2015), W_t consists of squares of factors and factors in y_{jt}^2 to capture possible nonlinearity. We include the four lags ($p = 4$) when estimating the baseline model. A careful inspection of residual autocorrelation supports this selection. Besides, including more or less lags would not have a significant impact on our macro uncertainty estimates. To concentrate our analysis, we only report one period ahead of macro uncertainty measures (h = 1), which is also the most commonly discussed and cross-comparable measure in the literature.

3.3 SVAR Framework

In the baseline case, we adopt a standard SVAR framework to analyze the impacts of macro uncertainty shocks on the formation of natural gas prices. More specifically, we follow the framework of Bloom (2009), which subsequently adopted in Jurado et al. (2015), and incorporate energy prices into the model. The model includes four major macroeconomic indicators, such as GDP growth, unemployment rate, inflation rates, and short-term interest rate. The model allows us to investigate the impacts of macroeconomic fundamentals on natural gas price, and has the form listed below,

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[4] These two methods generate very similar results. In the following empirical sections, we report the results based on the factor structure. The results based on simple averaging are available upon request.

$$\begin{bmatrix} Uncertainty \\ Natrual\ Gas\ Price \\ Oil\ Price \\ Interest\ Rate \\ CPI \\ Umemployment \\ GDP\ GRO \end{bmatrix}. \tag{3}$$

Following Bloom (2009) and Jurado et al. (2015), we adopt a recursive method to achieve identification. We assume that uncertainty is allowed to respond to all other variables on impact.[5] We include four lags when estimating the baseline model. The empirical results are robust to reasonable changes in lag orders. After estimating the model, we conduct the standard impulse responses and variance decomposition to analyze the underlying drivers of gas price fluctuations.

We also follow the idea of Killian (2009) and adopt the natural gas specific structural model to analyze the role of macro uncertainty shocks as one kind of demand type factors in driving the natural gas price fluctuations. Kilian (2009) points out the importance of separating the demand and supply factors in understanding the energy price movements. To do so, we estimate impulse-response functions (IRFs) from an 8-variable SVAR model similar to Zhang et al. (2018a):

$$\begin{bmatrix} Uncertainty \\ Natrual\ Gas\ Price \\ Oil\ Price \\ REA \\ PRO \\ IMP \\ CON \\ GDP\ GRO \end{bmatrix}. \tag{4}$$

The types of each variable are listed in Table 1. As in the baseline model, we adopt the recursive method and order uncertainty last to achieve the identification. We adopt four lags when estimating the model.

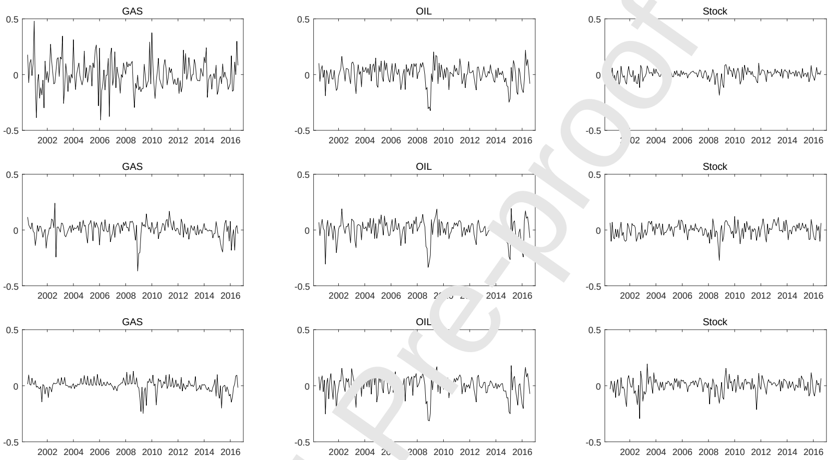
[5] Note that we also experiment the results when ordering uncertainty before oil and natural gas prices. Our findings are robust to this alternative identification scheme. The corresponding results are available upon request.

4 Macroeconomic uncertainty and gas prices: Data and Results

4.1 Natural gas prices in the three markets

Fig. 2 shows the dynamics of gas returns in three major natural gas markets, the U.S., Japan, and Germany. We also plot the oil series and equity return series for comparison. Tab. 2 reports the summary statistics for these series.

Figure 2. Gas, oil and equity returns in three industrial countries



The figure and summary statistics point out the facts of substantial heterogeneity of gas price fluctuations in the three different markets. In particular, the gas price in the U.S. is highly volatile. The standard deviation of 0.136 in the U.S. natural gas market is substantially higher than that in the U.S. oil and equity market. One possible explanation is that gas price is more likely affected by weather, due to power generation and heating, than oil price. However, the standard deviation of gas prices in Japan is 0.073, which is similar to the level of volatility in its oil or equity market, mainly due to indexation to oil prices. The gas price in the German market is relatively stable. Its standard deviation is 0.056, which is significantly lower than that in the oil and equity market.

The summary statistics also report that the gas series in Asia and Europe is left-skewed, which is in line with other financial assets, such as stock and oil. However, the gas in the U.S. is an exception, which is skewed to the right. Meanwhile, all nine series are leptokurtic, implying the risk in investing in these markets and highlighting the importance of identifying the underlying drivers of price fluctuation in these markets.

Table 2. Gas, oil and equity returns in three industrial countries: descriptive statistics

	Gas			Oil			Stock		
	The US	Japan	Germany	The US	Japan	Germany	The US	Japan	Germany
Mean	-0.001	0.002	0.001	0.002	0.003	0.003	0.002	0.000	0.002
Std	0.136	0.073	0.056	0.089	0.088	0.091	0.044	0.058	0.064
Min	-0.407	-0.368	-0.248	-0.324	-0.335	-0.313	-0.186	-0.272	-0.293
Max	0.479	0.240	0.129	0.219	0.192	0.179	0.102	0.121	0.194
Skewness	0.224	-1.261	-1.279	-0.808	-1.144	-0.939	-0.781	-0.722	-0.943
Kurtosis	4.040	7.346	7.057	4.392	5.200	4.120	4.472	4.487	5.837

Tab. 3 further reports the correlation patterns in three markets. The results show a minor correlation among gas markets in the U.S., East Asia, and Europe. These results reflect the status that a global gas market is still under development, the gas price in each region is mainly driven by its regional specific factors. In contrast, the oil markets are highly integrated. The average correlation is above 0.90. The facts confirm oil as the world's most efficient and liquidised financial commodity. The global equity market also shows a substantially integrated pattern. The average correlation is around 0.70, which confirms the financial interdependence of the major world economy after thirty years of rapid globalization.

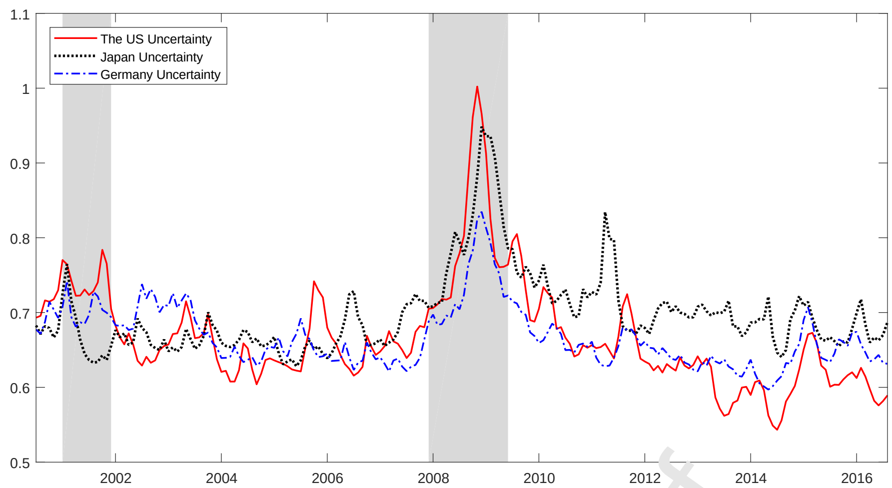
Table 3. Gas, oil and equity returns in three industrial countries: correlation

	Gas			Oil			Stock		
	The US	Japan	Germany	The US	Japan	Germany	The US	Japan	Germany
The US	1.00	0.00	0.19	1.00	0.91	0.93	1.00	0.64	0.83
Japan		1.00	0.17		1.00	0.97		1.00	0.59
Germany			1.00			1.00			1.00

4.2 Country-specific macroeconomic uncertainty measure

We present estimates of our macroeconomic uncertainty measures in Fig. 3, along with the NBER US recession dates (the shadow parts). In general, Fig. 3 shows that macroeconomic uncertainty exhibits a countercyclical pattern to the U.S. business cycle. For example, all three macroeconomic uncertainty measures show spikes around the 2001 dot com bubble recessions and the Great Recession of 2007-2009. Meanwhile, the country-specific macroeconomic uncertainty is sensitive to the major economic events in particular countries. For example, the unexpected 2011 Tohoku earthquake and tsunami hit east coast Japan and caused nuclear accidents at Fukushima, triggering a spike of macroeconomic uncertainty in Japan.

Figure 3. Country-specific macroeconomic uncertainty measure



Notes: We construct the country-specific macroeconomic uncertainty measure by estimating the model introduced in Jurado et al. (2015).

To translate the graphical pattern into a statistical representation, we report the correlations of uncertainty measures in Tab. 4 and summary statistics in Tab. 5. The first point that needs to highlight is the existence of commonality in uncertainty shocks. In particular, the correlation between the U.S. and Japan is 0.612. The correlation between the U.S. and German uncertainty is even higher, reaching the level of 0.814. The results indicate the existence of global components in uncertainty shocks. The rationale is that the major global economic and political events may lead to the commonality of macroeconomic uncertainty across the world, fostering the fluctuations of global uncertainty. Two examples of such events are the Great Recession and recent US-China trade tensions.

Table 4. Uncertainty index: correlation

	The US	Japan	Germany
The US	1.000	0.612	0.814
Japan		1.000	0.509
Germany			1.000

Table 5. Uncertainty index: summary statistics

	The US	Japan	Germany
Mean	0.67	0.70	0.67
Std	0.07	0.06	0.04
Min	0.54	0.63	0.60
Max	1.00	0.95	0.83
Skewness	1.71	2.09	1.31
Kurtosis	7.78	8.43	5.42
Ar(1)	0.95	0.94	0.94
Half Life	14.62	10.43	11.36

Tab. 5 further reports the summary statistics of our uncertainty measures. Tab. 4 also displays the first-order auto-correlation coefficient (Ar(1)), and estimates of the half-life of uncertainty innovations from a univariate auto-regression (Half Life) for each measure. The half-life coefficient reflects the time required for a shock to reduce to half of its initial value, which measures the persistence of the series. Overall, several statistical facts about the estimate of macroeconomic uncertainty stand out in Tab. 5. First, all the uncertainty measure is right-skewed and fat-tailed, which is line with uncertainty measures in other existing literature (e.g. Jurado et al, 2015). Second, the U.S. uncertainty shocks are fairly persistent. The half-life of the U.S. uncertainty is nearly 14 months, which is more persistent to Japanese and German uncertainty measures. In sum, regional uncertainty proxies share some commonalities with each other. However, we also document substantial heterogeneity.

4.3 Baseline model results: natural gas price and macroeconomic fundamentals

We adopt two frameworks to analyze the impacts of uncertainty shocks on the formation of natural gas prices. The baseline results follow the framework of Bloom (2009), which subsequently adopted in Jurado et al. (2015). More specifically, the model treats natural gas as a general commodity and investigates impacts of macroeconomic fundamentals on natural gas price movements.

In below, Fig. 4 presents the impulse response functions (IRFs) given a regional uncertainty shocks. Tab. 5 reports the variance decomposition results. Note that the IRFs of economic indicators such as industrial production, unemployment, and inflation are in line with conventional wisdom.[6] For example, the regional uncertainty shocks are associated with a negative movement in industrial production and inflation, and a positive movement in unemployment. Therefore, in the analysis below, we only focus on macroeconomic uncertainty impacts on natural gas markets, which is also of key interest in this study.

The figure and table deliver some interesting observations.

First, IRFs results show that the regional macroeconomic uncertainty shocks have a negative effect on both oil and gas prices in the U.S. and German market. Compared to oil market, the impacts of uncertainty on natural gas markets are moderate but significant. Moreover, the timing of the responses yields some interesting results. The uncertainty shocks trigger an instant decline in oil prices. In contrast, the responses of the gas market are substantially slower. The U.S. gas price reacts to the uncertainty shocks in 6 months while German prices react in 5 months. The timing patterns reflect the degree of financialization and liquidity in natural gas markets. The responses of Japanese gas prices are an exception. The uncertainty shocks have negligible effects on natural gas pricing, which is in line with the fact that gas price in Asia are highly pegged to oil price.

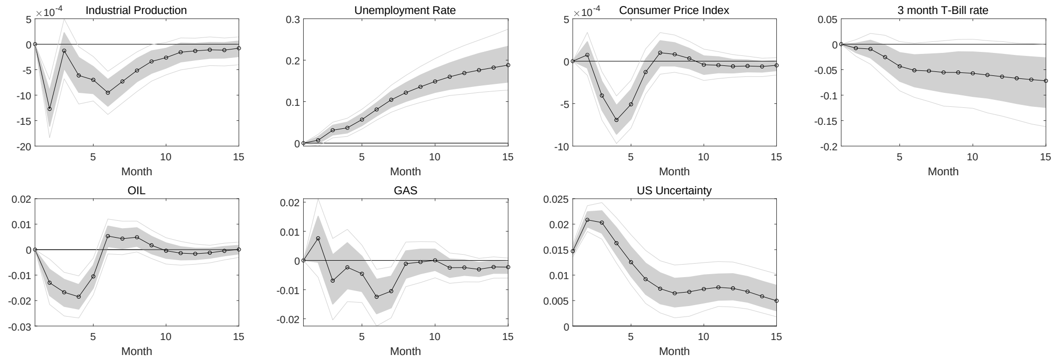
Second, heterogeneities in drivers of price movements are underpinned in different regional natural gas markets. According to variance decomposition results in Tab 5, oil plays an important role in gas price determination in Asia. However, oil effects are relatively moderate in the U.S. and German market. Regional uncertainty shocks have a stronger effects in these two markets, which reflects the facts that the U.S. and Germany, which have more or less adopted market mechanism to price the gas, have the gas market that is more sensitive to changes in economic fundamentals.

[6] Industrial production is used to proxy GDP in a monthly frequency.

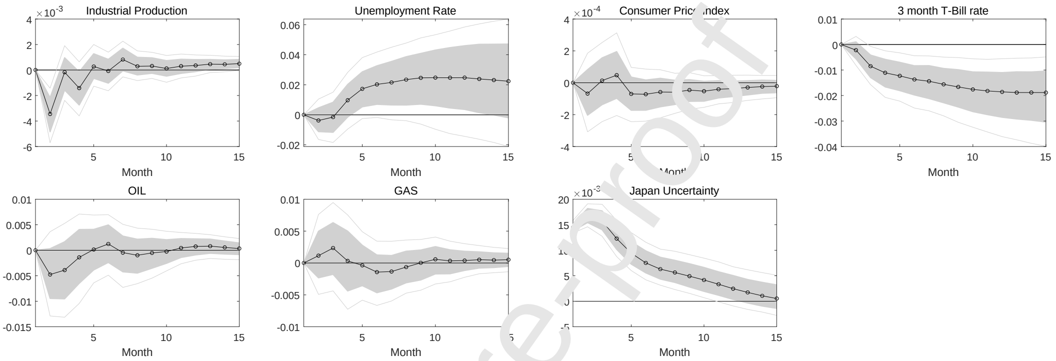
Among all the macroeconomic variables, uncertainty plays a similar role to industrial production in driving the gas price fluctuations in the U.S. All of these findings point out the importance of macroeconomic uncertainty in the energy price formation, cautioning future studies to take uncertainty into account when investigating energy price movements.

Figure 4. Impulse response functions of the uncertainty shcok

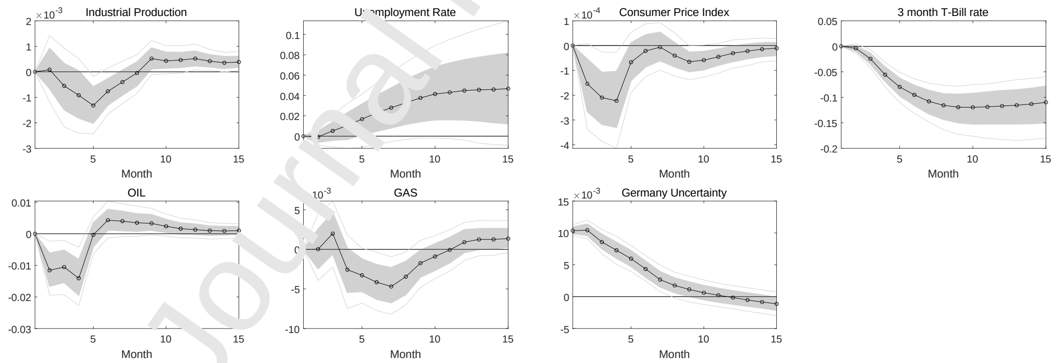
Panel A. The U.S.



Panel B. Japan



Panel C. Germany



Notes: The dotted line represents the IRFs of each variable given a one standard deviation uncertainty shock. Shaded areas and solid lines represent 68% and 95% confidence bands, which are based a recursive-design wild bootstrap with 10,000 replications (see Goncalves and Kilian, 2004).

Table 5. Variance decomposition: natural gas

	IP	Unemployment	CPI	Interest Rate	OIL	GAS	Uncertainty
Panel A. The US							
K=3	1.84%	3.98%	7.13%	3.65%	6.11%	74.13%	1.05%
	(0.74%, 3.74%)	(2.01%, 6.46%)	(4.54%, 10.57%)	(1.98%, 6.38%)	(3.55%, 9.30%)	(69.12%, 79.28%)	(0.29%, 2.46%)
K=12	4.00%	5.50%	8.13%	5.49%	7.43%	63.90%	3.57%
	(2.35%, 6.26%)	(3.53%, 7.96%)	(5.76%, 11.31%)	(3.50%, 8.41%)	(4.73%, 10.29%)	(59.13%, 69.55%)	(2.02%, 5.30%)
K=20	4.10%	5.51%	8.14%	5.59%	7.43%	63.62%	3.69%
	(2.44%, 6.40%)	(3.53%, 7.94%)	(5.80%, 11.32%)	(3.58%, 8.49%)	(4.75%, 10.28%)	(58.70%, 69.18%)	(2.12%, 5.48%)
Panel B. Japan							
	IP	Unemployment	CPI	Interest Rate	OIL	GAS	Uncertainty
K=3	2.64%	1.68%	1.78%	4.34%	24.55%	62.73%	0.58%
	(1.15%, 4.68%)	(0.61%, 3.28%)	(0.75%, 3.40%)	(2.22%, 7.04%)	(19.96%, 29.41%)	(57.96%, 68.15%)	(0.14%, 1.61%)
K=12	4.53%	3.33%	3.76%	5.20%	28.03%	51.73%	1.70%
	(2.56%, 6.51%)	(1.72%, 5.10%)	(2.12%, 5.89%)	(3.02%, 7.83%)	(23.33%, 33.31%)	(46.47%, 57.68%)	(0.77%, 3.11%)
K=20	4.57%	3.52%	3.79%	5.30%	27.92%	51.37%	1.76%
	(2.64%, 6.73%)	(1.97%, 5.50%)	(2.18%, 5.99%)	(3.19%, 7.93%)	(23.30%, 33.20%)	(46.42%, 57.65%)	(0.90%, 3.36%)
Panel C. Germany							
	IP	Unemployment	CPI	Interest Rate	OIL	GAS	Uncertainty
K=3	1.50%	1.85%	7.67%	1.57%	3.93%	80.94%	0.65%
	(0.55%, 3.32%)	(0.72%, 3.77%)	(4.65%, 10.80%)	(0.62%, 3.31%)	(1.87%, 6.85%)	(76.45%, 85.44%)	(0.20%, 1.75%)
K=12	8.22%	3.08%	8.90%	3.20%	14.35%	56.61%	3.60%
	(5.37%, 12.08%)	(1.57%, 5.30%)	(5.63%, 12.28%)	(1.74%, 5.18%)	(10.22%, 18.93%)	(51.07%, 63.20%)	(1.88%, 5.85%)
K=20	8.32%	3.45%	8.85%	3.34%	14.34%	55.81%	3.88%
	(5.60%, 12.25%)	(1.95%, 5.76%)	(5.70%, 12.21%)	(1.94%, 5.41%)	(10.4[illegible]%, 19.16%)	(49.69%, 61.85%)	(2.24%, 6.15%)

Notes: The symbol of 'K' denotes forecasting periods in variance decomposition of gas by each variable. We also report 68% confidence bands in the brackets.

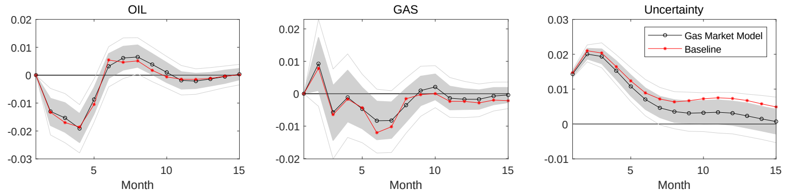
4.4 Alterative model results from a natural gas specific structural model: Revisit the "Asian Premium" in natural gas trade

In this section, we follow the idea of Kilian (2009) and adopt a natural gas specific structural model to analyze the role of uncertainty shocks in the price formation of gas. The work of Kilian (2009) proposes a market-specific supply and demand framework on the oil market and shows the importance of understanding roots of energy price fluctuations. Regarding the gas market, we follow the gas market-specific supply and demand framework introduced by Zhang et al. (2018a).

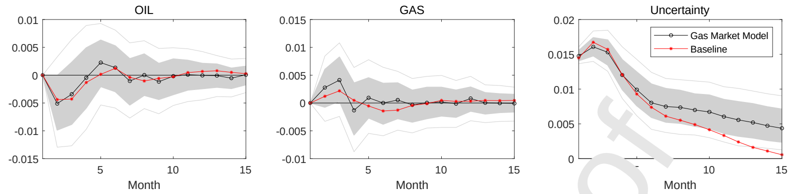
Fig. 5 and Tab. 6 show our baseline results are robust under this alternative gas market specific framework. In particular, the IRFs results show that the regional uncertainty shocks have a negative effect on both oil and gas prices in the U.S. and Germany. Compared to the oil market, uncertainty impacts on the gas market are relatively moderate. Meanwhile, variance decomposition results confirm that uncertainty shocks play an important role in explaining gas price fluctuations in the U.S. and Germany, which is in line with their market structure.

Figure 5. Impulse response functions in a gas market model

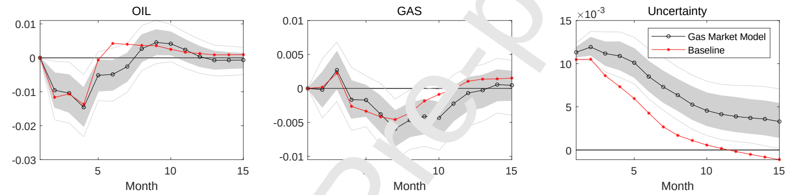
Panel A. The U.S.



Panel B. Japan



Panel C. Germany



Notes: The dotted line represents the IRFs and variance decomposition results. Shaded areas and solid lines represent 68% and 95% confidence bands over 10,000 bootstrap repetitions. We also report the baseline results for comparison.

Table 6. Variance decomposition in a gas market model: Natural gas

Panel A. The US

	IP	CON	IMP	PRO	REA	OIL	GAS	Uncertainty
K=3	2.10%	9.53%	1.78%	4.73%	6.76%	5.71%	65.43%	1.08%
	(0.93%, 4.04%)	(6.39%, 13.23%)	(0.71%, 0.345%)	(2.78%, 7.44%)	(2.37%, 13.45%)	(3.26%, 8.78%)	(59.46%, 71.08%)	(0.28%, 2.53%)
K=12	4.07%	9.16%	4.01%	6.89%	10.50%	6.10%	54.35%	2.67%
	(2.50%, 6.33%)	(6.39%, 12.28%)	(2.40%, 6.35%)	(4.46%, 9.87%)	(5.68%, 16.95%)	(3.78%, 8.92%)	(48.17%, 60.16%)	(1.51%, 4.37%)
K=20	4.33%	9.08%	4.11%	6.86%	11.49%	6.05%	52.81%	2.87%
	(2.69%, 6.76%)	(6.28%, 12.18%)	(2.52%, 6.44%)	(4.49%, 9.92%)	(6.49%, 18.26%)	(3.78%, 8.74%)	(46.71%, 58.67%)	(1.64%, 4.54%)

Panel B. Japan

	IP	CON	IMP	PRO	REA	OIL	GAS	Uncertainty
K=3	2.53%	2.24%	2.44%	1.12%	20.19%	18.12%	50.13%	0.80%
	(1.13%, 4.60%)	(0.91%, 4.26%)	(1.20%, 4.23%)	(0.41%, 2.34%)	(12.44%, 30.01%)	(13.18%, 22.91%)	(44.12%, 57.04%)	(0.22%, 1.90%)
K=12	3.40%	3.77%	3.16%	2.34%	26.55%	19.58%	37.42%	1.66%
	(1.92%, 5.44%)	(2.24%, 5.91%)	(1.79%, 4.80%)	(1.21%, 3.89%)	(17.87%, 35.62%)	(14.52%, 25.09%)	(31.23%, 43.60%)	(0.88%, 2.98%)
K=20	3.45%	3.82%	3.22%	2.48%	27.60%	19.16%	36.13%	1.83%
	(1.94%, 5.47%)	(2.33%, 5.93%)	(1.83%, 4.84%)	(1.33%, 4.03%)	(18.71%, 37.09%)	(14.19%, 24.55%)	(29.97%, 42.49%)	(1.03%, 3.24%)

Panel C. Germany

	IP	CON	IMP	PRO	REA	OIL	GAS	Uncertainty
K=3	1.67%	4.87%	2.07%	1.75%	3.37%	5.62%	77.13%	0.83%
	(0.57%, 3.41%)	(2.65%, 7.85%)	(0.83%, 3.90%)	(0.72%, 3.63%)	(1.11%, 7.83%)	(3.30%, 8.72%)	(71.29%, 82.21%)	(0.20%, 2.13%)
K=12	7.10%	3.86%	2.73%	2.55%	19.92%	13.48%	43.06%	3.72%
	(4.47%, 11.02%)	(2.30%, 6.10%)	(1.55%, 4.39%)	(1.42%, 4.32%)	(11.37%, 31.16%)	(9.65%, 18.66%)	(35.60%, 49.91%)	(1.83%, 6.74%)
K=20	7.10%	3.94%	2.89%	2.70%	21.53%	13.27%	40.73%	4.16%
	(4.39%, 10.93%)	(2.25%, 6.17%)	(1.68%, 4.53%)	(1.53%, 4.54%)	(12.46%, 34.20%)	(9.21%, 18.21%)	(32.21%, 48.43%)	(2.21%, 7.11%)

Notes: The symbol of 'K' denotes forecasting periods in variance decomposition of gas by each variable. We also report 68% confidence bands in the brackets.

Based on the gas market-specific supply and demand framework, we may further implement a similar exercise as in the Kilian (2009), among others, and decompose historical movements in gas prices into different supply and demand components. This decomposition is important and allows us to investigate the drivers of well-acknowledged decoupling of gas prices in different pricing mechanisms, as well as to understand the "Asian Premium" in more detail. A previous study suggests that the Asian Premium in natural gas trade is more likely due to this oil-indexed pricing mechanism rather than market fundamentals (Zhang et al., 2018a). However, there still have nearly a half of variance has not been explored, which is also confirmed in Tab. 6.

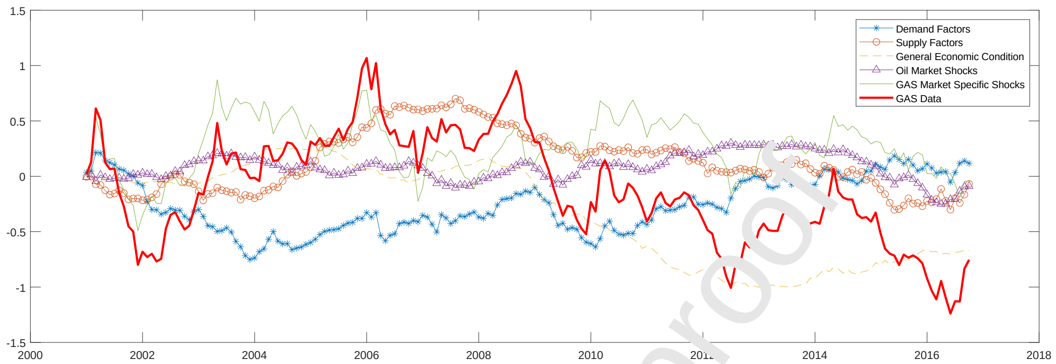
In Fig. 6, we plot the gas prices and its historical decompositions by the supply and demand factors across three markets, as defined in Zhang et al., (2018a) and shown in Tab. 1. The macroecnomic uncertainty is defined as one type of demand factor in driving the natural gas price fluctuations. We further define the unexplained component in gas prices as gas market-specific shocks. Different from Zhang et al. (2018a) that only examined the variance decomposition, this historical decomposition exercise shows the dynamics of different supply and demand factors over time, which delivers further interesting observations.

First, the market fundamentals, that is, the supply and demand factors, play significantly different roles in gas prices for different markets over the time span, confirming the findings in Zhang et al., (2018a). The supply factors play a major role in the long-run gas price fluctuations in the U.S. The trend of the U.S. gas prices is highly correlated to the supply factor, particularly after 2008, which supports the hypothesis that the shale gas revolution has reduced the U.S. gas prices (Geng et al., 2016). Supply and demand factors only play a minor role in the Japanese gas price movements, which can be attributed to its oil-indexed gas pricing mechanisms. In 2017, oil-indexed contracts accounted for 72% of the global total LNG imports (IGU, 2019) while Japan is entirely relying on LNG imports for its gas supply. For the German gas market, the oil market shocks and demand factors are the two most important roots for the long-run gas price movements. The relatively important role of demand factor in German gas prices suggests that gas pricing transition has moved away from oil indexation. However, the German pricing has not reached the full competitive level as in the U.S. In sum, these results reflect the gas pricing mechanism for diffident regions.

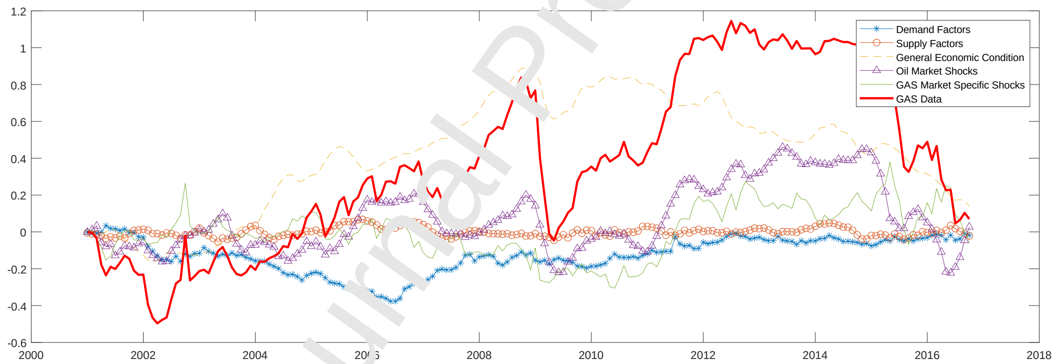
Second, the distinct role of the market factors, that is, oil prices in the Japanese gas prices, support the previous findings that the Asia Premium is more likely due to oil indexation than market fundamentals. However, the unexplained gas market-specific shocks also contribute substantially to the "Asian Premium". Meanwhile, the gas market-specific shocks also account for the short-run movements of gas prices in the U.S. The oil market plays a minor role in U.S. gas prices, which is totally different from the Japanse gas pricing. Oil price shocks are vital to foster the long-run movements in Japanese gas prices. We show that recovery of oil prices can explain nearly half of the surge in gas prices in Japan after the 2008 GFC, while the supply and demand factors play relatively minor roles in determining gas pricing movements. In the competitive U.S. gas market, the oil price factor has little impact on its gas price movements. The divergence of oil price factor and natural gas price in Japanese and German gas prices suggests that gas pricing transition has made progress. The further increasing role of the demand factor in the German prices in 2011, in contrast to its stable role in the Japanese market, varifies that the gas pricing transition proceeded faster in the German market.

Figure 6. Historical decomposition: Natural gas

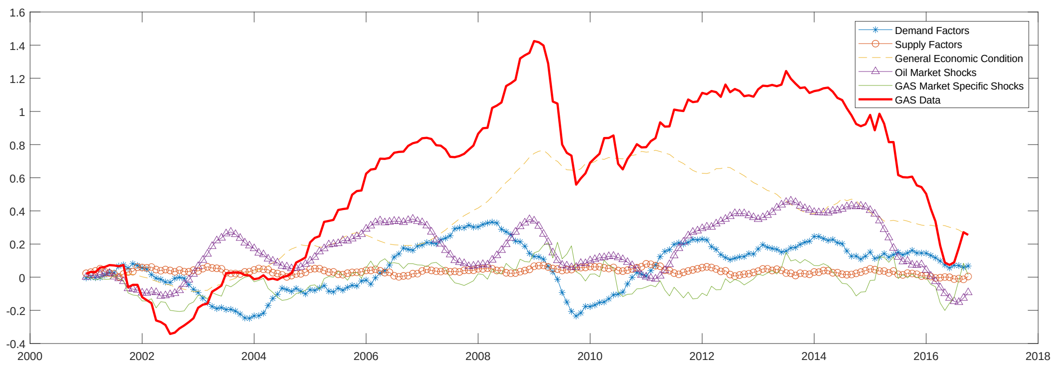
The U.S.



Japan



Germany



Notes: Estimates derived from gas market-specific supply and demand model.

5 Conclusion and policy implications

Macroeconomic uncertainty and its impact on commodity, mainly oil prices, have been frequently studied. However, while natural gas is increasingly being commoditized, there is no study investigating the role of uncertainties in natural gas prices. The diversified natural gas pricing mechanisms provide an excellent case to study the heterogeneous roles of uncertainty in determining gas prices. Studying the impact of uncertainty on natural gas prices has pratical relevance given the ongoing development of the natural gas markets. Further investigation of how uncertainty and market fundamentals determine gas prices under different mechanisms also can inform policy development to ensure a smooth transition of the gas pricing transition.

We construct homogeneous country-specific macroeconomic uncertainty measures for three major natural gas markets and investigate dynamic causal effects of macroeconomic uncertainty on the formation of natural gas prices in the three representative gas markets: the U.S., Japanese and German markets. We show that macroeconomic uncertainty plays an important role in determining natural gas price variations, in addition to driving business cycle fluctuations in these economies. The market-specific supply and demand analysis shows the drivers of gas prices are substantially different in three different markets, while uncertainty plays a significant role in all three prices. Our revisit of the "Asian Premium" phenomenon in natural gas trade verifies the findings in the previous study that the oil-indexed gas pricing mechanism is accountable for the Asian Premium.

Our study has serval important policy implications. First, the natural gas industry and governments need to prepare for the increasing role of macroeconomic shocks after the integration of gas markets and the rise of the number of market players from emerging economies. Emerging economies often have higher uncertainty than developed ones. Therefore, the increasing consumption from emerging economies, such as China and India, will add more uncertainty to the natural gas prices.

Second, Asian markets that are transition from oil indexation to hub prices need to prepare more uncertainty shocks in the future. While East Asian LNG importers use “Asian Premium” as a motivation for Asia to transit their pricing mechanism away from oil indexation (Shi and Variam, 2016), others argue that the higher prices are partially justified by Asian market fundamentals while not pricing discrimination (Zhang et al., 2018a). Our finding that the gas market is sensitive to uncertainty thus suggests that the Asian markets will face more volatility after the transition to hub prices. The primary reason is that in the oil-indexed pricing regime, natural gas is priced as a moving average of oil prices in proceeding months (Grafton et al., 2018; Shi and Variam, 2017) and thus are less uncertain than hub prices.

Last, the transition from oil indexation to a hub pricing regime is desirable. This revisited “Asian Premium” confirms the findings in the previous study that oil indexation partly caused the “Asian Premium”. The significant role of uncertainty in the three natural gas prices, especially in the competitive U.S. prices, however, suggests that non-market fundamental factors will still influence hub prices. The low oil prices caused by COVID-19 create a conducive environment for the pricing transition as the consequently low indexed prices make the transition acceptable to LNG producers (Shi and Variam, 2017).

We should note that taking uncertainty into account only improves our understanding on the natural gas price fluctuations, but cannot fully explain it. In particular, the unexplained gas market specific components surges during the sample period in Japan, making the “Asia Premium” phenomenon still a puzzle for us. Meanwhile, the gas market specific components are also an important driver for the short-run gas price movements in the U.S. These facts show that the unexplorable components still play a significant role in the gas price changes and suggest that further studies on the driving forces of gas prices are necessary.

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Appendix

Table A1: Data Source

Panel A. US			
Order	Variable	Detrend	Scource
1	Industrial Production	LD	FRED
2	Producer Price Index	LD	FRED
3	Consumer Price Index	LD	FRED
4	Hours	LD	FRED
5	Unemployment Rate	N	FRED
6	Wage	LD	FRED
7	Exports	LD	FRED
8	Imports	LD	FRED
9	Short term Interest Rate	N	FRED
10	Long term Interest Rate	N	FRED
11	M2 Money Stock	LD	FRED
12	Stock Index	LD	Bloomberg
13	Real Effective Exchange Rate	LD	FRED

Panel B. Japan			
Order	Variable	Detrend	Scource
1	Industrial Production	LD	FRED
2	Producer Price Index	LD	FRED
3	Consumer Price Index	LD	FRED
4	Hours	LD	FRED
5	Unemployment Rate	N	FRED
6	Wage	LD	FRED
7	Exports	LD	FRED
8	Imports	LD	FRED
9	Short term Interest Rate	N	FRED
10	Long term Interest Rate	N	FRED
11	M2 Money Stock	LD	FRED
12	Stock Index	LD	Bloomberg
13	Real Effective Exchange Rate	LD	FRED

Panel C. Germany			
Order	Variable	Detrend	Scource
1	Industrial Production	LD	FRED
2	Producer Price Index	LD	FRED
3	Consumer Price Index	LD	FRED
4	Hours	LD	NA
5	Unemployment Rate	N	FRED
6	Wage	LD	NA
7	Exports	LD	FRED
8	Imports	LD	FRED
9	Short term Interest Rate	N	FRED
10	Long term Interest Rate	N	FRED
11	M2 Money Stock	LD	FRED
12	Stock Index	LD	Bloomberg
13	Real Effective Exchange Rate	LD	FRED

Notes: "LD" refers to the log difference. "N" refers to no transformation for the original data.

Macroeconomic uncertainty and natural gas prices: Revisiting the Asian Premium

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This Version： 2020.12.03

Abstract: While macroeconomic uncertainty and its impact on commodity, mainly oil prices, have been frequently studied, there is no study investigating the role of macroeconomic uncertainty in natural gas pricing. To fill this gap, we construct homogeneous macroeconomic uncertainty measures for three major natural gas markets and investigate the dynamic causal effects of macroeconomic uncertainty shocks on the formation of natural gas prices. We show that macroeconomic uncertainty plays a vital role in determining natural gas price variations, in addition to driving business cycle fluctuations in these economies. Compared to oil price, the uncertainty impact on gas pricing is relatively moderate but significant. Market specific supply and demand analysis shows the drivers of gas prices are substantially different in three different markets, which helps to understand the "Asian Premium" phenomenon in the natural gas trade.

Keywords: Macroeconomic Uncertainty; Drivers of Commodity Prices; Natural Gas; Oil; Asian Premium

Credit author statement

Two authors contribute equally to this project. Shi provides the initial ideas. Shen is responsible for the empirics. The authors conduct the writing part together.

Shi Xunpeng and Shen Yifan

2020.12.03

Macroeconomic uncertainty and natural gas prices:

Revisiting the Asian Premium

Highlights:

- While macroeconomic uncertainty may influence natural gas prices, there is no investigation in the literature.
- Studying of uncertainty and natural gas pricing can inform the ongoing gas pricing transition.
- Macroeconomic uncertainty plays a vital role in determining natural gas prices.
- Decomposition of gas price by supply and demand factors help to understand the "Asian Premium" phenomenon.

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