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Business Cycles and Hydrocarbon Gas Liquids Prices

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Business Cycles and Hydrocarbon Gas Liquids Prices

by

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Abstract

This thesis examines the basic stylized facts of hydrocarbon gas liquids (HGL) prices using monthly data for the United States, over the period from 1985:1 to 2018:1. I follow the Kydland and Prescott (1990) methodology, using the Hamilton's (2017) regression filter to investigate the cyclical properties of HGL prices. The results indicate that HGL prices are procyclical and mostly lead the cycle of industrial production. HGL prices are also positively contemporaneously correlated with crude oil and natural gas prices and are synchronous with the cycle of crude oil and natural gas prices. I also find that industrial production causes natural gas and HGL prices, where, normal butane, isobutane, and crude oil prices cause industrial production. Moreover, I find that crude oil prices cause all HGL prices. Finally, there is no causality from natural gas prices to HGL prices, however, there is causality from ethane, normal butane, and naphtha prices to natural gas prices.

JEL classification: C32, E32, Q4.
Keywords: Business cycles; Hydrocarbon gas liquids prices, Stylized facts; Hamilton filter; Hodrick-Prescott (HP) filter, Granger causality tests.

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Chapter 1

Introduction

In the field of macroeconomics and financial economics, the cyclical behavior of energy prices has important implications for economic activity. In recent years, the rapid growth of onshore natural gas and crude oil production in the United States has led to increasing the volumes of hydrocarbon gas liquids (HGL) production. These increasing volumes of hydrocarbon gas liquids production have a large scale economic importance as HGL are both fuel and feedstock in various markets. Traditionally, hydrocarbon gas liquids – include ethane, propane, normal butane, isobutane, and naphtha – have accounted for only minor importance in global energy markets. Oglend (2015) mentioned the literature is too much focused towards the relationship between oil and natural gas markets instead of paying adequate attention to other important petroleum products, and their relationship with the real economic activity, as well as with the oil and the natural gas markets.

For the first time in the literature, this paper investigates the basic stylized facts of hydrocarbon gas liquids (ethane, propane, isobutane, normal butane, and naphtha) prices movements using monthly data for the United States, over the period from January 1985 to January 2018. I also systematically examine the causal relationship between the hydrocarbon gas liquids, crude oil, and natural gas prices and industrial production.

In the second chapter, following the methodology suggested by Kydland and Prescott (1990), and using Hamilton's (2017) regression filter, I investigate cyclical behavior of the variables. The results suggest that hydrocarbon gas liquids prices are procyclical and mostly lead the cycle of industrial production in the United States. In addition, hydrocarbon gas liquids prices are positively contemporaneously correlated with the crude oil and natural gas prices and are synchronous with the cycle of the crude oil and the natural gas prices. The robustness of my results is tested by using the alternative Hodrick and Prescott filter (1981, 1997).

In chapter three, for the same monthly United States data, I examine Granger causal relationships between the hydrocarbon gas liquids, crude oil, and natural gas prices and industrial production. My results show that there exists a unidirectional causal relationship between the hydrocarbon gas liquids, crude oil and natural gas prices and the industrial production, except for propane. I find that industrial production causes the natural gas prices as well as the prices of ethane and naphtha. I also find that the normal butane, isobutane, and crude oil prices cause industrial production. Further, I find unidirectional causality between natural gas prices and crude oil prices, and crude oil prices cause all the HGL prices. Finally, there are causality from ethane, normal butane and naphtha prices to natural gas prices, but there is no causality from natural gas prices to hydrocarbon gas liquids prices.

The final chapter provides a brief conclusion.

Chapter 2

The Cyclical Behavior of Hydrocarbon Gas Liquids Prices

2.1 Introduction

In macroeconomics, one of the fundamental empirical issues is the relationship between the price of oil and economic activity. In recent years, the rapid growth in onshore natural gas and crude oil production in the United States has led to increasing volumes of hydrocarbon gas liquids production. These increasing volumes of hydrocarbon gas liquids (henceforth, HGL) production have a large scale economic importance as HGL are both fuel and feedstock in various markets. The seasonal and regional fluctuations in energy prices affect investment and production decisions throughout the different sectors of the economy. Thus, the cyclical behavior of HGL prices has important implications in the field of macroeconomics and financial economics, as HGL prices are correlated with production costs and hence directly affect the prices of goods and services in the economy.

Based on how energy prices changed over the past century, Hamilton (2011) suggested five main periods of interest: 1859–1899, 1900–1945, 1946–1972, 1973–1996, and 1997–present. He named the period 1973-1996 as ‘the age of OPEC’ and the period from 1997-present as ‘a new industrial age’. The new industrial age is significantly important in recent research, as in this period the world economy has experiencing tremendous growth especially in the major emerging markets such as, for example, China and India. This growth led to a significant increase in the real oil price. In this paper, I focus on the period after 1973 and investigate whether HGL prices in the United States are procyclical, countercyclical, or acyclical. I also examine the cyclical behaviour of HGL prices with crude oil and natural gas prices.

According to traditional economic theory, crude oil prices, and other energy prices are linked to both demand and supply. Therefore, investigating the cyclical behavior of energy prices is a challenging measurement issue in macroeconomics, and over the years, researchers have used a variety of techniques to investigate the cyclical properties of energy prices. Using pre-1972 data, and based on vector autoregression (VAR) analysis, Hamilton (1983) concluded that energy prices are countercyclical and lead the cycle. Afterward, using the Kydland and Prescott (1990) methodology, and the data for the period when energy has been traded on organized exchanges, Serletis and Kemp (1998) showed that energy prices are in general procyclical. More recently, using stationary Hodrick and Prescott (1981, 1997) and Baxter and King (1999) cyclical components, Serletis and Shahmoradi (2005) found that natural gas prices are also procyclical and lag the cycle of industrial production.

According to an Energy Information Administration (EIA) report in 2017, hydrocarbon gas liquids prices are related to crude oil and natural gas prices. According to the report, in terms of dollars per million British thermal unit (Btu), the U.S. spot prices of natural gas and crude oil were closely related until 2009. Moreover, the U.S. spot prices for propane and West Texas Intermediate (WTI) crude oil prices are generally strongly positively correlated. Although there exists a vast literature investigating the effects of oil prices on the real economy, there are relatively few studies that examine the effect of HGL prices on the level of economic activity and their relationship to crude oil and natural gas prices. In this regard, recently Jadidzadeh and Serletis (2018) provide evidence that HGL prices can be explained by structural demand and supply shocks in the global crude oil market.

In this paper, I use the methodology suggested by Kydland and Prescott (1990) and investigate the cyclical properties of HGL prices. In doing so, I use Hamilton's (2017) new regression filter, but also investigate the robustness of my results to alternative detrending methods and in particular to the use of the Hodrick and Prescott (1981, 1987) filter.

The paper is organized as follows. Section 2 provides some background regarding the North American hydrocarbon gas liquids market. Section 3 discusses the data and provides some graphical representations. Section 4 presents the methodology and Section 5 the empirical results. Section 6 provides a robustness investigation, and the final section concludes the paper.

2.2 Background

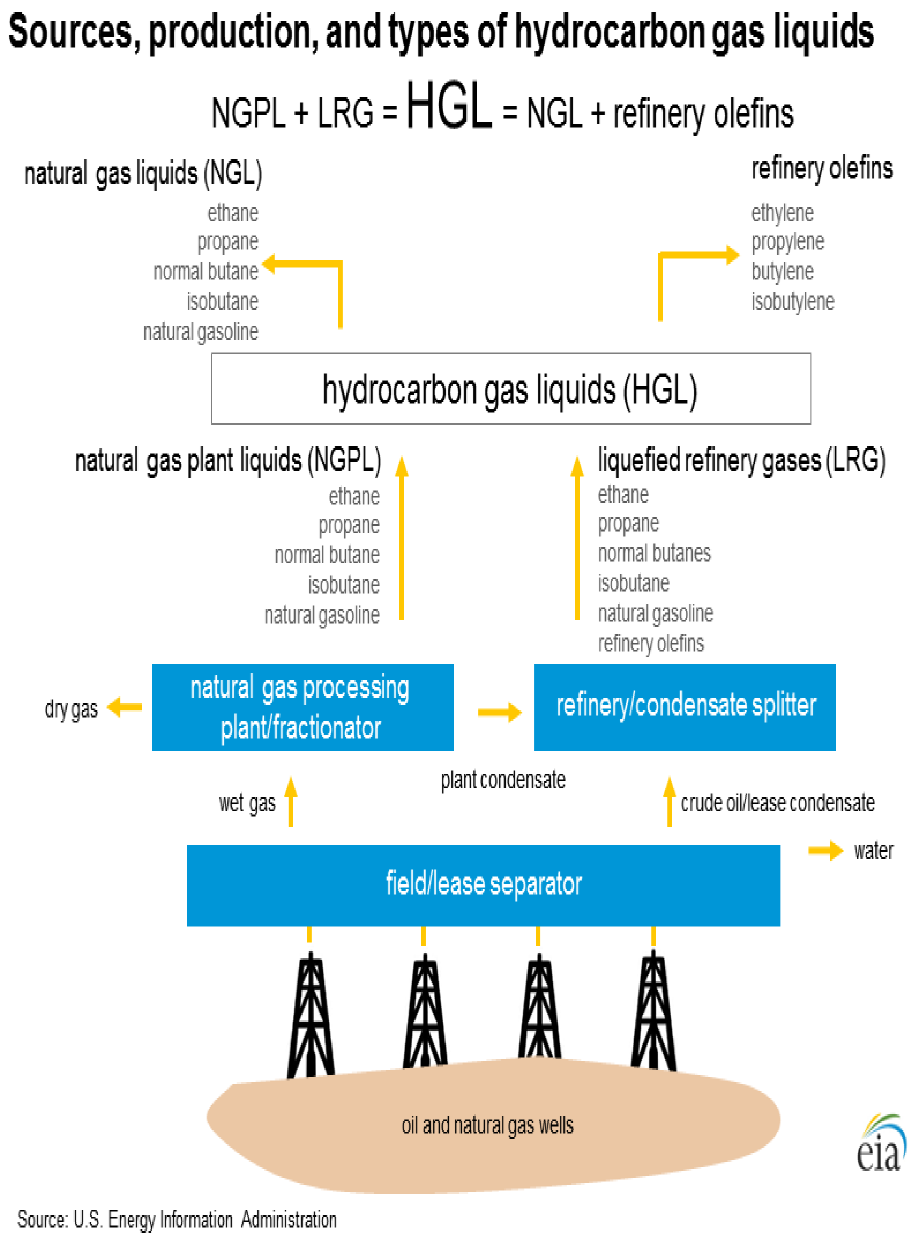
Hydrocarbon gas liquids are derived from processed raw natural gas and refined crude oil. In the United States, since 2010, most of the HGL are produced from natural gas at natural gas processing plants. Hydrocarbon gas liquids include natural gas liquids (NGLs), such as propane, ethane, butanes, and pentane plus, i.e. naphtha. Further, butanes can be divided into two broad types, normal butane and isobutane. Figure 2.1 provides a taxonomy of supply, demand, and chemistry of HGL by the U.S. Energy Information Administration.

Hydrocarbon gas liquids are used in almost every sector, such as residential, commercial, industrial (e.g. manufacturing and agriculture), transportation, and electric power. In 2016, 13% of total U.S. petroleum consumption consisted of HGL products [see EIA report (2017)]. It is seen that hydrocarbon gas liquids prices are related to natural gas and crude oil prices, as well as to their demand and supply conditions. Historically, the U.S. spot prices of natural gas and crude oil have been closely related. Moreover, the spot price of WTI crude oil and the U.S. spot price of propane generally track closely. Based on the general assumption that most fuels are interchangeable, these historical price relationships reflect international consumption trends, but they also reflect demand and supply conditions in the respective markets.

The level of economic activity can be affected by energy prices through several channels or transmission mechanisms. In their business cycle models, Kim and Loungani (1992), Rotemberg and Woodford (1996), and Finn (2000) argue energy prices may affect economic activity through their effects on the productivity of labor and capital. There are also many empirical studies regarding the macroeconomic effects of energy prices, especially after the 1973 and 1979 oil price shocks. See, for example, see Burbidge and Harrison (1984), Mork (1989), Hooker (1996), Hamilton (1983, 2003), Kilian (2009), Lee *et al*. (1995), Lee and Ni (2002), and Elder and Serletis (2010), among others.

In this paper, my objective is to investigate the cyclical behavior of crude oil, natural gas, and (for the first time) HGL prices, using monthly data for the United States, over the period from January 1985 to January 2018, and the new Hamilton (2017) regression filter to decompose the series into trend and cyclical components.

Figure 2.1. Taxonomy of Hydrocarbon gas liquids (HGL)



2.3 The Data

I study monthly time series data for the United States, over the period from January 1985 to January 2018 (a total of 397 observations). I use the North American spot purity ethane price and the North American spot liquefied petroleum gas (LPG) propane, butane, isobutene, and naphtha prices (all in dollars per gallon), as compiled by Bloomberg. I also use the Henry Hub natural gas spot price, as compiled by Bloomberg. For crude oil, I use the West Texas Intermediate crude oil spot price, compiled by the U.S. Energy Information Administration (EIA).

To investigate the cyclical behavior of the HGL prices as well as of the natural gas and crude oil prices, I use the U.S. Industrial Production Index (IPI), obtained from the Federal Reserve Economic Data (FRED) database maintained by the St. Louis Fed. In doing so, I follow a large number of other studies --- such as, for example, Bernanke *et al*. (1997), Lee and Ni (2002), Hamilton and Herrera (2004), Edelstein and Kilian (2009), Elder and Serletis (2011), Rahman and Serletis (2011), and Serletis and Istiak (2013) --- that also use the Industrial Production Index as a proxy of the level of real economic activity in the United States.

Figures 2.2-2.9 show the logged level (on the Y_1 axis) and the growth rates (on the Y_2 axis) for each of the series, with shaded areas indicating NBER recessions, and Figure 10 shows the historical evolution of the crude oil, natural gas, and the HGL prices over the sample period.

2.4 The Methodology

I use the recently introduced, by Hamilton (2017), new method for extracting the cyclical component from a time series. With monthly data (as in my case), for an observed nonstationary time series, Y_t, Hamilton (2017) suggests an OLS regression of Y_t against four lags of itself shifted 24 periods back, as follows

$$\mathcal{Y}_t = \beta_0 + \beta_1\mathcal{Y}_{t-24} + \beta_2\mathcal{Y}_{t-25} + \beta_3\mathcal{Y}_{t-26} + \beta_4\mathcal{Y}_{t-27} + \nu_t.$$

The regression residuals, $\hat{\nu}_t$, provide the cyclical (or stationary) component of the series

$$\hat{\nu}_t = \mathcal{Y}_t - \hat{\beta}_0 - \hat{\beta}_1\mathcal{Y}_{t-24} - \hat{\beta}_2\mathcal{Y}_{t-25} - \hat{\beta}_3\mathcal{Y}_{t-26} - \hat{\beta}_4\mathcal{Y}_{t-27}.$$

I then describe the empirical regularities of HGL prices (and also crude oil and natural gas prices) using the Kydland and Prescott (1990) methodology. In particular, after I apply the Hamilton (2017) filter to obtain cyclical components, I investigate whether the cyclical components of HGL prices (and crude oil and natural gas prices) are correlated, and at what leads and lags, with the cyclical component of the Industrial Production Index.

I measure the degree of cyclical comovement by the magnitude of the correlation coefficient

$$\rho\ (X_t, Y_{t+j}),\ for\ \ j = -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12.$$

with all the variables being in logarithms. $\rho(X_t,Y_t)$ gives information on the degree of contemporaneous comovement. In particular, if $\rho(X_t,Y_t)$ is positive, I say that the series X_t is procyclical, if $\rho(X_t,Y_t)$ is negative, I say that X_t is countercyclical, and if $\rho(X_t,Y_t)$ is zero, I say that X_t is acyclical. Also, the cross correlation coefficient, $\rho\ (X_t,Y_{t+j})$ for $j \neq 0$, gives information on the phase shift of the series X_t. In particular, if the absolute value of $\rho\ (X_t,Y_{t+j})$ is maximum for a positive, zero, or negative j, I say that X_t is leading the cycle by j periods, is synchronous, or is lagging the cycle by j periods, respectively.

2.5 Empirical Results

In Table 2.1 I report the contemporaneous and cross-correlation coefficients between the cyclical components of HGL prices, crude oil prices, and natural gas prices and the cyclical component of U.S. industrial production (all obtained using Hamilton's (2017) regression filter), at lags and leads of 1, 2, 3, 6, 9, and 12 months between. A value of ρ near 1 in the j = 0 column indicates strong procyclical movements and a value near -1 indicates strong countercyclical movements. The ρ values in the remaining columns indicate the phase shift relative to industrial production index.

As can be seen in Table 2.1, HGL prices are procyclical. Moreover, the cycles of propane, normal butane, and isobutane are synchronous with the cycle of industrial production, whereas ethane, naphtha, crude oil, and natural gas lead the cycle. These results are consistent with the evidence in Serletis (1994), Serletis and Kemp (1998), and Serletis and Shahmoradi (2005).

In Table 2.2, I report cyclical correlations, in the same fashion as in Table 2.1, of HGL prices and natural gas prices with the crude oil price. The results indicate that the contemporaneous correlation is strikingly positive and strong in all six cases of ethane, propane, normal butane, isobutane, naphtha, and natural gas. Moreover, the HGL and natural gas prices are all synchronous with the crude oil price cycle.

Finally, in Table 2.3, I report cyclical correlations, in the same fashion as in Tables 2.1 and 2.2, of HGL prices with the natural gas price. The results indicate that the contemporaneous correlation is positive and strong in all five cases of ethane, propane, normal butane, isobutane, and naphtha, and that the HGL prices are all synchronous with the natural gas price cycle.

In Figures 2.11-2.17 I show the cyclical behavior of the U.S. industrial production index and each of the HGL prices as well as the crude oil and natural gas prices, over the sample period (from January 1985 to January 2018). Moreover, in Figures 2.18-2.20 I show the contemporaneous correlations (in descending order) between the cyclical components of the HGL prices and the cyclical component of U.S. industrial production (see Figure 2.18), the crude oil (see Figure 2.19), and the natural gas price (see Figure 2.20).

2.6 Robustness

To investigate the robustness of my results to the use of alternative filters for extracting the cyclical component, I use the HP filter and present contemporaneous and cross-correlation coefficients in Appendix Tables 2.1-2.3, in the same fashion as those in Table 2.1-2.3. I also present the cyclical behavior of the U.S. industrial production index and each of the HGL prices as well as the crude oil and natural gas prices, in Appendix Figures 2.1-2.7, in the same fashion as those in Figures 2.11-2.17. The evidence in Appendix Tables 2.1-2.3 and Appendix Figures 2.1-2.7 is consistent with that presented earlier based on the use of the Hamilton (2017) filter.

2.7 Conclusion

In this paper, and for the first time in the literature, I investigate the cyclical properties of HGL prices, using monthly data, over the period from January 1985 to January 2018, and the methodology suggested by Kydland and Prescott (1990). Based on the new Hamilton (2017) regression filter, my main result is that HGL prices are procyclical and lead the cycle of industrial production. Also, HGL prices are positively contemporaneously correlated and synchronous with the WTI crude oil price cycle. Moreover, HGL prices are synchronous with the Henry Hub natural gas prices. My results are robust to the use of the traditional Hodrick-Prescott filter.

Figure 2.2 Logged Industrial Production and Its Growth Rate

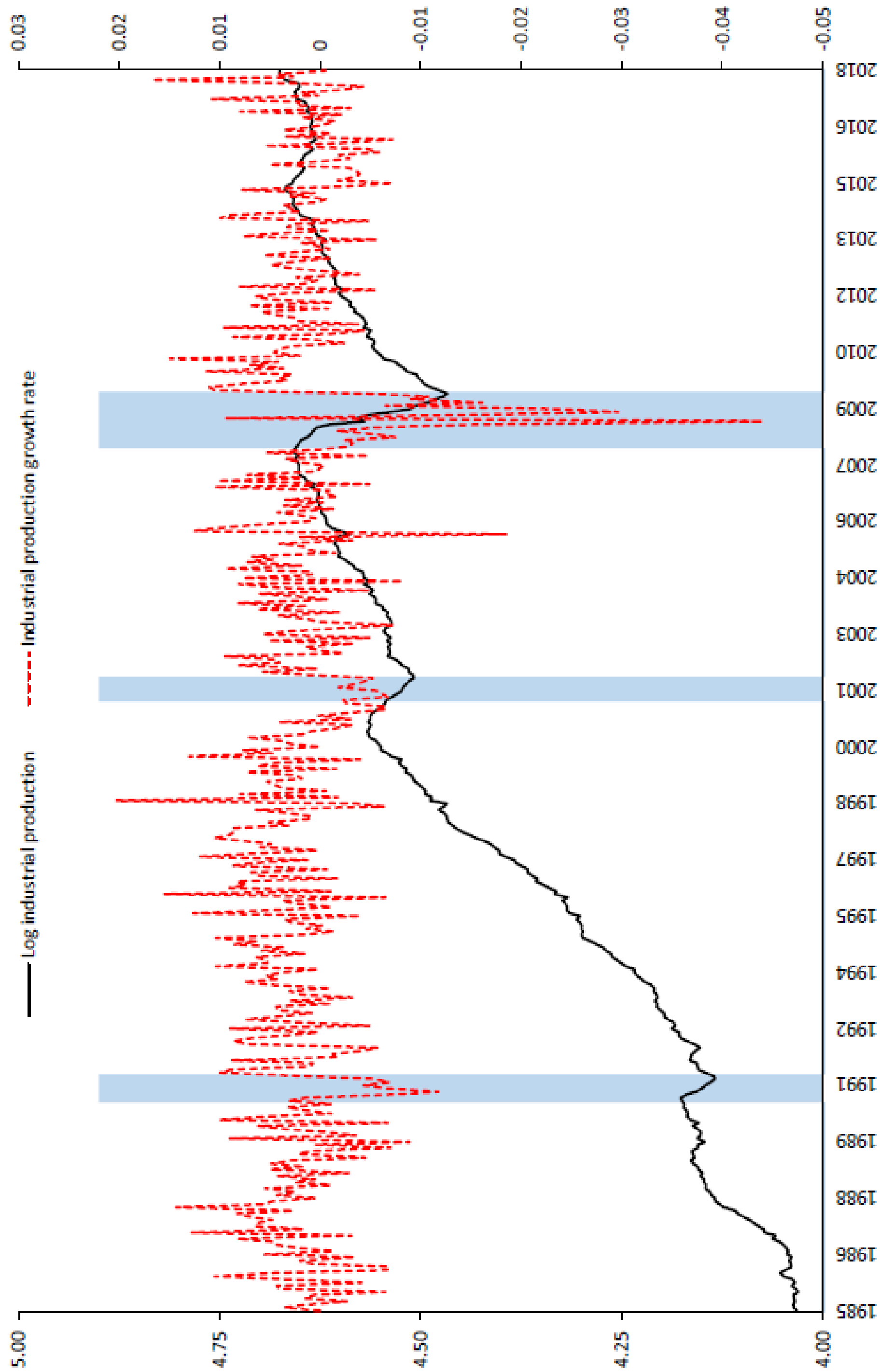


Figure 2.3 Logged Ethane Price and Its Growth Rate

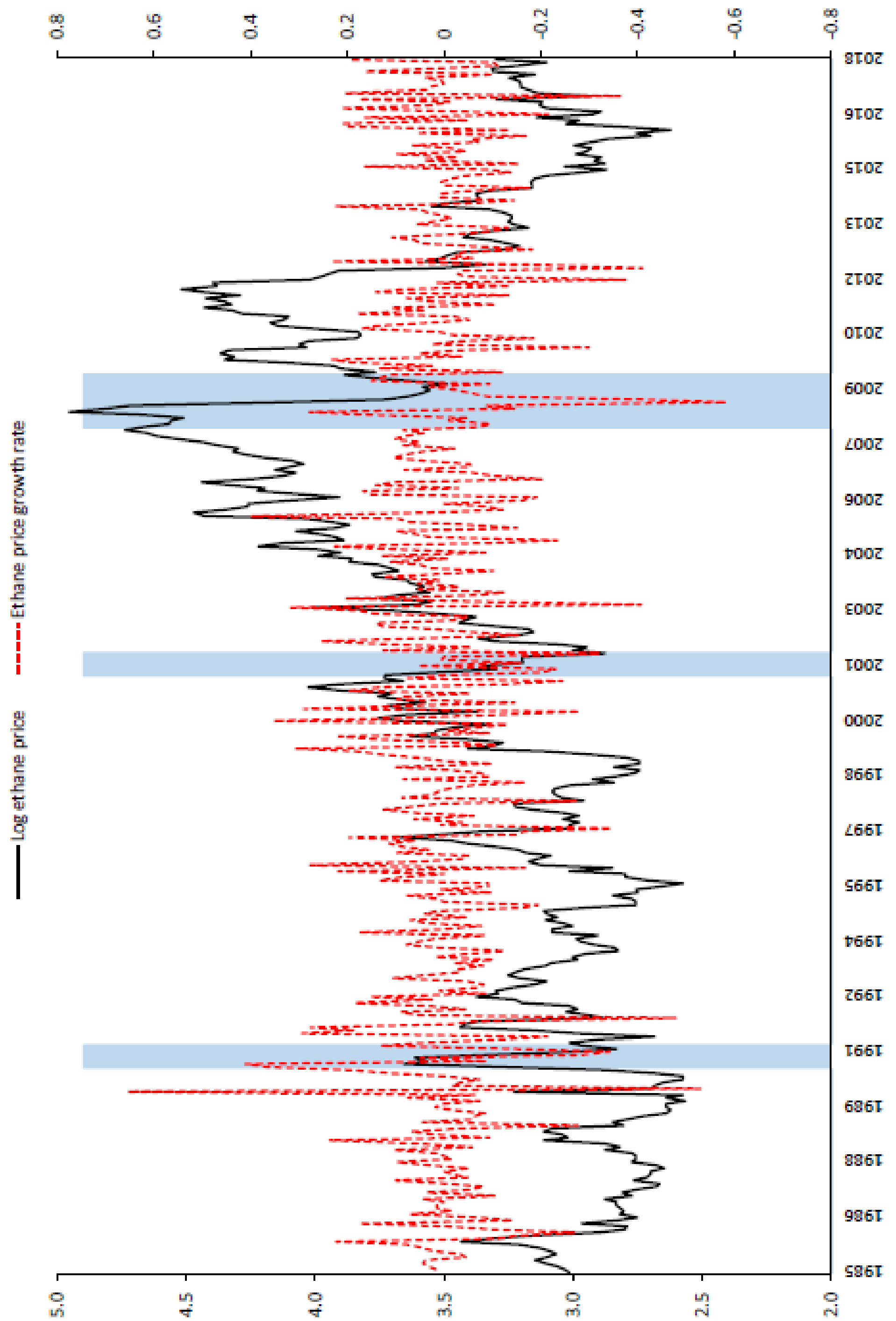


Figure 2.4 Logged Propane Price and Its Growth Rate

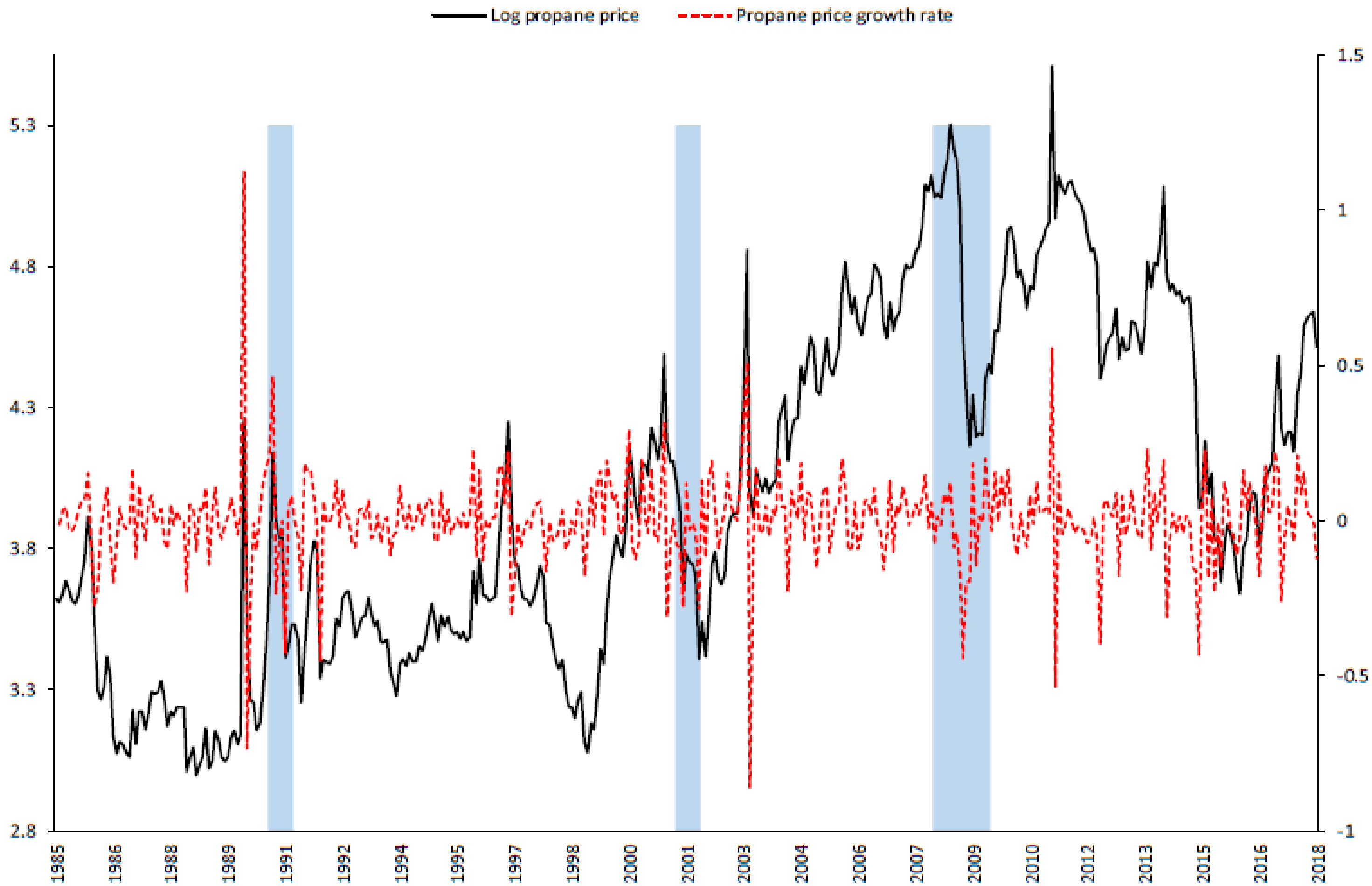


Figure 2.5 Logged Normal Butane Price and Its Growth Rate

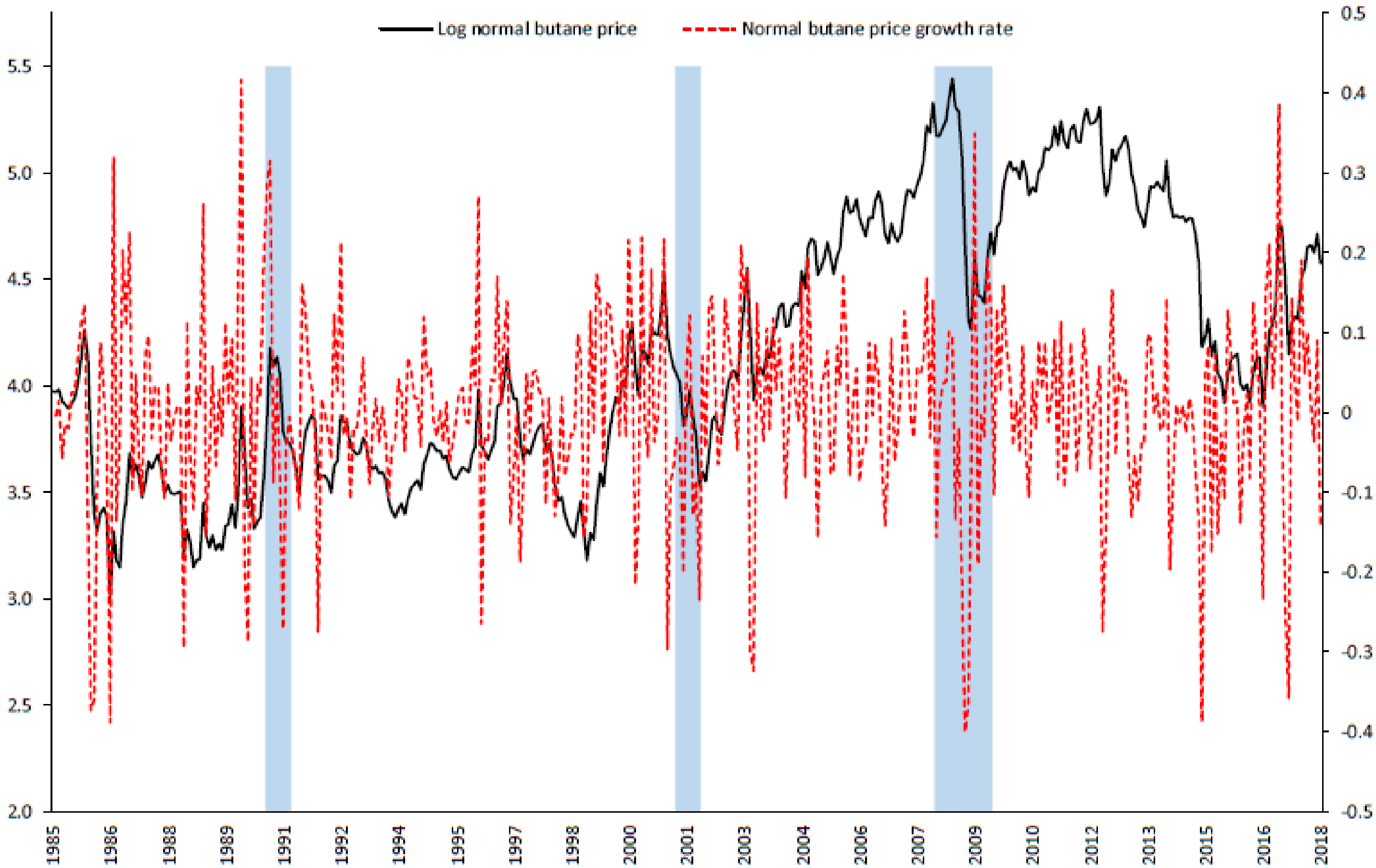


Figure 2.6 Logged Isobutane Price and Its Growth Rate

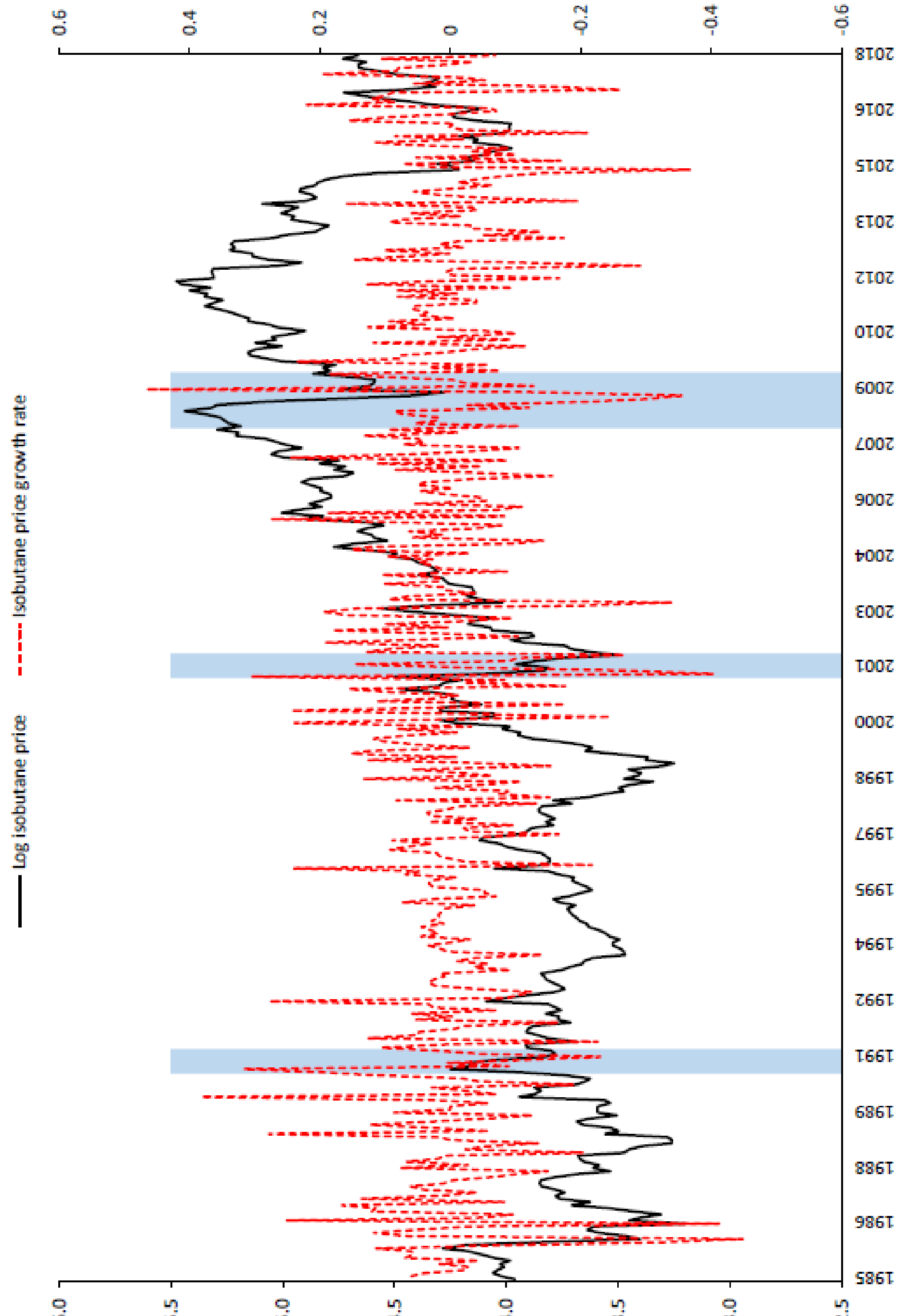


Figure 2.7 Logged Naphtha Price and Its Growth Rate

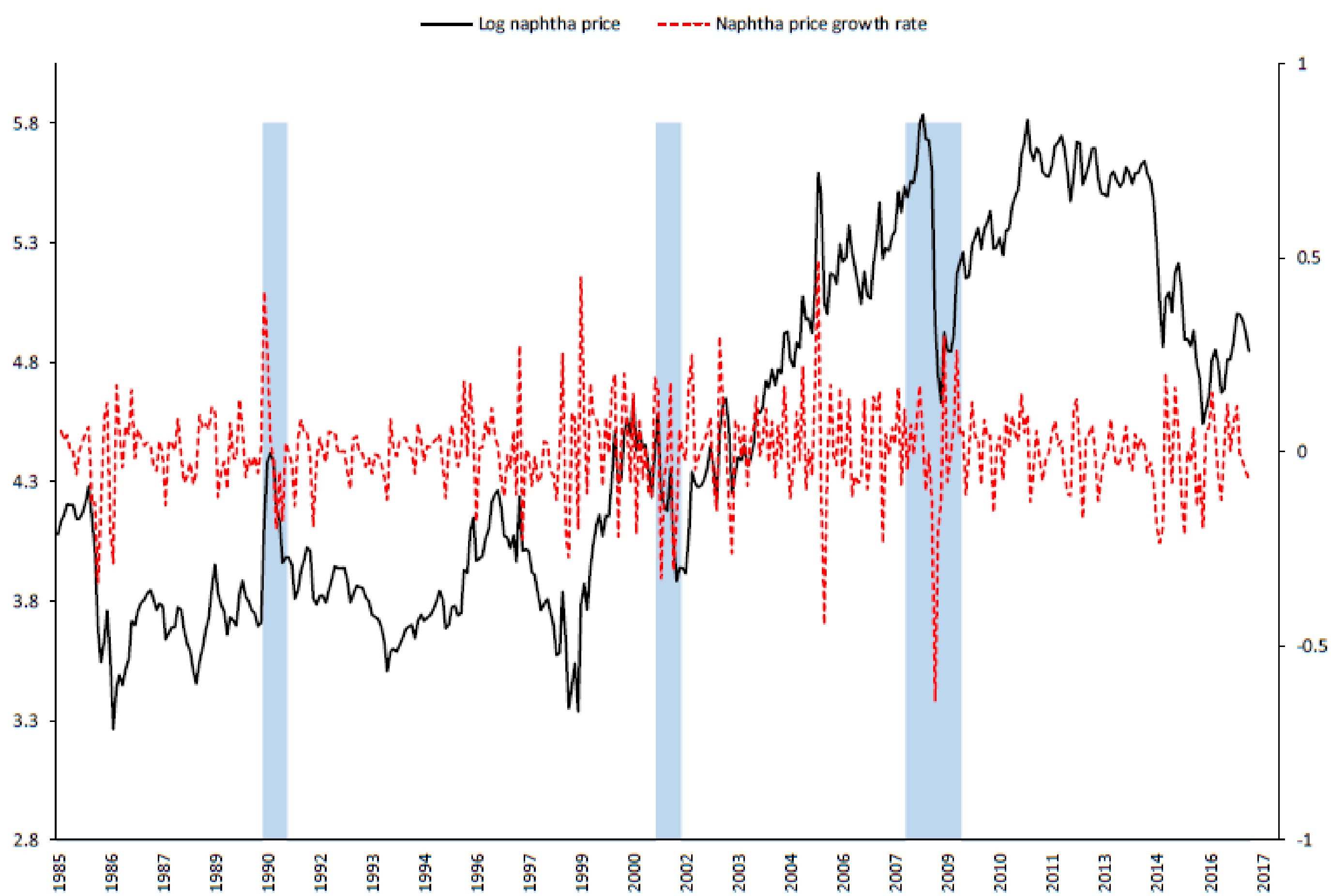


Figure 2.8 Logged Crude Oil Price and Its Growth Rate

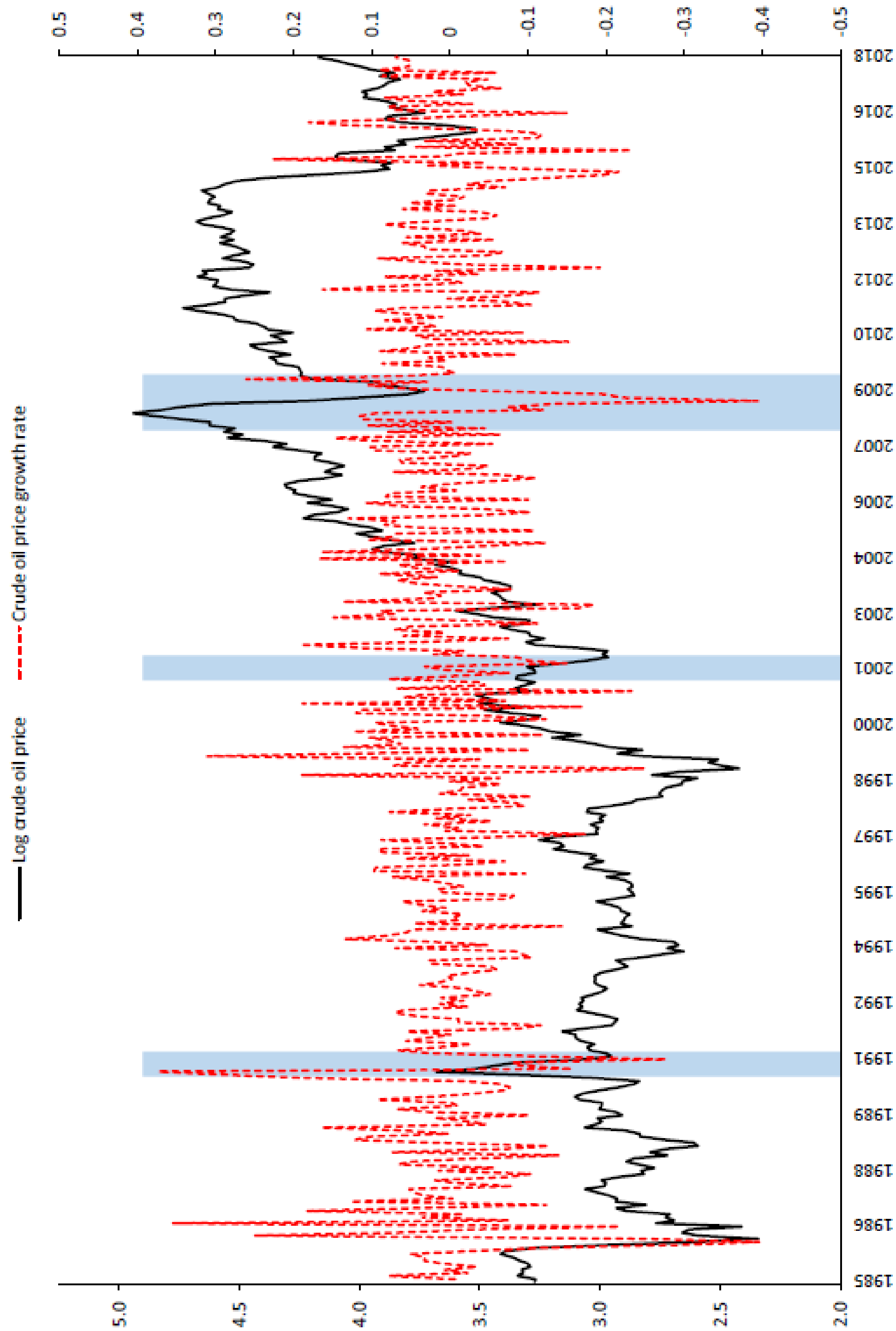


Figure 2.9 Logged Natural Gas Price and Its Growth Rate

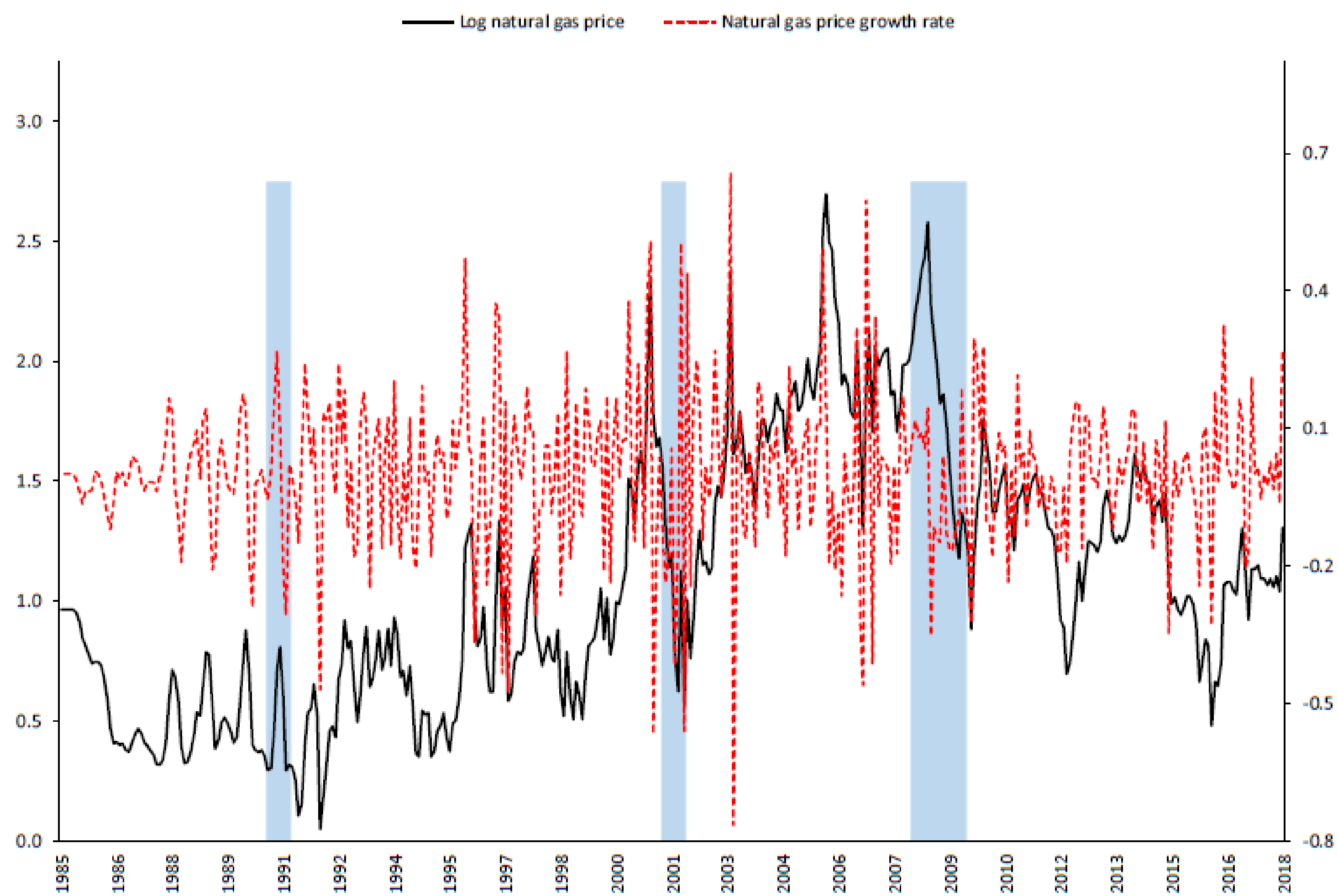
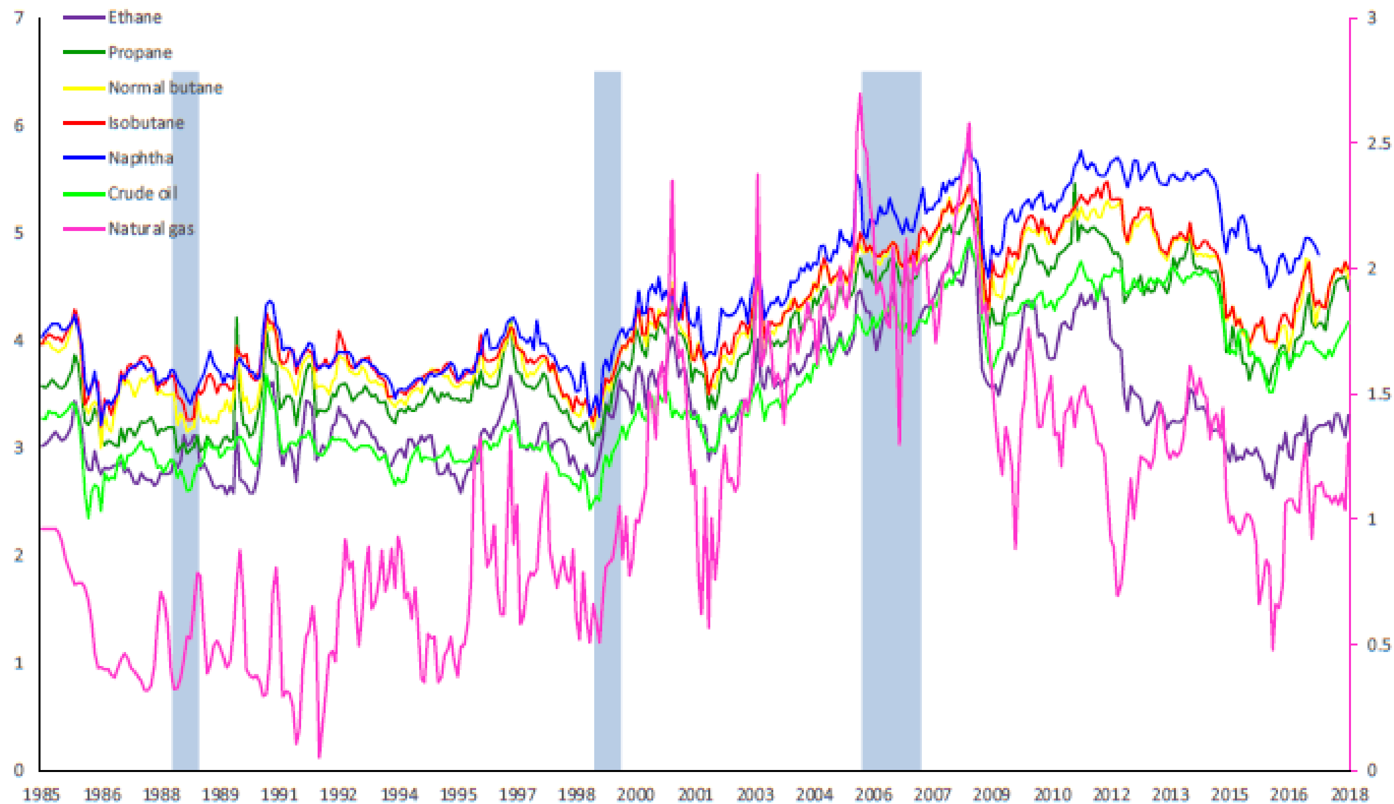


Figure 2.10 Logged Crude Oil, Natural Gas, and HGL Prices



Note: Natural gas is shown on the y_2 axis and the other prices are on the y_1 axis.

Table 2.1 Cyclical Correlations between Crude Oil, Natural Gas, and HGL Prices and Industrial Production

Series	$\rho(x_t, y_{t+j})$, j = -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12												
	j = - 12	j = - 9	j = - 6	j = - 3	j = - 2	j = - 1	j = 0	j = 1	j = 2	j = 3	j = 6	j = 9	j = 12
Ethane	-0.093	-0.003	0.081	0.154	0.175	0.188	0.201	**0.203**	0.199	0.187	0.112	0.015	-0.076
Propane	-0.077	0.009	0.081	0.150	0.167	0.181	**0.190**	0.187	0.176	0.161	0.091	-0.008	-0.093
Normal butane	-0.053	0.025	0.096	0.154	0.168	0.180	**0.183**	0.179	0.169	0.151	0.084	-0.009	-0.084
Isobutane	-0.080	-0.012	0.057	0.118	0.132	0.145	**0.148**	0.142	0.135	0.121	0.063	-0.015	-0.084
Naphtha	-0.036	0.041	0.121	0.195	0.216	0.231	0.240	**0.247**	0.244	0.235	0.182	0.107	0.035
Crude oil	-0.114	-0.027	0.053	0.144	0.173	0.194	0.209	**0.214**	0.209	0.201	0.161	0.095	0.032
Natural gas	-0.054	0.032	0.140	0.232	0.262	0.281	0.297	0.312	0.320	**0.324**	0.297	0.230	0.170

Note: Results are reported using monthly data over the period from January 1985 to January 2018.

Table 2.2 Cyclical Correlations between Natural Gas and HGL Prices and Crude Oil Prices

Series	$\rho(x_t, y_{t+j})$, j= -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12												
	j = - 12	j = - 9	j = - 6	j = - 3	j = - 2	j = - 1	j = 0	j = 1	j = 2	j = 3	j = 6	j = 9	j = 12
Ethane	0.340	0.427	0.500	0.642	0.684	0.727	**0.751**	0.707	0.646	0.584	0.417	0.274	0.133
Propane	0.324	0.477	0.567	0.738	0.805	0.860	**0.894**	0.853	0.795	0.733	0.560	0.403	0.216
Normal Butane	0.403	0.537	0.626	0.782	0.834	0.883	**0.915**	0.868	0.802	0.737	0.556	0.401	0.226
Isobutane	0.419	0.552	0.646	0.789	0.840	0.888	**0.917**	0.874	0.808	0.743	0.571	0.427	0.246
Naphtha	0.347	0.484	0.603	0.783	0.843	0.914	**0.960**	0.920	0.863	0.800	0.625	0.494	0.348
Natural gas	0.164	0.254	0.357	0.490	0.529	0.574	**0.608**	0.606	0.592	0.556	0.428	0.289	0.157

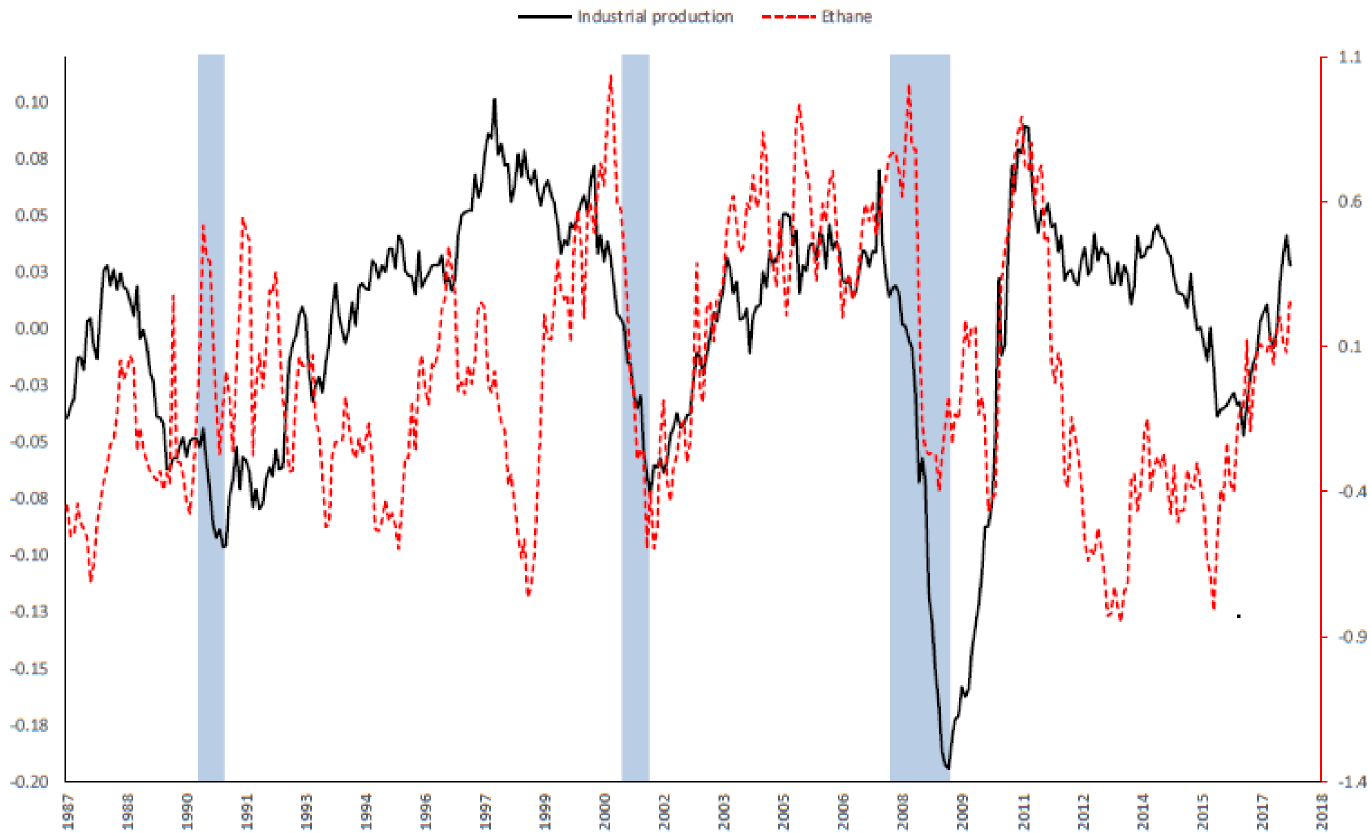
Note: Results are reported using monthly data over the period from January 1985 to January 2018.

Table 2.3 Cyclical Correlations between HGL Prices and Natural Gas Prices

Series	$\rho(x_t, y_{t+j})$, j= -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12												
	j = - 12	**j = - 9**	**j = - 6**	**j = - 3**	**j = - 2**	**j = - 1**	**j = 0**	**j = 1**	**j = 2**	**j = 3**	**j = 6**	**j = 9**	**j = 12**
Ethane	0.202	0.262	0.363	0.524	0.572	0.609	**0.631**	0.572	0.508	0.455	0.305	0.230	0.102
Propane	0.161	0.253	0.367	0.538	0.587	0.624	**0.650**	0.594	0.535	0.489	0.327	0.222	0.083
Normal Butane	0.216	0.299	0.394	0.519	0.549	0.567	**0.579**	0.532	0.470	0.420	0.265	0.165	0.057
Isobutane	0.199	0.277	0.372	0.498	0.532	0.551	**0.566**	0.532	0.470	0.423	0.257	0.149	0.046
Naphtha	0.156	0.275	0.405	0.547	0.582	0.605	**0.608**	0.568	0.514	0.473	0.309	0.220	0.144

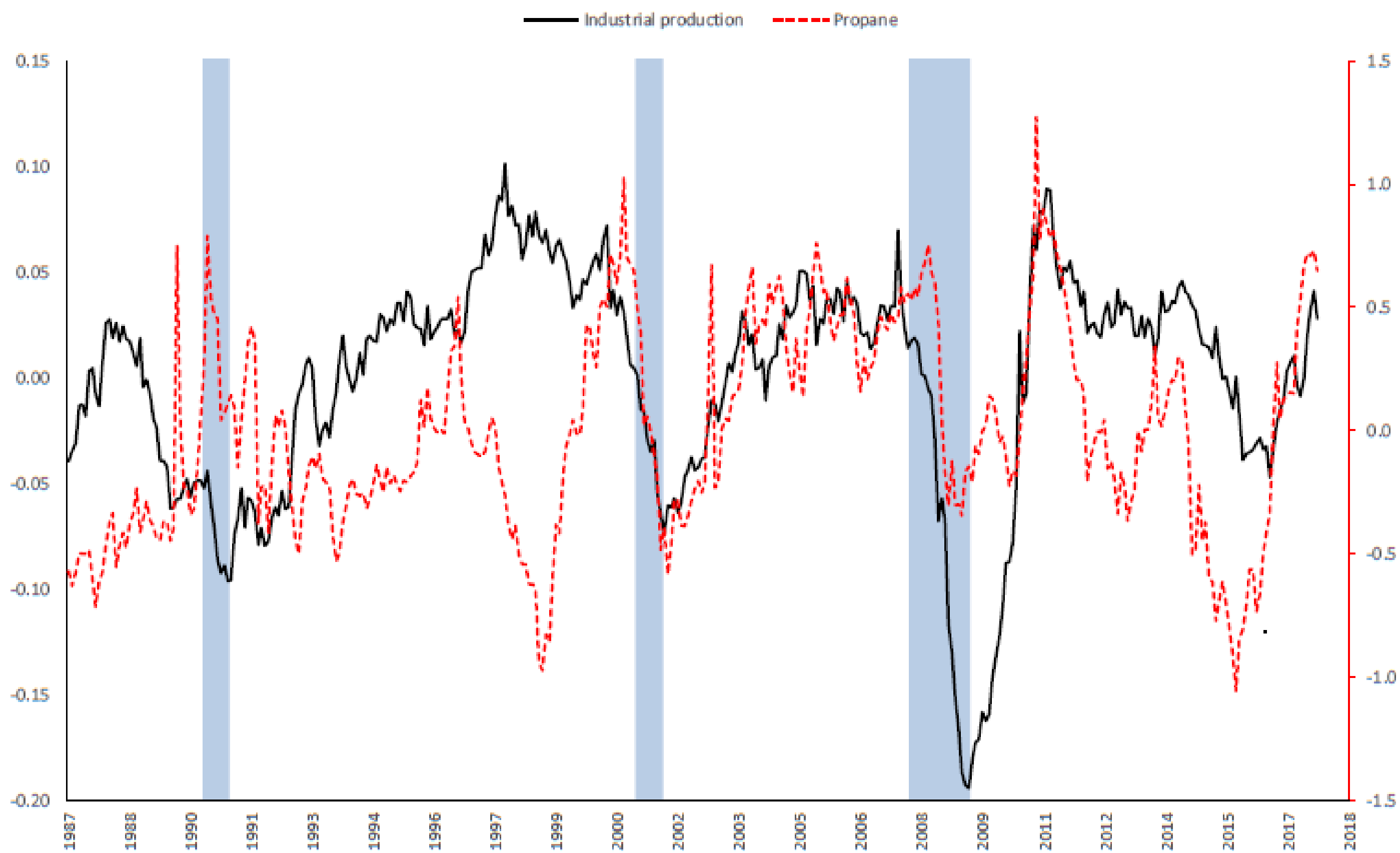
Note: Results are reported using monthly data over the period from January 1985 to January 2018.

Figure 2.11 Cyclical Behavior of Industrial Production and Ethane



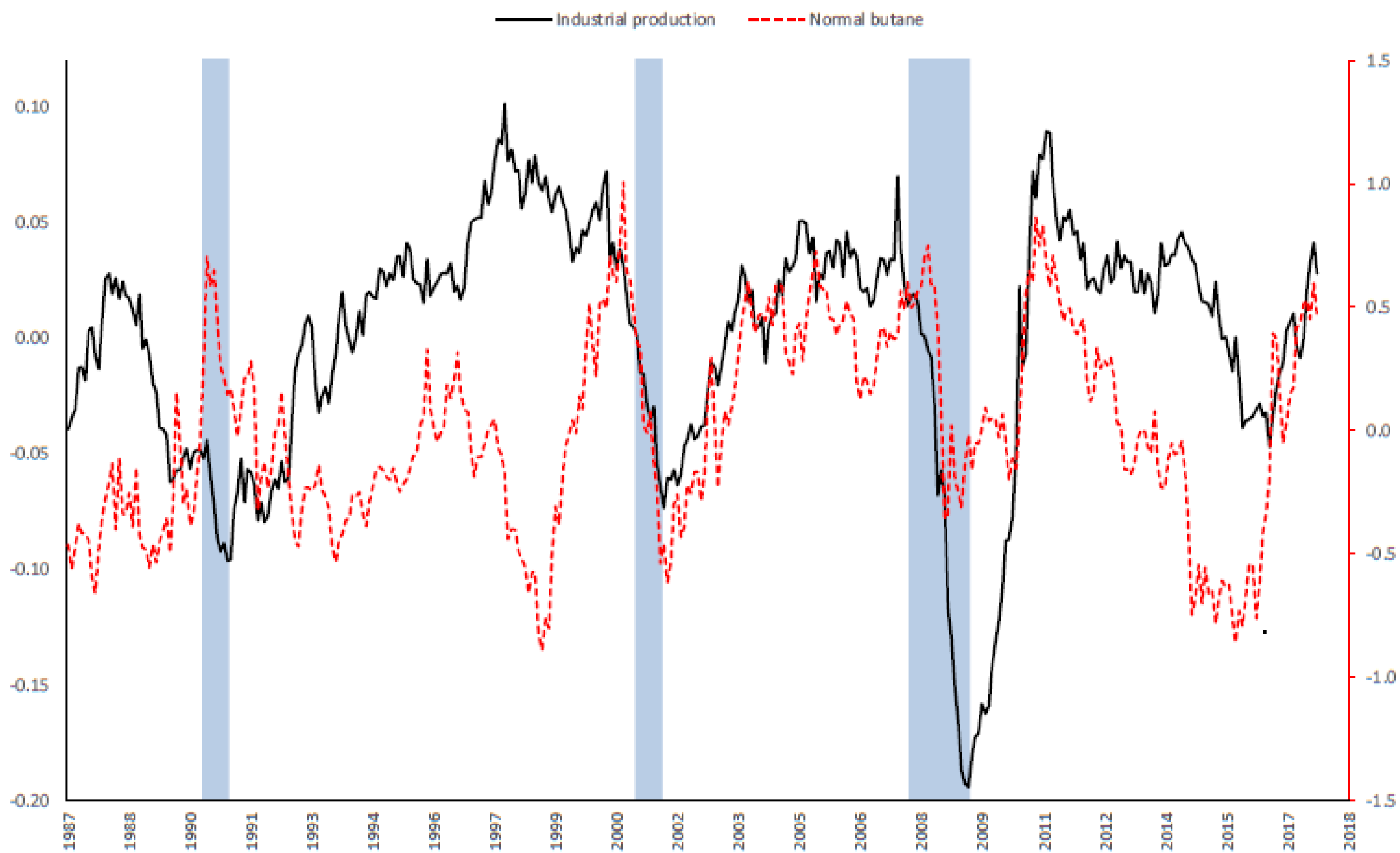
Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.12 Cyclical Behavior of Industrial Production and Propane



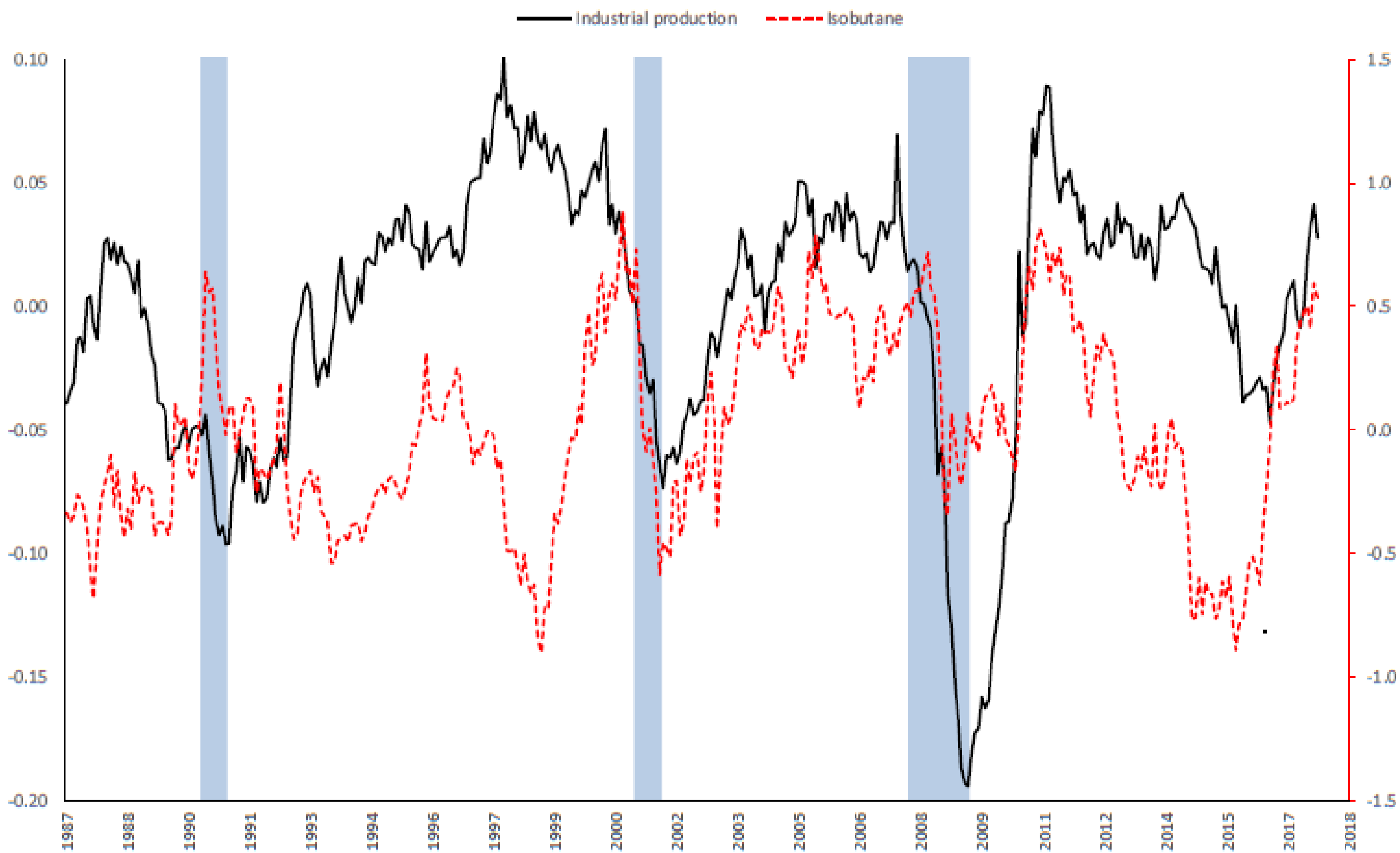
Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.13 Cyclical Behavior of Industrial Production and Normal Butane



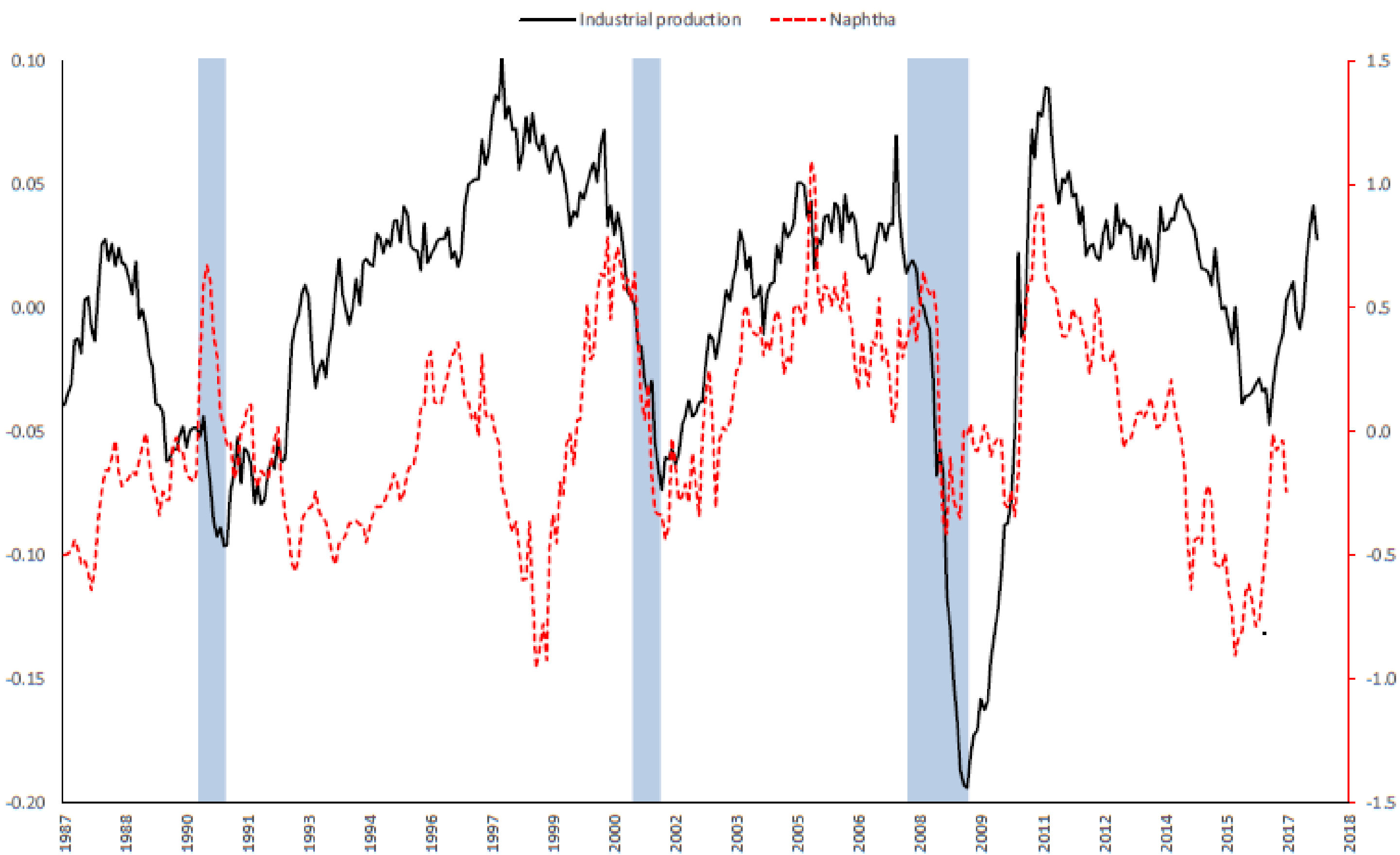
Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.14 Cyclical Behavior of Industrial Production and Isobutane



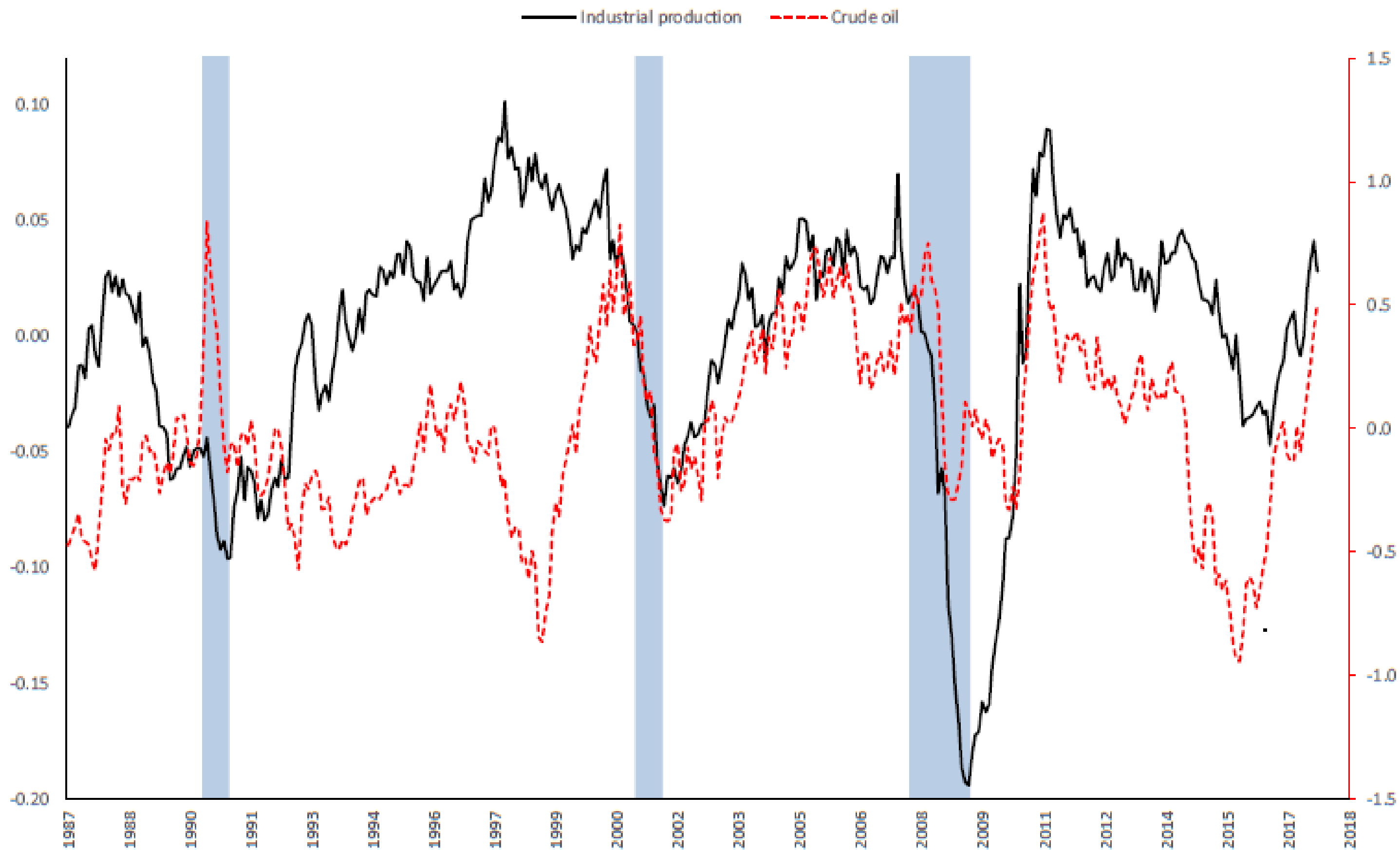
Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.15 Cyclical Behavior of Industrial Production and Naphtha



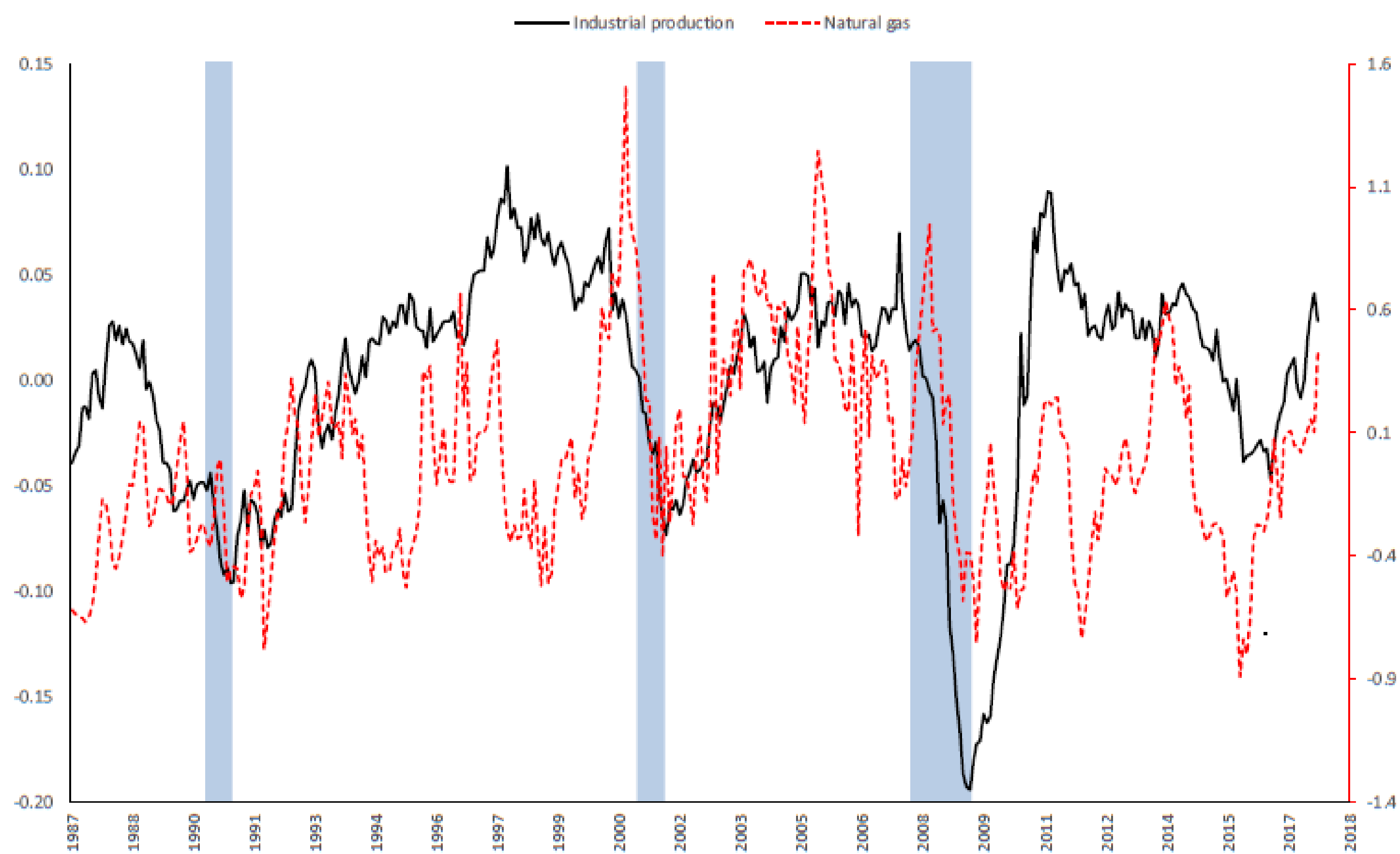
Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.16 Cyclical Behavior of Industrial Production and Crude Oil



Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.17 Cyclical Behavior of Industrial Production and Natural Gas



Note: Results are reported using monthly data over the period from April 1987 to January 2018.

Figure 2.18 Contemporaneous Correlation Coefficients Between the Cyclical Component of Industrial Production and the Cyclical Components of Crude Oil, Natural Gas, and HGL Prices

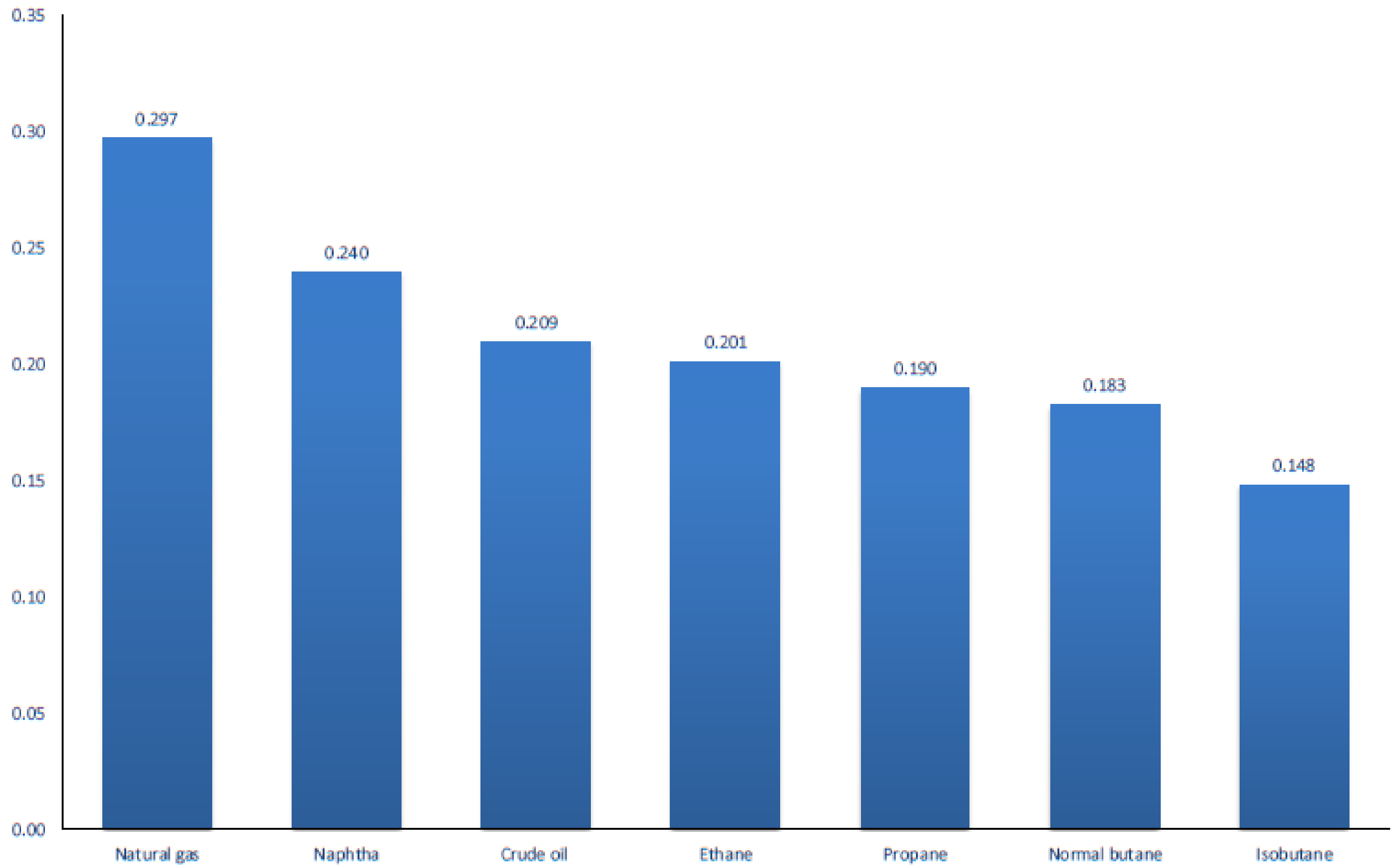
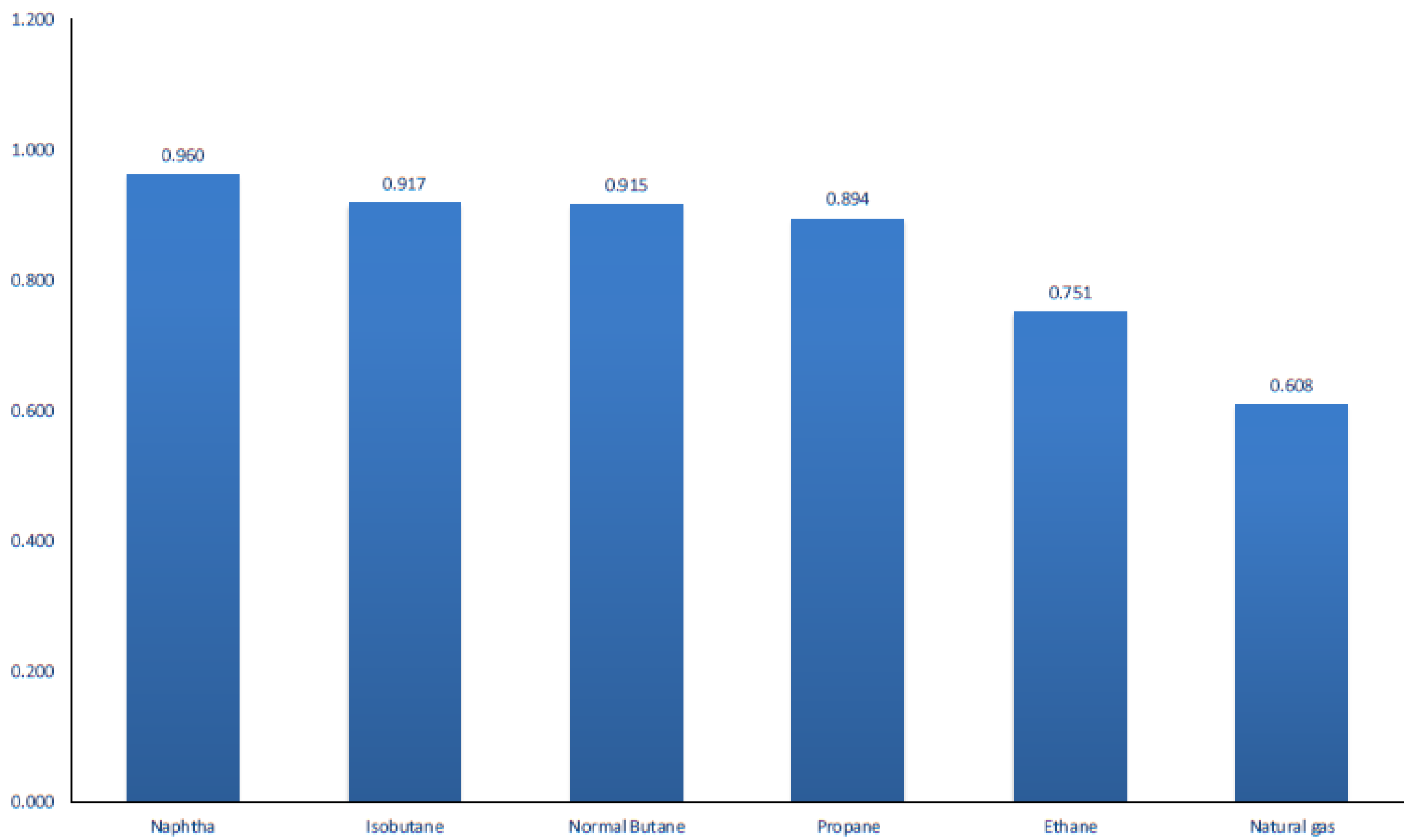


Figure 2.19 Contemporaneous Correlation Coefficients Between the Cyclical Component of Crude Oil and the Cyclical Components of Natural Gas and HGL Prices



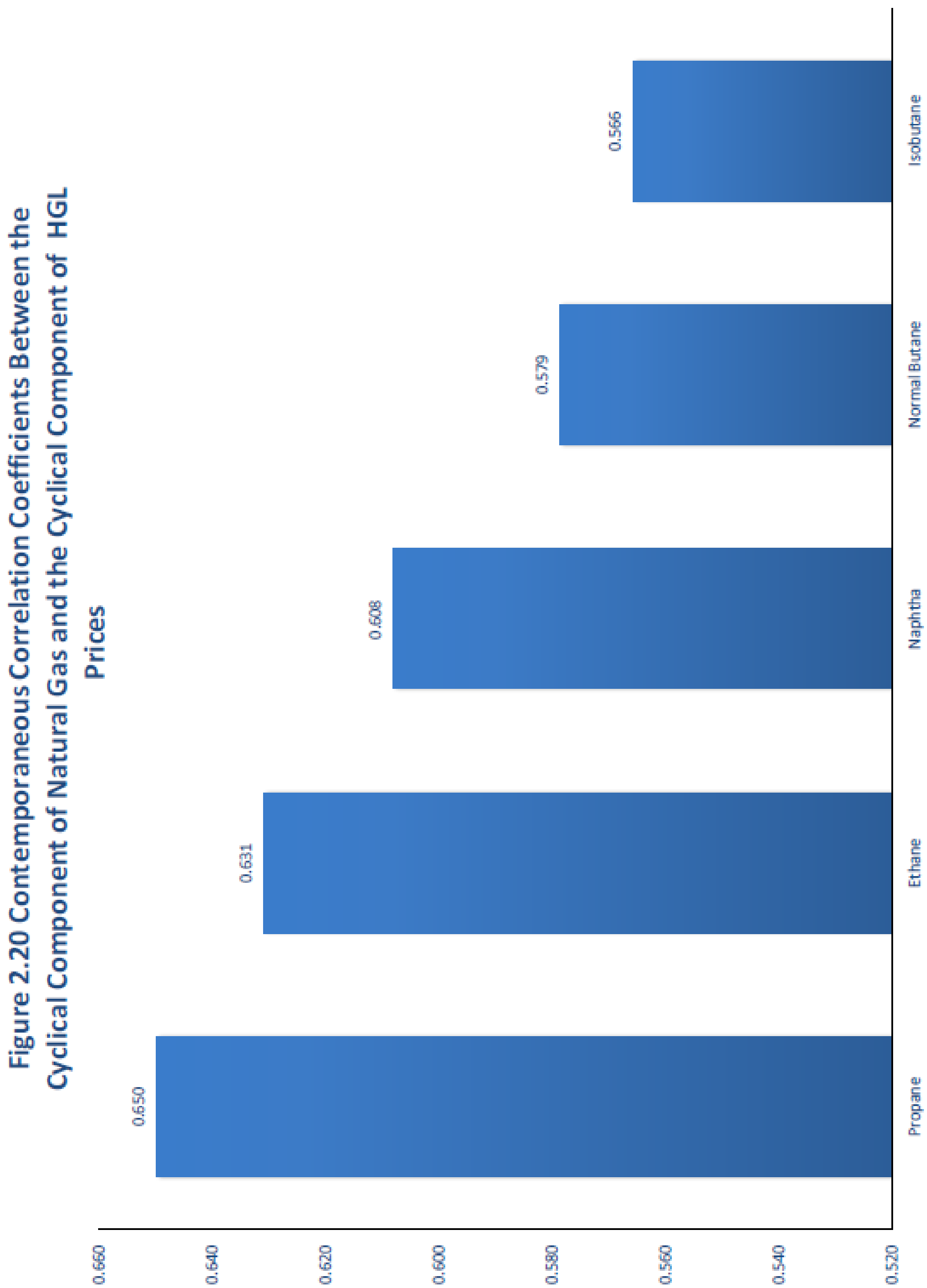


Figure 2.20 Contemporaneous Correlation Coefficients Between the Cyclical Component of Natural Gas and the Cyclical Component of HGL Prices
0.650
0.631
0.608
0.579
0.566
Propane
Ethane
Naphtha
Normal Butane
Isobutane
0.660
0.640
0.620
0.600
0.580
0.560
0.540
0.520

Appendix Table 2.1 HP Cyclical Correlations between Crude Oil, Natural Gas, and HGL Prices and Industrial Production

Series	$\rho(x_t, y_{t+j})$, *j= -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12*												
	j = - 12	**j = - 9**	**j = - 6**	**j = - 3**	**j = - 2**	**j = - 1**	**j = 0**	**j = 1**	**j = 2**	**j = 3**	**j = 6**	**j = 9**	**j = 12**
Ethane	-0.139	0.042	0.227	0.379	0.412	0.417	**0.419**	0.392	0.360	0.309	0.115	-0.054	-0.144
Propane	-0.124	0.052	0.234	0.398	0.426	**0.441**	0.429	0.405	0.368	0.317	0.112	-0.083	-0.200
Normal butane	-0.149	0.045	0.246	0.417	0.445	**0.458**	0.437	0.407	0.364	0.303	0.093	-0.108	-0.218
Isobutane	-0.150	0.039	0.250	0.407	0.427	**0.438**	0.409	0.374	0.333	0.284	0.079	-0.095	-0.191
Naphtha	-0.180	0.005	0.204	0.366	0.395	**0.401**	0.387	0.387	0.351	0.303	0.122	-0.059	-0.148
Crude oil	-0.175	0.014	0.212	0.395	0.433	**0.445**	0.434	0.405	0.351	0.296	0.110	-0.070	-0.171
Natural gas	-0.264	-0.136	0.058	0.231	0.281	0.317	0.345	**0.361**	**0.361**	0.347	0.221	0.060	-0.062

Note: Results are reported using monthly data over the period from January 1985 to January 2018

Appendix Table 2.2 HP Cyclical Correlations between Natural Gas and HGL Prices and Crude Oil Prices

Series	$\rho(x_t, y_{t+j})$, j= -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12												
	j = - 12	j = - 9	j = - 6	j = - 3	j = - 2	j = - 1	j = 0	j = 1	j = 2	j = 3	j = 6	j = 9	j = 12
Ethane	-0.183	-0.049	0.066	0.344	0.458	0.585	**0.667**	0.585	0.448	0.318	0.040	-0.103	-0.156
Propane	-0.165	0.002	0.082	0.394	0.546	0.690	**0.785**	0.701	0.579	0.465	0.213	-0.013	-0.211
Normal Butane	-0.193	-0.022	0.089	0.407	0.567	0.723	**0.840**	0.759	0.628	0.503	0.171	-0.096	-0.289
Isobutane	-0.195	-0.025	0.132	0.441	0.592	0.741	**0.841**	0.753	0.600	0.465	0.167	-0.070	-0.294
Naphtha	-0.221	-0.109	0.056	0.420	0.578	0.767	**0.897**	0.791	0.621	0.463	0.136	-0.054	-0.202
Natural gas	-0.216	-0.099	0.036	0.235	0.286	0.364	0.447	**0.459**	0.453	0.415	0.234	0.061	-0.095

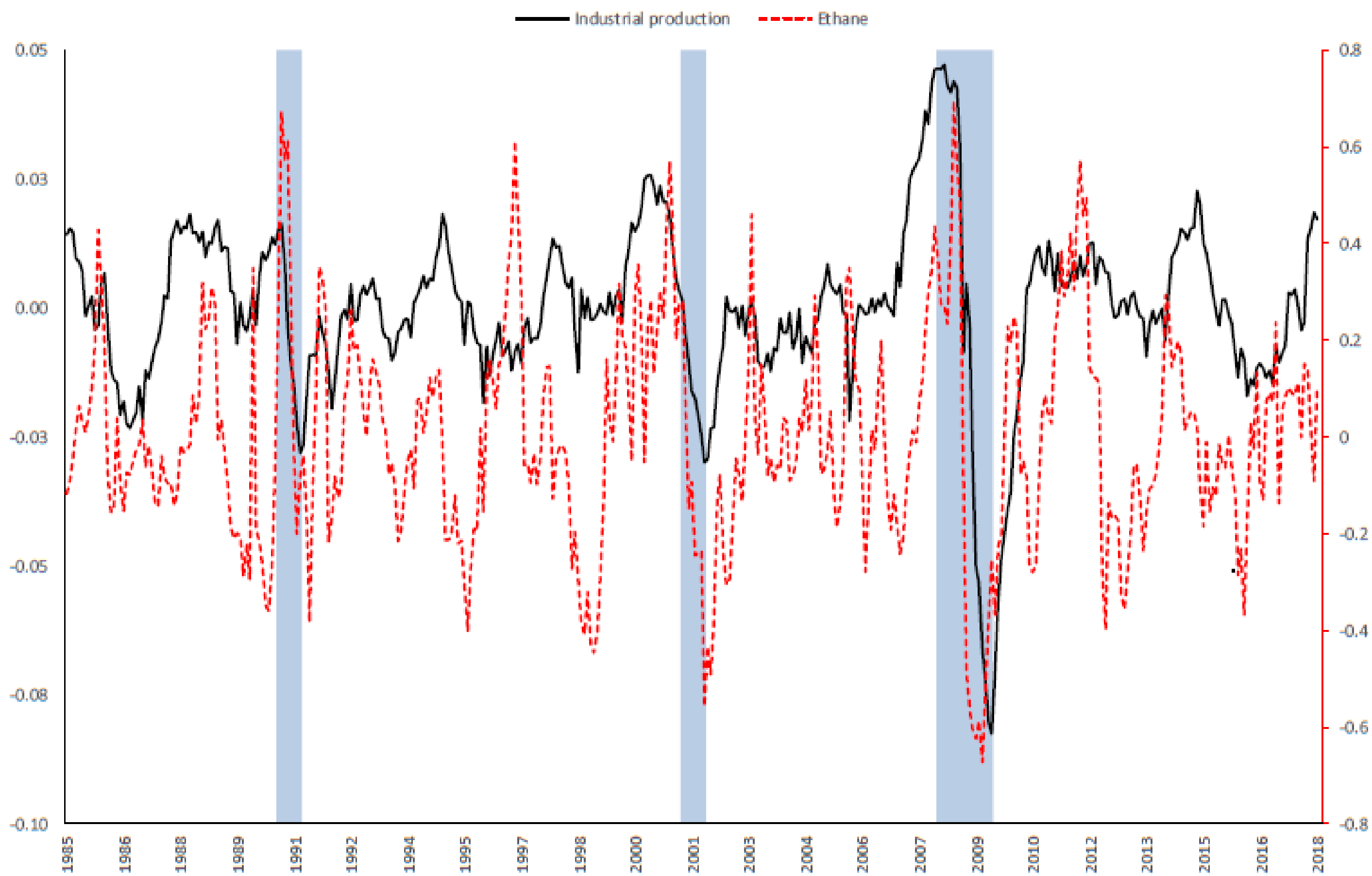
Note: Results are reported using monthly data over the period from January 1985 to January 2018

Appendix Table 2.3 HP Cyclical Correlations between HGL Prices and Natural Gas Prices

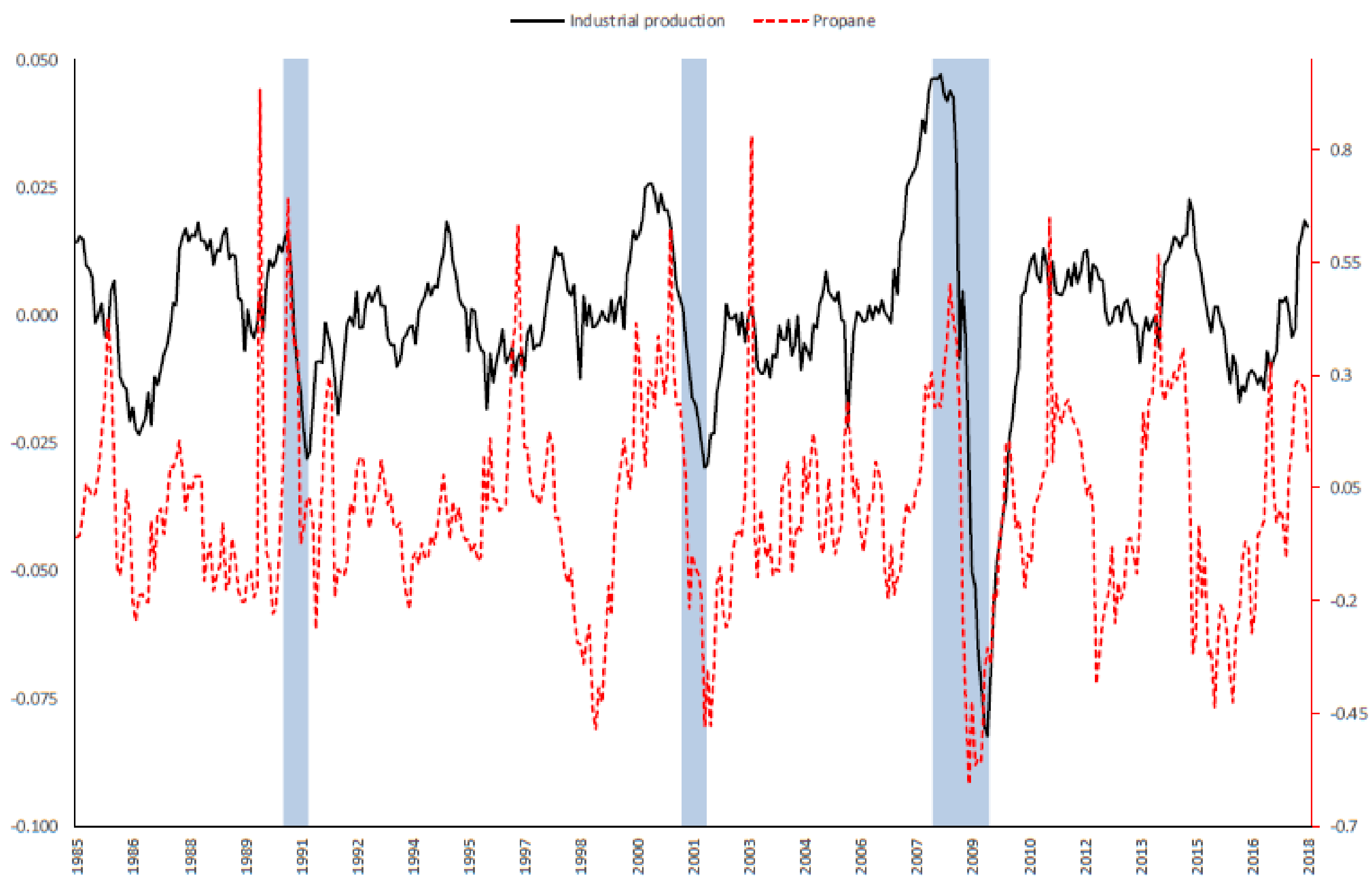
Series	$\rho(x_t, y_{t+j})$, *j= -12, -9, -6, -3, -2, -1, 0, 1, 2, 3, 6, 9, 12*												
	j = - 12	**j = - 9**	**j = - 6**	**j = - 3**	**j = - 2**	**j = - 1**	**j = 0**	**j = 1**	**j = 2**	**j = 3**	**j = 6**	**j = 9**	**j = 12**
Ethane	-0.117	-0.067	0.065	0.316	0.414	0.495	**0.554**	0.428	0.304	0.229	0.032	-0.007	-0.244
Propane	-0.094	0.009	0.164	0.399	0.471	0.532	**0.582**	0.455	0.343	0.280	0.054	-0.037	-0.232
Normal Butane	-0.028	0.066	0.185	0.383	0.440	0.475	**0.505**	0.413	0.297	0.220	-0.030	-0.116	-0.249
Isobutane	-0.048	0.078	0.204	0.383	0.443	0.477	**0.513**	0.443	0.334	0.262	-0.030	-0.157	-0.285
Naphtha	-0.121	0.063	0.206	0.389	0.444	0.484	**0.485**	0.402	0.304	0.257	-0.017	-0.136	-0.224

Note: Results are reported using monthly data over the period from January 1985 to January 2018

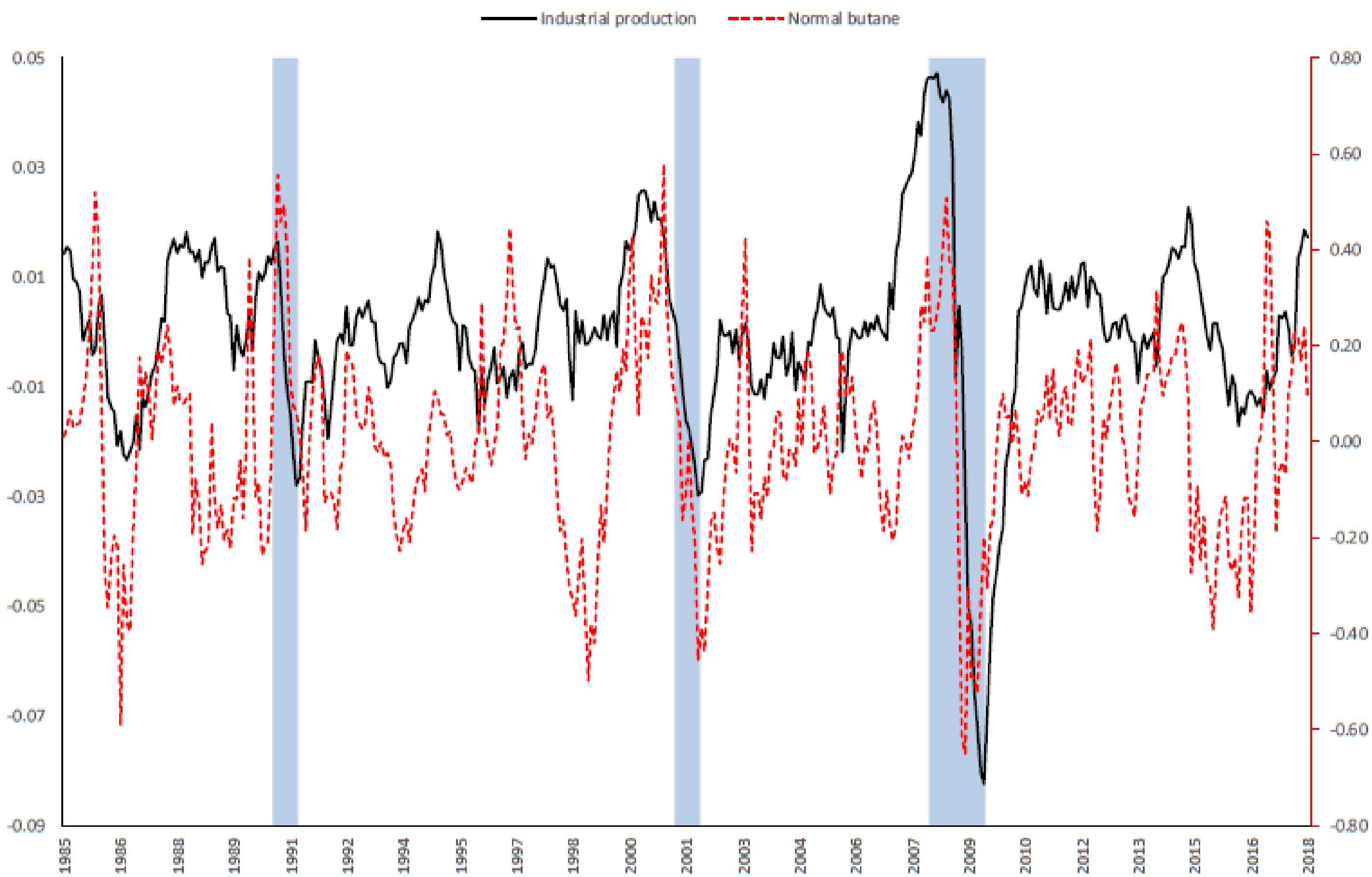
Appendix Figure 2.1 HP Cyclical Behavior of Industrial Production and Ethane



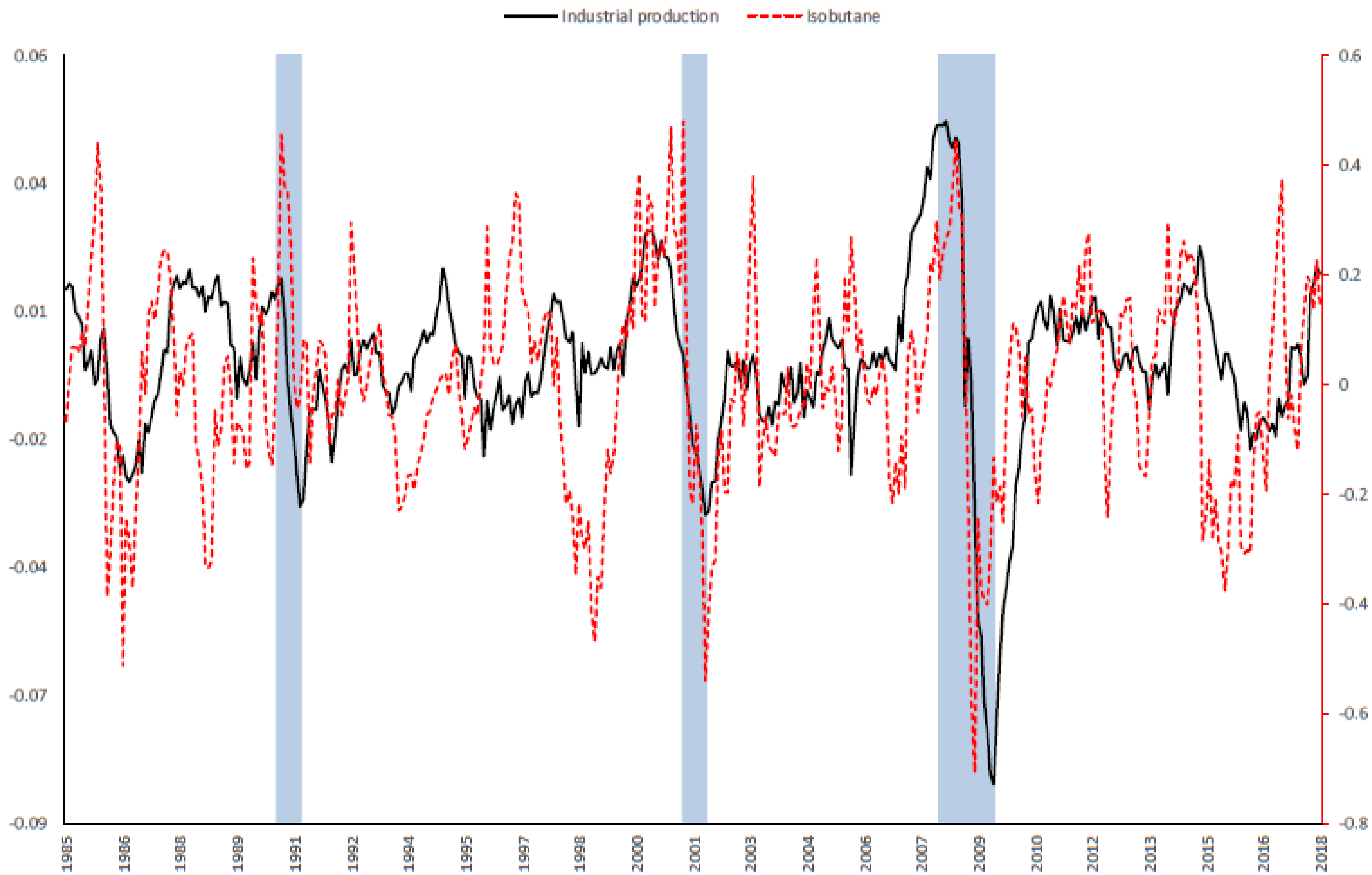
Appendix Figure 2.2 HP Cyclical Behavior of Industrial Production and Propane



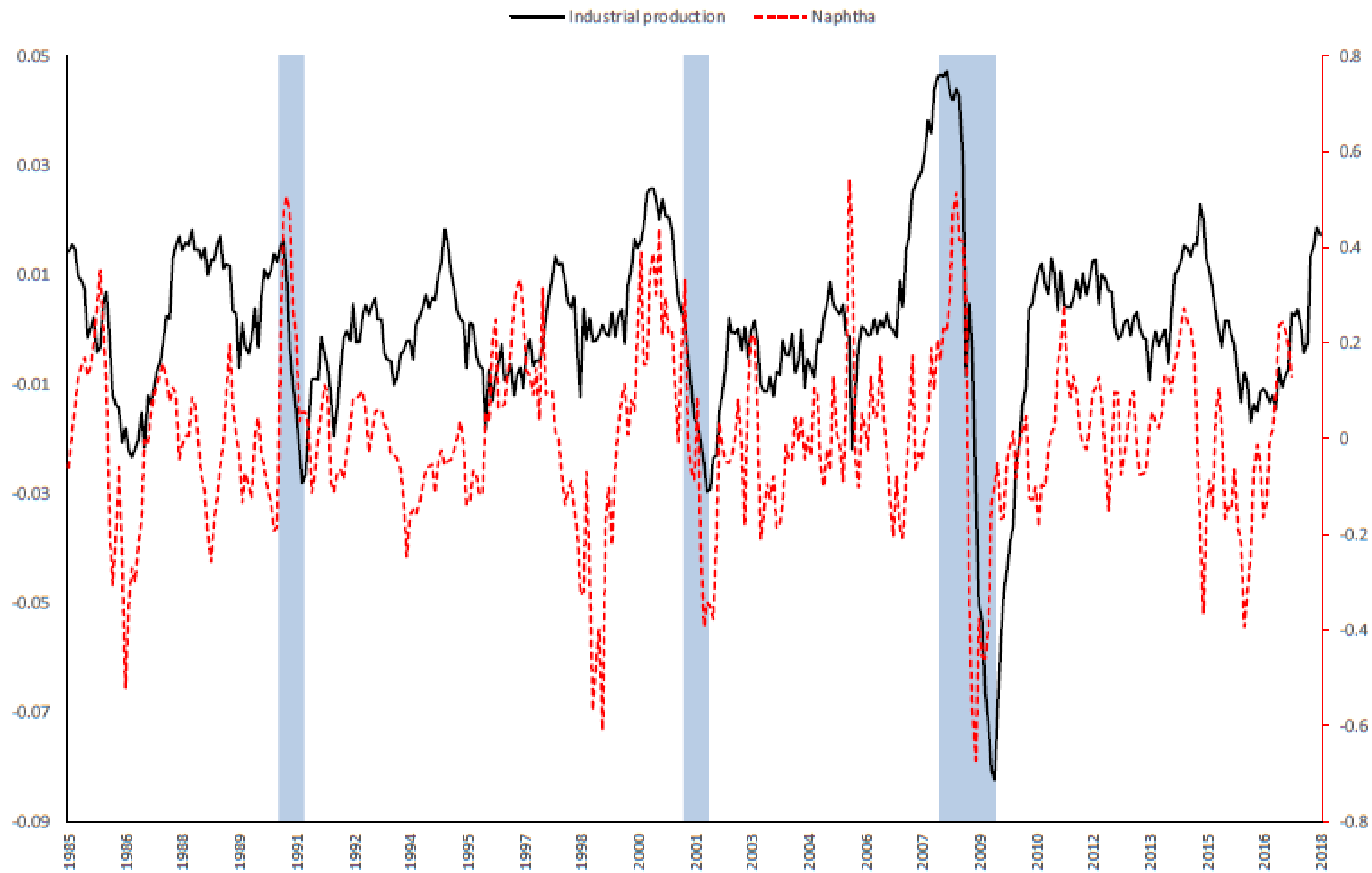
Appendix Figure 2.3 HP Cyclical Behavior of Industrial Production and Normal Butane



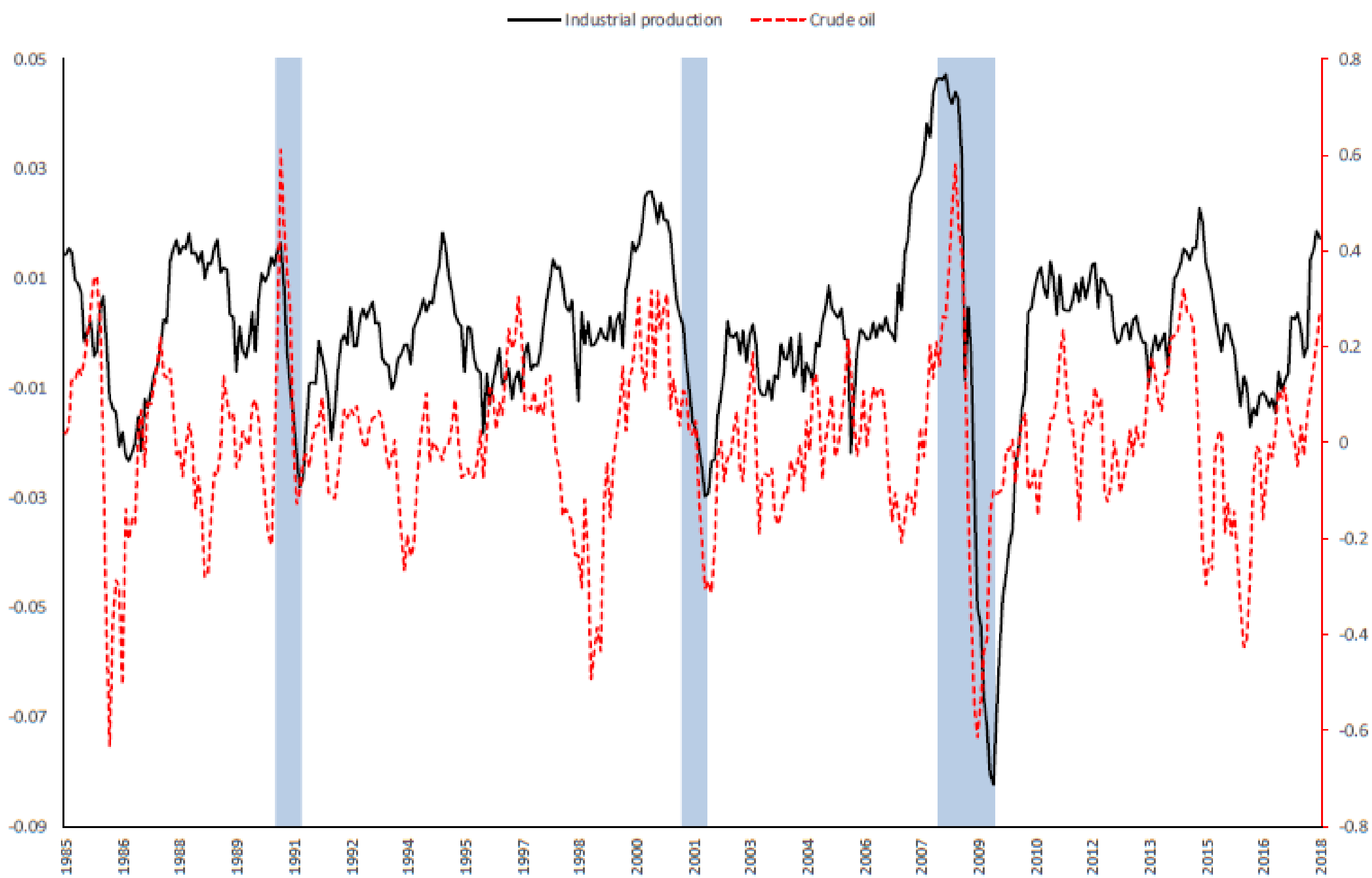
Appendix Figure 2.4 HP Cyclical Behavior of Industrial Production and Isobutane



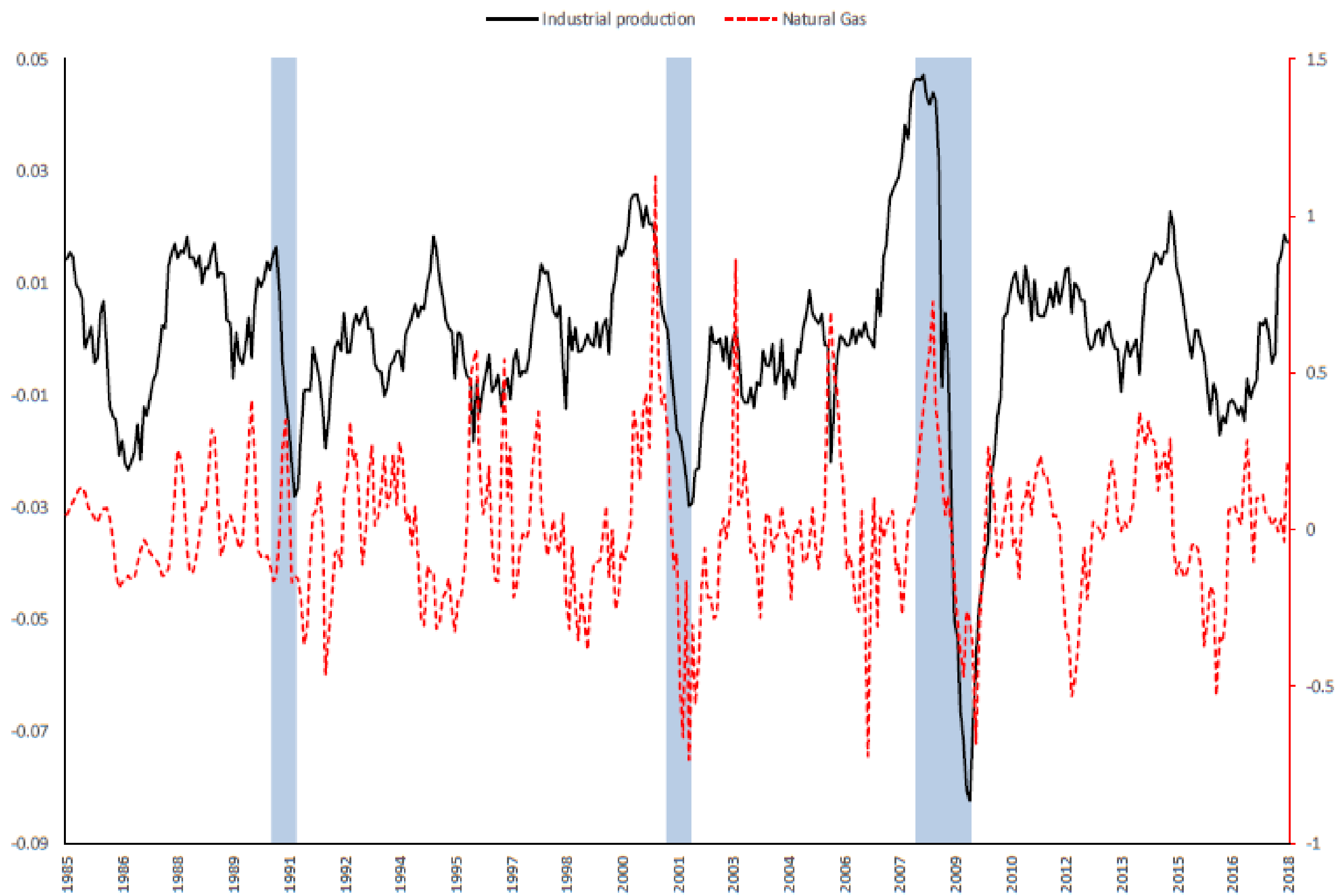
Appendix Figure 2.5 HP Cyclical Behavior of Industrial Production and Naphtha



Appendix Figure 2.6 HP Cyclical Behavior of Industrial Production and Crude Oil



Appendix Figure 2.7 HP Cyclical Behavior of Industrial Production and Natural Gas



Chapter 3

Causal Relationships between HGL Prices and Economic Activity

3.1 Introduction

The purpose of this chapter is to investigate the relationship between the hydrocarbon gas liquids (HGL) prices and industrial production in the United States. We test whether the apparent phase shift between ethane, naphtha, crude oil, and natural gas prices that I established in Chapter 1 justifies a causal relationship between these prices and the industrial production index. In this regard, I interpret causality in terms of predictability and not as suggesting the existence of underlying structural relationships between the variables.

For causality analysis, it is required that I investigate the univariate and multivariate properties of the series to determine whether the analysis should be carried out in the context of an error correction model or in the context of a model with the logarithmic first differences of the series. Thus, I test for unit roots using three alternative approaches to deal with the inconsistency that arises when the series do not yield information about the presence of a unit root. I also investigate the long run relationship among the variables by testing for cointegration using the Johansen (1988) maximum likelihood methodology. The results of the unit root and cointegration tests determine the framework within which I conduct the Granger causality analysis.

I use the same monthly data for the United States, over the period from January 1985 to January 2018, already discussed in detail in Chapter 1. I show that there exists a unidirectional causal relationship between the hydrocarbon gas liquids prices and the level of real economic activity. The estimation is performed in Estima RATS, and in carrying out the Granger causality analysis I use the optimal lag structure, determined by minimizing the Akaike Information Criterion (AIC).

The chapter is organized as follows. Section 2 discusses the data and investigates their univariate time series properties. Section 3 tests for cointegration while Section 4 presents the Granger causality test results. The final section 5 briefly concludes the chapter.

3.2 Unit Root Tests

In empirical time series analysis, it is very important to know whether the economic time series have a unit root or not. Estimation of time series models and hypothesis testing, both depend on asymptotic distribution theory. According to Nelson and Plosser (1982), most macroeconomic and financial time series have a unit root (a stochastic trend). This means that logarithmic first differences are stationary, and this property is known as 'difference stationarity' (DS). The alternative 'trend stationary' (TS) model has been found to be less appropriate.

It is also argued in the literature that at low frequencies, inappropriate detrending of integrated processes produces spurious variation in the detrended series. On the contrary, at high frequencies, inappropriate differencing of trending processes produces spurious variation in the differenced series. Therefore, the time series properties of the data must first be investigated in order to determine the correct specification in terms of which the Granger causality tests will be carried out.

In panel A of Table 3.1 I report the results of unit root and stationary tests, conducted using the natural logs of the series --- the industrial production index and the HGL, crude oil, and natural gas prices. To be specific, I report the test statistics for the Augmented Dickey-Fuller (ADF) test [see Dickey and Fuller (1981)], and the Dickey-Fuller GLS (DF-GLS) test [see Elliot, Rothenberg, and Stock, 1996], assuming both a constant and trend, to assess the null hypothesis of a unit root against the alternative of a trend stationary process. The optimal lag length is determined to be the order selected by the Akaike information criterion (AIC). In addition, given that unit root tests have low power against relevant trend stationary alternatives, I also execute the KPSS test [see Kwiatkowski, Phillips, Schmidt, and Shin (1992)] to test the null hypothesis of stationarity around a constant and trend against the alternative of a unit root.

Based on the test statistics shown in panel A of Table 3.1, the null hypothesis of a unit root in log levels cannot be rejected by both the ADF and DF-GLS test statistics at conventional significance levels. Further, the null hypothesis of stationarity can be rejected at conventional significance levels by the KPSS test. Therefore, the industrial production and the HGL, crude oil, and natural gas prices are nonstationary, or integrated of order one, I(1). This is consistent with the argument that most macroeconomic time series have a stochastic trend [see Nelson and Plosser (1982)].

To eliminate the unit root problem, the commonly used detrending procedure is taking first logarithmic differences. So, I repeat the unit root and stationarity tests using the first differences of the logs of the series, and present the results in panel B of Table 3.1. Now the null hypotheses of the ADF and DF-GLS tests are rejected and the null hypothesis of the KPSS test cannot be rejected, which clearly suggests that the logarithmic first differences are stationary, or integrated of order zero, I(0).

Next, I test for cointegration in order to determine the specification in which causality tests will be carried out.

3.3 Cointegration Tests

According to the Engle and Granger (1987), cointegration allows individual time series to be integrated of order one, I(1), but requires that a linear combination of the integrated time series to be integrated of order zero, I(0). They name the linear combination of such series as the cointegrating vector. If the variables are nonstationary and cointegrate, then there is a long-run equilibrium relationship between the variables. In contrast, if the variables are nonstationary and do not cointegrate, then ordinary least squares (OLS) yields misleading results. In this situation, the only valid relationship that can exist between the variables is in terms of their first differences.

To test for a long-term relationship between the nonstationary time series, a pairwise Johansen (1988) cointegration test is used, this being a generalization of the most frequently used Engle and Granger (1987) cointegration test. In Tables 3.2-3.4, I list the *p*-values of bivariate Johansen (1988) cointegration test using my monthly time series. These tests include bivariate relationships between each of the HGL, crude oil, and natural gas prices and the industrial production index (in Table 3.2), bivariate relationships between each of the HGL and natural gas prices and the crude oil price (in Table 3.3), and bivariate relationships between each of the HGL prices and the natural gas price (in Table 3.4).

As can be seen in Table 3.2, I reject the null of no cointegration with industrial production only in the case of natural gas. In Table 3.3, I reject the null of no cointegration with the crude oil price in the cases of propane, normal butane, and isobutane. Finally, in Table 3.4, I reject the null of no cointegration with the natural gas price only in the case of ethane.

With these results in mind, in the next section, I carry out Granger causality tests.

3.4 Granger Causality Tests

In testing for Granger causality, I use an error correction model in the cases where cointegration has been established. In particular, when the series cointegrate, according to the representation theorem of Engle and Granger (1987), there must exist an error correction representation relating current and lagged first differences of Y_t and X_t, and at least one lagged value of $\hat{\varepsilon}_t$, the latter being the estimated OLS residual from the cointegrating regression

$$Y_t = a + bX_t + \varepsilon_t. \qquad (1)$$

Thus, following Engle and Granger (1987), I can estimate the error correction model as follows,

$$\Delta Y_t = \alpha_1 + \alpha_Y \hat{\varepsilon}_{t-1} + \sum_{j=1}^{r} \alpha_{11}(j)\, \Delta Y_{t-j} + \sum_{j=1}^{s} \alpha_{12}(j)\, \Delta X_{t-j} + \varepsilon_{yt} \qquad (2)$$

This model shows how Y_t and X_t change in response to stochastic shocks, represented by ε_{yt}, and the previous period's deviation from the long-run equilibrium, represented by $\hat{\varepsilon}_{t-1}$. For the positive value of $\hat{\varepsilon}_{t-1}$, which means that $(Y_{t-1} - \alpha - \beta X_{t-1}) > 0$, X_t would rise and Y_t would fall until a long-run equilibrium is attained, $Y_t = \alpha + \beta X_t$.

The coefficient α_Y can be interpreted as the speed of adjustment parameter. For example, the larger the value of α_Y, the greater the response of Y_t to the previous period's deviation from the long-run equilibrium. In contrast, small values of α_Y imply that Y_t is unresponsive to last period's equilibrium error. By the empirical definition of Granger causality in cointegrated systems, in equation (2), α_Y and all the α_{12} (j) coefficients must be equal to zero for ΔY_t to be unaffected by X_t. That is, the speed of adjustment coefficient also needs to be equal to zero. This is an additional required condition to determine the absence of Granger causality in cointegrated systems.

Therefore, the causal relationship between Y_t and X_t can be determined by first fitting equation (2), by ordinary least squares, to obtain the unrestricted sum of squared residuals, SSR_u. Then, by running another regression equation under the null hypothesis that α_Y and all the coefficients of the lagged values of ΔX_t are zero, I obtain the restricted sum of squared residuals, SSR_r. Then

I calculate the following statistic which has an asymptotic *F*-distribution with numerator degrees of freedom (s + 1) and denominator degrees of freedom ($T - r - s - 2$),

$$\frac{(SSR_r - SSR_u)/\,(s+1)}{\frac{SSR_u}{T-r-s-2}}$$

where T is the number of observations, s represents the number of lags for ΔX_t in equation (2), and 2 is subtracted out to account for the constant term and the error correction term in equation (2). If the null hypothesis cannot be rejected, then the conclusion is that the data do not show causality. If the null hypothesis is rejected, then the conclusion is that the data do show causality.

To see whether there is a feedback relationship between these series, the roles of Y_t and X_t are reversed in another *F*-test as in equation (3) below

$$\Delta X_t = \alpha_2 + \alpha_x \hat{\varepsilon}_{t-1} + \sum_{j=1}^{r} \alpha_{21}(j)\, \Delta Y_{t-j} + \sum_{j=1}^{s} \alpha_{22}(j)\, \Delta X_{t-j} + \varepsilon_{xt} \qquad (3)$$

To estimate the error-correction model and perform Granger-causality tests, I need to select the lengths of lags *r* and *s* in equations (2) and (3). In the literature, *r* and *s* are frequently chosen to have the same value, and for monthly data, lag lengths of 3, 6, or 12 are used most often. Such arbitrary lag specifications can give misleading results because they may imply misspecification of the order of the autoregressive process. For instance, the estimates will be unbiased yet inefficient if either *r* or *s* (or both) is too large. In the same way, the estimates will be biased but have a smaller variance, if either *r* or *s* (or both) is too small.

For this reason, I use the data to determine the 'optimal' lag structure, by running OLS regression in Estima RATS. In particular, the optimal *r* and *s* in each of equations (2) and (3) is determined using Akaike's information criterion (AIC). The AIC is calculated as follows,

$$\text{AIC}(r, s) = \log\left(\frac{SSR}{T}\right) + 2\left(\frac{r+s+1}{T}\right) \qquad (4)$$

where *T* is the number of observations and SSR is the sum of squared residuals. Notice that, as implied by the second term in the equation (5), the AIC balances the degrees of freedom used (as implied by the second term in the expression) and the fit of the equation as implied by the SSR.

I use the AIC with a maximum value of 12 for each of *r* and *s* in equations (2) and (3) and I chose the one that produces the smallest value for the AIC after running 144 regressions for each bivariate relationship. Based on these optimal specifications, I report the results in Tables 3.5-3.10 --- I report the *p*-values for Granger causality *F*-tests (for those series that cointegrate, according to the cointegration results established in Tables 3.2-3.4).

However, for the variables which are nonstationary and do not cointegrate, as suggested by Engle and Granger (1987), the only valid relationship that can exist between the variables is in terms of their first differences. In those cases, I test for Granger causality using the same specifications as above, but without the error correction terms. That is, I use the following equations, instead of equations (2) and (3), respectively

$$\Delta Y_t = \alpha_1 + \sum_{j=1}^{r} \alpha_{11}(j)\, \Delta Y_{t-j} + \sum_{j=1}^{s} \alpha_{12}(j)\, \Delta X_{t-j} + \varepsilon_{yt} \tag{5}$$

and

$$\Delta X_t = \alpha_2 + \sum_{j=1}^{r} \alpha_{21}(j)\, \Delta Y_{t-j} + \sum_{j=1}^{s} \alpha_{22}(j)\, \Delta X_{t-j} + \varepsilon_{xt} \tag{6}$$

3.5 Empirical Results

I report the *p*-values for Granger causality *F*-tests in Tables 3.5-3.10, for both ad hoc lag structures of 3, 6, and 12, as well as the optimal lag structure determined using the AIC criterion. In what follows, however, I only discuss the results based on the optimal lag structure and summarize the Granger causality test results under the 'Decision' column in each of the Tables 3.2-3.10.

As can be seen in Table 3.5, normal butane, isobutane, and crude oil prices Granger cause industrial production at the 5 percent level, whereas industrial production causes the prices except for propane, normal butane, isobutane, and crude oil (see Table 3.6). That is, I find unidirectional causality in all the cases, except for propane. This result is consistent with the results reported by Eksi *et al*. (2011), who, for seven OECD countries and data over the period 1997 to 2008, find unidirectional causality from crude oil prices to industrial production. It is to be noted that I find no evidence of natural gas prices causing industrial production (see Table 3.5), although there is evidence of a causal relationship from industrial production to natural gas prices at the 5% level (see Table 3.6).

As can be seen in Table 3.7, I find causality from each of isobutene and naphtha prices to crude oil prices. On the other hand, the *p*-values in Table 3.8, indicate strong causal relationships from the crude oil price to all HGL prices, as well as to natural gas prices (at 10% level). This provides a new evidence, which is different from the previous studies that show a decoupling of crude oil prices from the natural gas prices. See, for example, Erdös (2009).

Finally, in Table 3.9, I find causality from ethane, normal butane, and naphtha prices to natural gas prices, but as can be seen in Table 3.10, there is no causality whatsoever from natural gas prices to HGL prices, at conventional significance levels.

3.6 Conclusion

I investigate the causal relationship between HGL, crude oil, and natural gas prices with industrial production in the United States, using monthly data for the period January 1985 to January 2018 and the methodology suggested by Engle and Granger (1987).

I find that industrial production causes the prices except for propane, normal butane and isobutene prices and that only normal butane, isobutane, and crude oil prices cause industrial production. I find weak unidirectional causality from crude oil to natural gas prices, but that crude oil prices cause all HGL prices. Finally, there is no causality from natural gas prices to HGL prices, but there is causality from ethane, normal butane, and naphtha prices to natural gas prices.

Table 3.1 Unit Root and Stationarity Tests

Variable	Test			
	ADF	**DF-GLS**	**KPSS**	**Decision**
A. Log levels				
Industrial production	-1.80	-1.49	0.48	I(1)
Ethane	-2.87	-2.89	0.32	I(1)
Propane	-3.58	-2.86	0.21	I(1)
Normal butane	-3.52	-2.49	0.21	I(1)
Isobutane	-3.04	-2.59	0.21	I(1)
Naphtha	-0.29	-1.18	0.20	I(1)
Crude oil	-3.25	-2.38	0.25	I(1)
Natural gas	-1.97	-1.90	0.36	I(1)
B. Logarithmic first differences				
Industrial production	-5.33	-5.34	0.06	I(0)
Ethane	-18.81	-18.41	0.04	I(0)
Propane	-16.14	-15.87	0.04	I(0)
Normal butane	-14.51	-17.91	0.05	I(0)
Isobutane	-15.02	-17.96	0.05	I(0)
Naphtha	-19.40	-19.40	0.14	I(0)
Crude oil	-16.79	-16.75	0.06	I(0)
Natural gas	-6.70	-4.12	0.05	I(0)

Note: The 1% and 5% critical values are -3.98 and -3.42 for the ADF test, -3.48 and -2.89 for the DF-GLS test, and 0.216 and 0.146 for the KPSS test, respectively.

Table 3.2 Johansen Bivariate Cointegration Tests of HGL, Crude Oil, and Natural Gas Prices and Industrial Production

Trace Test

Log-level prices	**Eigenvalue**	**Trace**	**Critical value**	**P- value**	**Decision**
Ethane	0.03	12.62	15.49	0.13	No cointegration
Propane	0.02	13.09	15.49	0.11	No cointegration
Normal butane	0.02	12.85	15.49	0.12	No cointegration
Isobutane	0.02	11.23	15.49	0.20	No cointegration
Naphtha	0.02	6.83	15.49	0.60	No cointegration
Crude oil	0.02	11.81	15.49	0.17	No cointegration
Natural gas	0.04	17.88	15.49	0.02	Cointegration

Maximum Eigenvalue Test

Log-level prices	**Eigenvalue**	**Max-Eigen**	**Critical value**	**P- value**	**Decision**
Ethane	0.03	10.05	14.26	0.21	No cointegration
Propane	0.02	9.46	14.26	0.25	No cointegration
Normal butane	0.02	9.02	14.26	0.28	No cointegration
Isobutane	0.02	7.35	14.26	0.45	No cointegration
Naphtha	0.02	6.81	14.26	0.51	No cointegration
Crude oil	0.02	7.60	14.26	0.42	No cointegration
Natural gas	0.04	14.64	14.26	0.04	Cointegration

Note: All variables are in logarithms.

Table 3.3 Johansen Bivariate Cointegration Tests of HGL and Natural Gas Prices and Crude Oil Prices

Trace Test

Log-level prices	Eigenvalue	Trace	Critical value	P- value	Decision
Ethane	0.02	11.50	15.49	0.18	No cointegration
Propane	0.04	16.57	15.49	0.03	Cointegration
Normal butane	0.05	23.04	15.49	0.00	Cointegration
Isobutane	0.05	22.41	15.49	0.00	Cointegration
Naphtha	0.01	3.12	15.49	0.96	No cointegration
Natural gas	0.03	12.57	15.49	0.13	No cointegration

Maximum Eigenvalue Test

Log-level prices	Eigenvalue	Max-Eigen	Critical value	P- value	Decision
Ethane	0.02	8.93	14.26	0.29	No cointegration
Propane	0.04	14.33	14.26	0.05	Cointegration
Normal butane	0.05	20.71	14.26	0.00	Cointegration
Isobutane	0.05	20.07	14.26	0.01	Cointegration
Naphtha	0.01	3.02	14.26	0.95	No cointegration
Natural gas	0.03	10.07	14.26	0.21	No cointegration

Note: All variables are in logarithms.

Table 3.4 Johansen Bivariate Cointegration Tests of HGL and Natural Gas Prices

Trace Test

Log-level prices	Eigenvalue	Trace	Critical value	P- value	Decision
Ethane	0.04	20.47	15.49	0.01	Cointegration
Propane	0.03	14.47	15.49	0.07	No cointegration
Normal butane	0.03	13.56	15.49	0.10	No cointegration
Isobutane	0.02	12.05	15.49	0.15	No cointegration
Naphtha	0.01	6.76	15.49	0.61	No cointegration

Maximum Eigenvalue Test

Log-level prices	Eigenvalue	Max-Eigen	Critical value	P- value	Decision
Ethane	0.04	15.44	14.26	0.03	Cointegration
Propane	0.03	11.07	14.26	0.15	No cointegration
Normal butane	0.03	10.09	14.26	0.21	No cointegration
Isobutane	0.02	8.99	14.26	0.29	No cointegration
Naphtha	0.01	5.77	14.26	0.64	No cointegration

Note: All variables are in logarithms.

Table 3.5 Granger Causality Tests: the Dependent Variable is Industrial Production

	Lag					
	3	6	12	Optimal AIC lag (r,s)	P- value	Decision
Ethane	0.26	0.64	0.82	5, 3	0.34	No causality
Propane	0.14	0.58	0.55	8, 2	0.27	No causality
Normal butane	0.04	0.15	0.36	8, 2	0.05	Causality
Isobutane	0.00	0.04	0.14	8, 2	0.01	Causality
Naphtha	0.18	0.08	0.22	8, 1	0.37	No causality
Crude oil	0.06	0.15	0.28	5, 3	0.05	Causality
Natural gas	0.82	0.91	0.60	8, 1	0.99	No causality

Table 3.6 Granger Causality Tests: the HGL, Crude Oil, and Natural Gas Prices are the Dependent Variables and Industrial Production is the Independent Variable

	Lag					
	3	6	12	Optimal AIC lag (r,s)	P- value	Decision
Ethane	0.12	0.12	0.24	5, 3	0.10	Causality
Propane	0.12	0.20	0.15	8, 2	0.41	No causality
Normal butane	0.11	0.11	0.07	8, 2	0.39	No causality
Isobutane	0.08	0.08	0.09	8, 2	0.24	No causality
Naphtha	0.95	0.82	0.97	8, 1	0.04	Causality
Crude oil	0.08	0.11	0.04	5, 3	0.13	No causality
Natural gas	0.05	0.10	0.07	8, 1	0.03	Causality

Table 3.7 Granger Causality Tests: the Dependent Variable is Crude Oil Prices

	Lag					
	3	6	12	Optimal AIC lag (r,s)	P- value	Decision
Ethane	0.28	0.30	0.35	2, 2	0.14	No causality
Propane	0.35	0.61	0.11	2, 1	0.10	No causality
Normal butane	0.28	0.60	0.44	2, 1	0.37	No causality
Isobutane	0.14	0.22	0.09	2,1	0.04	Causality
Naphtha	0.21	0.50	0.86	3, 3	0.06	Causality
Natural gas	0.60	0.62	0.74	2, 1	0.68	No causality

Table 3.8 Granger Causality Tests: the HGL and Natural Gas Prices are the Dependent Variables and Crude Oil Prices is the Independent Variable

	Lag					
	3	**6**	**12**	**Optimal AIC lag (r,s)**	**P- value**	**Decision**
Ethane	0.00	0.03	0.08	2, 2	0.00	Causality
Propane	0.00	0.00	0.00	2, 1	0.00	Causality
Normal butane	0.00	0.00	0.00	2, 1	0.00	Causality
Isobutane	0.00	0.00	0.00	2,1	0.00	Causality
Naphtha	0.20	0.53	0.62	3, 3	0.00	Causality
Natural gas	0.02	0.02	0.01	2, 1	0.08	Causality

Table 3.9 Granger Causality Tests: the Dependent Variable is Natural gas Prices

	Lag					
	3	**6**	**12**	**Optimal AIC lag (r,s)**	**P- value**	**Decision**
Ethane	0.00	0.02	0.10	3, 3	0.00	Causality
Propane	0.05	0.09	0.40	3, 1	0.16	No causality
Normal butane	0.09	0.07	0.24	3, 3	0.08	Causality
Isobutane	0.11	0.03	0.09	3, 3	0.11	No causality
Naphtha	0.50	0.75	0.60	3, 5	0.01	Causality

Table 3.10 Granger Causality Tests: the HGL Prices are the Dependent Variables and Natural Gas Prices is the Independent Variable

	Lag					
	3	6	12	Optimal AIC lag (r,s)	P- value	Decision
Ethane	0.35	0.42	0.06	3, 3	0.24	No causality
Propane	0.56	0.32	0.58	3, 1	0.28	No causality
Normal butane	0.48	0.67	0.75	3, 3	0.48	No causality
Isobutane	0.19	0.03	0.06	3, 3	0.19	No causality
Naphtha	0.11	0.14	0.35	3, 5	0.11	No causality

Chapter 4

Conclusion

For the first time in the literature, in this thesis, I investigate the cyclical behavior of hydrocarbon gas liquids prices, using monthly data for the period January 1985 to January 2018 and the methodology suggested by Kydland and Prescott (1990). Based on the new Hamilton (2017) regression filter and Hodrick and Prescott (1981) filter, my robust results indicate that hydrocarbon gas liquids prices are procyclical and lead the cycle of industrial production. Moreover, hydrocarbon gas liquids prices are positively contemporaneously correlated with the WTI crude oil price and synchronous with the cycle of crude oil. Finally, HGL prices are synchronous with the Henry Hub natural gas price.

I also examine the causal relationship between the hydrocarbon gas liquids prices and industrial production and crude oil prices, as well as between natural gas prices and each of hydrocarbon gas liquids prices. Following the methodology suggested by Engle and Granger (1987), I find that industrial production causes the HGL prices only for ethane and naphtha, as well as the prices for natural gas. On the other hand, only normal butane, isobutane, and crude oil prices cause industrial production. This finding is consistent with my cyclical correlation results, except for the crude oil prices, that the prices of ethane and naphtha as well as the prices of natural gas are procyclical and lead the cycle of industrial production. Where crude oil prices follow unidirectional relationship with the industrial production, are consistent with the evidence reported by Eksi *et al*. (2011).

Lastly, there is no causality from natural gas prices to hydrocarbon gas liquids prices, but there is causality from ethane, normal butane, and naphtha prices to natural gas prices.

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