The Global Crude Oil Market and Biofuel Agricultural Commodity Prices

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Abstract

In this paper we use quarterly data, over the period from 1975:2 to 2016:1, and a joint structural VAR model of the global crude oil market and the U.S. corn market, to disentangle demand and supply shocks in the global crude oil market and the U.S. corn market and investigate their effects on corn prices in the United States. We identify the model by assuming that innovations to the real price of crude oil are predetermined with respect to the corn market in the United States and show that close to 36% of the variation in the real price of corn can be attributed to structural supply and demand shocks in the global crude oil market.

JEL classification: C32; Q4; Q11.

Keywords: Oil price shocks; Corn market; Structural VAR.

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1 Introduction

After the United States authorities enacted in 2005 the Renewable Fuel Standard, also known as the ethanol mandate, there have been significant changes in the dynamics between fossil fuel and agricultural commodity prices. The ethanol mandate specifies that gasoline and diesel contain a certain amount of biofuel (mostly ethanol), derived from feedstocks (mostly corn). As recently put by Avalos and Lombardi (2015, p. 1), "some studies have then argued that ethanol and biodiesel subsidies in advanced economies may have strengthen the link between the prices of oil and those of some food commodities." In this regard, Serletis and Xu (2018), in their investigation of mean and volatility spillovers between the crude oil market and the main biofuel feedstock markets, also find that the ethanol mandate has strengthened the linkages between the oil market and the biofuel feedstock markets in terms of volatility spillovers. In fact, as can be seen in Figure 1, before the ethanol mandate, crude oil and corn prices move together and decouple episodically in response to economic growth, technological change, and weather conditions. However, after the ethanol mandate, the price of corn in the United States has increased significantly and moves more closely with the price of crude oil. See also Coronado *et al.* (2018) for a more detailed discussion regarding the relationship between crude oil prices and biofuel agricultural commodity prices.

Our approach in this paper complements Avalos and Lombardi (2015), who investigate the impact of oil market structural shocks on the prices of corn, soybean, and sugar, using the Kilian (2009) structural VAR with monthly data. However, our study differs from Avalos and Lombardi, as we follow Kilian (2010) and investigate the effects of demand and supply shocks in the global crude oil market and the U.S. corn market on corn prices in the United States. In particular, we estimate the structural VAR model of Kilian (2010), augmented with the real price of corn and corn consumption, in order to investigate the relationship between crude oil and corn prices. We treat the price of crude oil as endogenous and disentangle the causes underlying oil price shocks. In particular, we model changes in the real price of crude oil as arising from three different sources: shocks to the global supply of crude oil, shocks to the global demand for all industrial commodities (including crude oil) that are driven by the global business cycle, and oil-market specific demand shocks (also referred to as precautionary demand shocks). We use quarterly data, over the period from 1975:2 to 2016:1, and find that close to 36% of the variation in the real price of corn in the United States can be attributed to structural supply and demand shocks in the global crude oil market.

The paper is organized as follows. Section 2 discusses the data. Sections 3 and 4 describe the empirical method and present the results. Section 5 investigates the robustness of the results, and the final section briefly concludes the paper.

2 Data

We consider a structural VAR model based on quarterly time series data for the United States, from 1975:2 to 2016:1, for $\boldsymbol{z}_t = (\Delta prod_t, rea_t, rpo_t, rpcorn_t, \Delta CornUse_t)'$, where $\Delta prod_t$ is the percent change in global crude oil production, rea_t is a measure of real economic activity, rpo_t is the real price of oil, $rpcorn_t$ is the real price of corn, and $\Delta CornUse_t$ is the percent change in U.S. total corn consumption.

Regarding the percent change in global crude oil production, $\Delta prod_t$, we use the oil production data from the U.S. Department of Energy to compute the log differences of world crude oil production in millions of barrels pumped per day (and averaged by month). We use Kilian's (2009) detrended real freight rate index to measure the component of real economic activity (rea_t) that drives demand for industrial commodities in global markets. As noted by Kilian (2009), this index is constructed from dry cargo single voyage ocean freight rates and is deflated by the U.S. Consumer Price Index (CPI) to express it in real terms. The real freight rate index is linearly detrended to remove long-term trends and thus represent the global business cycle; whether the detrended freight rate index is an adequate reflection of the overall economic climate is an issue beyond the scope of this paper. See Kilian (2009) for more details regarding the construction of this measure of global real economic activity. Finally, we divide the U.S. composite refiners' acquisition cost of crude oil (RAC), as compiled by the U.S. Department of Energy, by the U.S. Consumer Price Index (CPI) to obtain the real price of crude oil, rpo_t.

We seasonally adjust the price received by U.S. corn producers (dollars per bushel), as compiled by the U.S. Department of Agriculture, and divide it by the U.S. CPI to obtain the real price of corn, $rpcorn_t$. Corn total disappearance (million bushels) from the U.S. Department of Agriculture is employed to calculate the percent change in seasonally adjusted U.S. total corn consumption, $\Delta CornUse_t$. The corn consumption data is only available quarterly on a marketing-year basis; based on the U.S. Department of Agriculture, the marketing year for corn supply-use statistics begins September 1 and is comprised of four quarters, September-November, December-February, March-May, and June-August. In order to match the frequency of the corn consumption series, we convert all the monthly data to quarterly data based on the corn marketing year. Finally, the fact that global oil production enters the VAR model in percent changes, $\Delta prod_t$, and the measure of real economic activity, rea_t, is expressed as percent deviations from trend, suggests that we should be using the demeaned forms (deviations from mean) of the natural logs of the real oil price and corn prices in order to have consistent variables in the VAR system of equations.

Figure 2 shows the historical evolution of our series (the percent change in global crude oil production, $\Delta prod_t$, real economic activity, rea_t, log real oil price, rpo_t, log real corn price, $rpcorn_t$, and the percent change in U.S. total corn consumption, $\Delta CornUse_t$) over the sample period.

3 The Structural VAR Model

The structural VAR representation is based on Kilian (2009) and Kilian and Park (2009) and is

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

where γ is a parameter vector, $\boldsymbol{B}$ and $\boldsymbol{\Gamma}_i$ denote the contemporaneous and lagged coefficient matrices, respectively, and $\boldsymbol{\varepsilon}_t$ is a vector of serially and mutually uncorrelated structural innovations, $\boldsymbol{\varepsilon}_t = \left(\varepsilon_t^{\Delta prod}, \varepsilon_t^{rea}, \varepsilon_t^{rpo}, \varepsilon_t^{rpcorn}, \varepsilon_t^{\Delta CornUse}\right)'$.

Assuming that $\boldsymbol{B}^{-1}$ exists, the reduced-form representation of equation (1) is

$$\boldsymbol{z}_t = \alpha + \sum_{i=1}^{p} \boldsymbol{A}_i \boldsymbol{z}_{t-i} + \boldsymbol{e}_t \tag{2}$$

where $\alpha = \boldsymbol{B}^{-1}\gamma$, $\boldsymbol{A}_i = \boldsymbol{B}^{-1}\boldsymbol{\Gamma}_i$, and the reduced form innovations, $\boldsymbol{e}_t$, are linear combinations of the structural shocks, $\boldsymbol{\varepsilon}_t$, $\boldsymbol{e}_t = \boldsymbol{B}^{-1}\boldsymbol{\varepsilon}_t$. We estimate the reduced-form (2) and recover the structural shocks, $\boldsymbol{\varepsilon}_t$, by imposing zero (exclusion) restrictions on the elements of $\boldsymbol{B}$. Then we use the structural moving average representation of the model to infer the impulse responses.

We assume that $\boldsymbol{B}^{-1}$ has a recursive structure such that the reduced-form innovations, $\boldsymbol{e}_t$, can be decomposed according to $\boldsymbol{e}_t = \boldsymbol{B}^{-1}\boldsymbol{\varepsilon}_t$, as follows

$$\boldsymbol{e}_t \equiv \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \\ e_t^{rpcorn} \\ e_t^{\Delta CornUSe} \end{pmatrix} = \begin{pmatrix} b_{11} & 0 & 0 & 0 & 0 \\ b_{21} & b_{22} & 0 & 0 & 0 \\ b_{31} & b_{32} & b_{33} & 0 & 0 \\ b_{41} & b_{42} & b_{43} & b_{44} & 0 \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{oil\ supply\ shock} \\ \varepsilon_t^{aggregate\ demand\ shock} \\ \varepsilon_t^{oil\ specific-demand\ shock} \\ \varepsilon_t^{corn\ supply\ shock} \\ \varepsilon_t^{corn\ demand\ shock} \end{pmatrix}. \tag{3}$$

We can think of our model (3) as being composed of two blocks, with the first block, consisting of the first three equations, describing the global crude oil market, and the second block, consisting of the last two equations, describing the corn market.

4 Structural VAR Estimates

We use the Akaike information criterion (AIC) to optimally select the lag structure in the VAR model. We choose $p = 3$ in (2), and estimate the reduced form VAR (with a total of 80 parameters) by the least squares method. We use the resulting estimates to construct the structural VAR representation of the model and calculate impulse response functions to one-standard deviation shocks, together with one- and two- standard error bands, based on the recursive-design wild bootstrap of Gonçalves and Kilian (2004). Our main objective is to investigate the effects of structural shocks in the crude oil market on the corn market in the United States.

4.1 Demand and Supply Shocks

In Figure 3 we plot the estimated quarterly structural residuals of the joint structural VAR model (1) of the global crude oil market and the U.S. corn market, using observations since 1976:1, reflecting the lags used up in estimating the model. The historical decomposition of shocks in the crude oil market (the first three graphs), are consistent with Kilian's (2009) findings. However, the historical decomposition of fluctuations in the corn market stands out. There is a sequence of negative supply and positive demand shocks after 2002, that may explain the dramatic rise of the real price of corn. Although large crude oil shocks are important in explaining movements in the real price of corn, a sequence of small shocks of the same sign and type, occurring over several periods, may have more dramatic effects on the real price of corn than any single large demand or supply oil shock. As Kilian (2010, p.

98) put it, in his investigation of fluctuations in gasoline prices, "this is particularly true of the sequence of positive aggregate demand shocks after 2002."

4.2 Crude Oil and Corn Price Responses to Shocks

In Figure 4 we plot the responses of the real price of crude oil and the real price of corn to the three types of shocks that drive the global crude oil market. The supply shock has been normalized to represent an oil supply disruption and the demand shock has been normalized to represent a demand expansion. Impulse responses are shown for an horizon of eight quarters, and we focus on responses to one-standard deviation demand and supply shocks; by construction, approximately one third of the historically observed shocks have exceeded a shock of this magnitude.

The first column of Figure 4 shows that shocks to the supply of crude oil increase the real price of crude oil after two quarters. The response is statistically significant based on one-standard error bands, and consistent with Kilian (2010) and Jadidzadeh and Serletis (2017). However, the real price of corn initially declines and then increases, with the response being statistically insignificant at all horizons. As shown in the second column, an unanticipated increase in global demand for industrial commodities, causes a persistent increase in both prices. The response of the real crude oil prices is highly significant at all horizons, while the response of the real corn price is statistically significant after the first quarter (according to the one-standard error bands). Finally, as shown in the third column of Figure 4, oil-market specific demand shocks cause an immediate (and statistically significant) increase in crude oil prices while they do not have a statistically significant effect on corn prices.

Figure 5 shows the corresponding responses to demand and supply shocks that are specific to the U.S. corn market. An unexpected decline in the supply of corn (say because of bad weather conditions) has an immediate, large, and positive effect on the real corn price, with the corn price response being statistically significant at all horizons. The same shock causes a temporary increase in the real price of crude oil which is statistically significant for up to three quarters. This result can be due to bad weather conditions, such as hurricanes Rita or Katrina, that affect both prices. The second column of Figure 5 shows that an unanticipated increase in U.S. corn demand has no statistically significant effect on the real price of either crude oil or corn.

4.3 Corn Consumption Responses to Shocks

Figure 6 focuses on the responses of the quantity of corn consumed in the United States to demand and supply shocks in the global crude oil market and the U.S. corn market. As can be seen, an oil supply disruption or oil-specific demand shock has no statistically significant effects on U.S. corn consumption. In contrast, aggregate demand shocks cause the consumption of corn to rise immediately, with the initial response being fairly large. Corn supply shocks cause corn consumption to drop immediately and then to rise over time. Finally, an unexpected corn demand shock causes an immediate increase in corn demand.

4.4 Forecast Error Variance Decompositions

Next, we investigate how much of the variation in U.S. corn prices can be attributed to each demand and supply shock. We do so, by computing forecast error variance decompositions based on the estimated VAR model of section 3. Table 1 reports the average contribution of each shock to the total variation in the real price of corn in percentage terms. On impact, 98% of the variation in corn prices is accounted for by corn supply shocks. The remaining shocks play no role. In contrast, in the long run, the importance of corn supply shocks declines to 63%, whereas that of aggregate demand shocks increases to 32%. The explanatory power of oil supply shocks, oil-specific demand shocks, and corn demand shocks remains below 2.5% at all horizons.

Table 2 shows the corresponding decomposition of the variation in the growth rate of U.S. corn consumption. That variation is dominated by corn demand shocks which account for 87% on impact and 81% in the long run. Corn supply shocks explain 3% of the variation on impact and 7% in the long run. Shocks in the crude oil market are less important, but gain in importance over time. In the long run, oil supply shocks account for 0.6% of the variation, aggregate demand shocks for 8%, and oil-market specific demand shocks for another 4%. This evidence is consistent with the view that U.S. corn consumption is only moderately sensitive to corn supply shocks.

These estimates are based on historical averages for the period since 1976. In practice, the relative importance of each shock may be quite different from one historical episode to the next. In fact, it has been observed that historically no two episodes of oil price shocks have been alike — see Kilian (2009). It is therefore instructive to investigate the movements in the real price of corn and to trace out the effect of each shock on the real price of corn through time. Of particular interest is the evolution of corn prices before and after ethanol mandate in 2006:1.

5 Robustness

The long sample period used in this paper raises the question of structural stability of the estimated structural VAR, suggesting an empirical analysis based on sub-samples. For example, there have been significant changes in the dynamics between crude oil and corn prices, after the United States enacted the ethanol mandate in 2005. In order to investigate the robustness of our results, in what follows we calculate the forecast-error-variance decompositions, impulse responses, and cumulative impulse responses for the period before 2006:1, that is, before the ethanol mandate.

For the period from 1975:2 to 2005:4 (with 119 quarterly observations), we estimate the structural VAR with three lags ($p = 3$ in (2)) as suggested by the AIC. As illustrated in Figures 7–9, the impulse responses are very similar to those in Figures 4–6 for the whole sample. The differences between the results based on forecast error variance decompositions are interesting. As shown in Table 3, in the long run, aggregate demand shocks account for 11% of the variation in the corn prices for the period before the mandate (i.e. 1975:2-2005:4), while for the whole period this contribution is more than 32%. It seems that after the ethanol mandate aggregate demand shocks play a bigger role in corn prices variation. Moreover, corn supply shocks explain 84% of the variation in the corn price before the mandate, compared to 63% for the whole sample. Comparing the results in Tables 2 and 4, we see that corn demand shocks explain about 68% of the variation in the growth rate of U.S. corn consumption before the mandate, compared to 81% of the variation in the case of the whole sample.

6 Conclusion

We have followed Kilian (2010) and used a joint model of the global crude oil market and the U.S. corn market to disentangle demand and supply shocks in the global crude oil market and the U.S. corn market and investigate their effects on corn prices in the United States. We use quarterly data, over the period from 1975:2 to 2016:1, and find that out of three shocks in the crude oil market — oil supply shocks, aggregate demand shocks, and oil-specific demand shock — only aggregate demand shocks cause statistically significant changes in corn price and consumption. In the corn market, an unexpected decline in the supply of corn has an immediate, large positive impact on the real price of corn, while the corn demand has no statistically significant impact. In the long run, the importance of corn supply shocks on corn prices declines from 98% to 63%, whereas that of aggregate demand shocks increases from 1% to 32%. The explanatory power of oil supply shocks, oil-specific demand shocks, and corn demand shocks remains below 2.5%. Moreover, after the ethanol mandate aggregate demand shocks play a more important role in corn price fluctuations.

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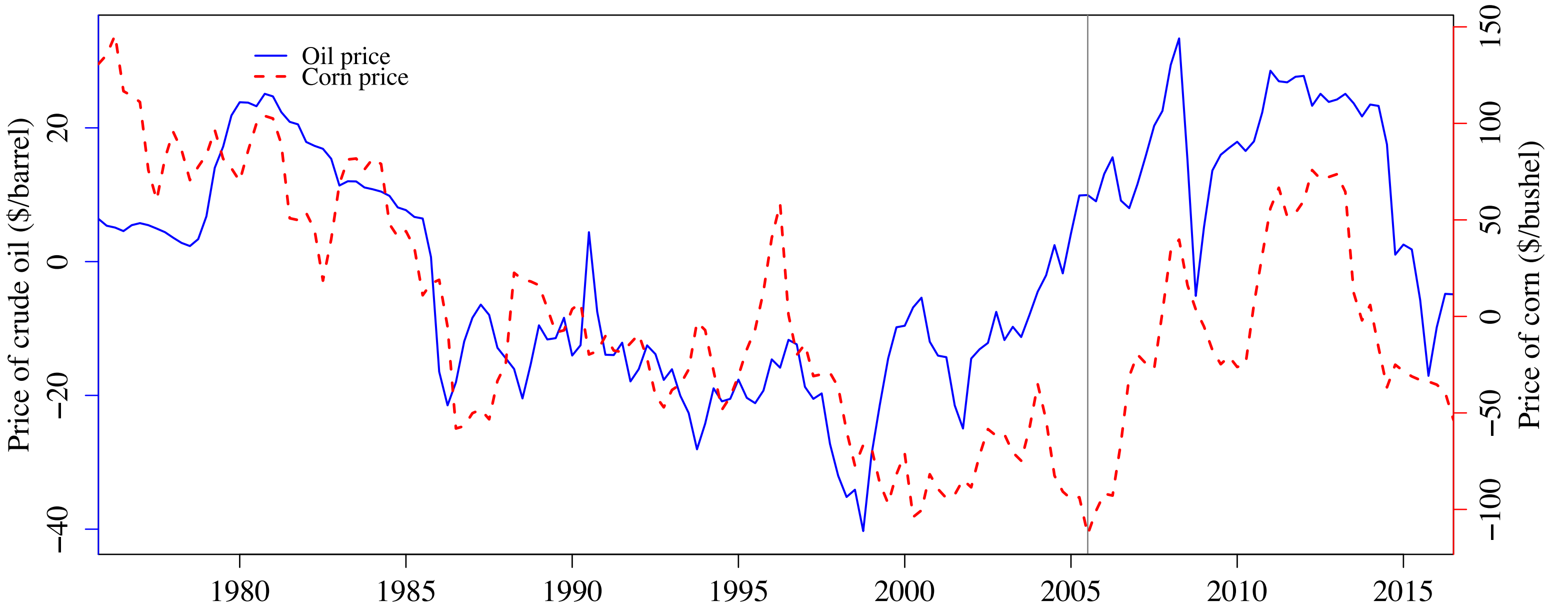

Figure 1. Crude oil and corn prices, 1975:Q2−2016:Q1.

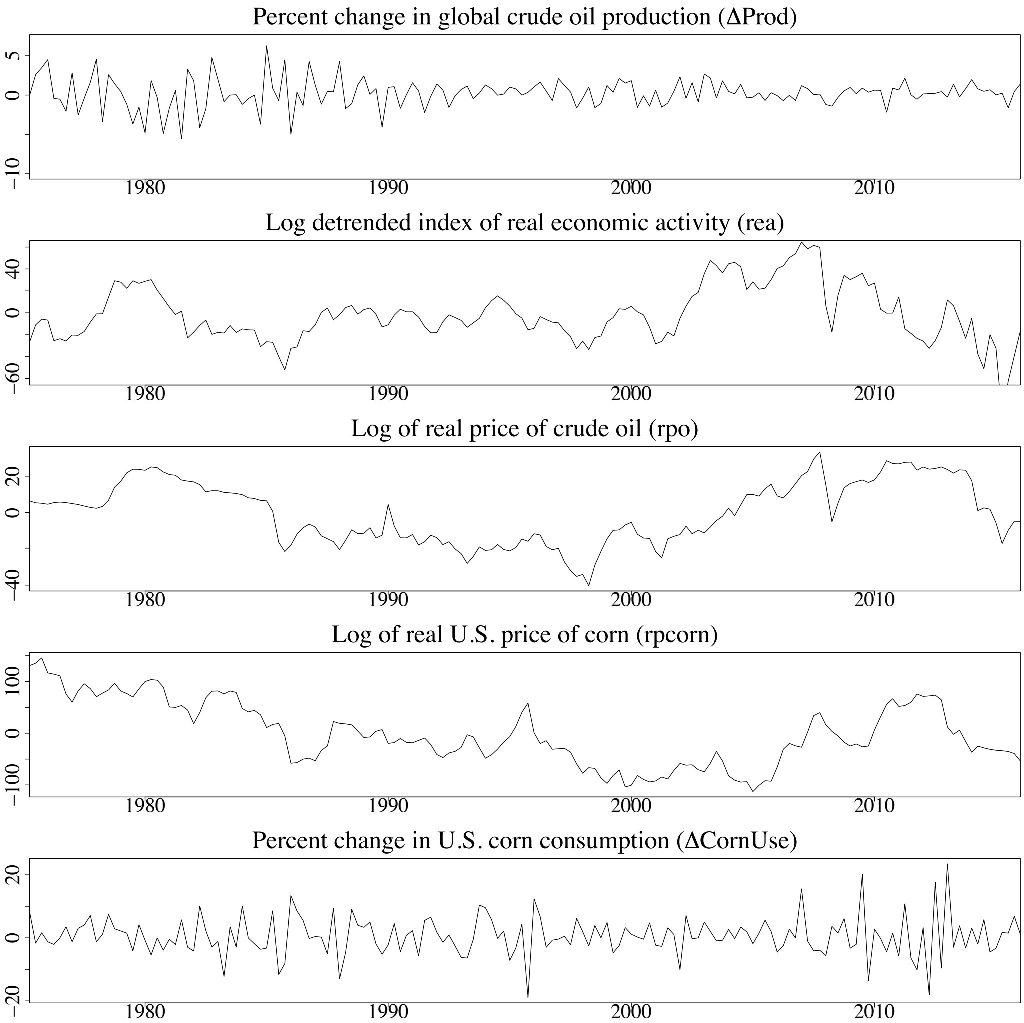

Figure 2. Historical evolution of the series, 1975:Q2−2016:Q1.

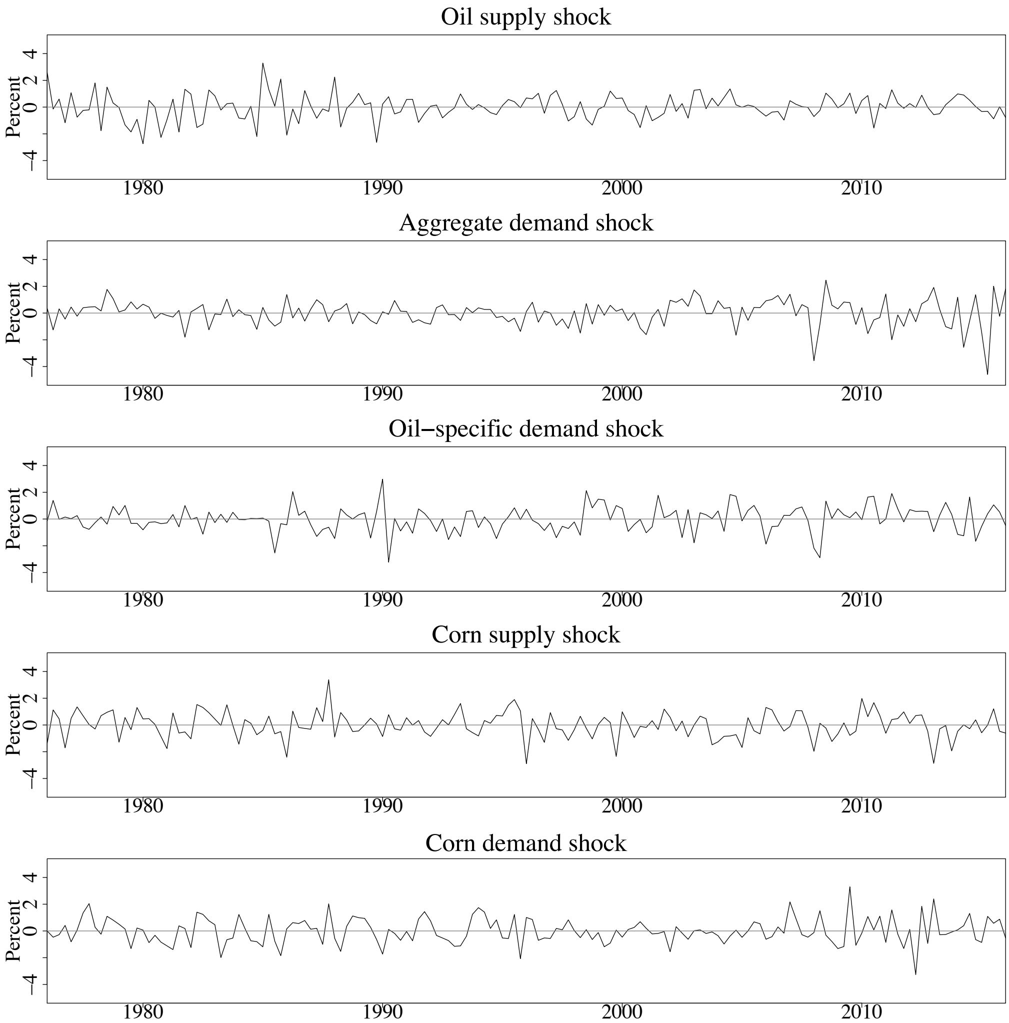

Figure 3. History of demand and supply shocks in the structural VAR model, 1976:Q1-2016:Q1.

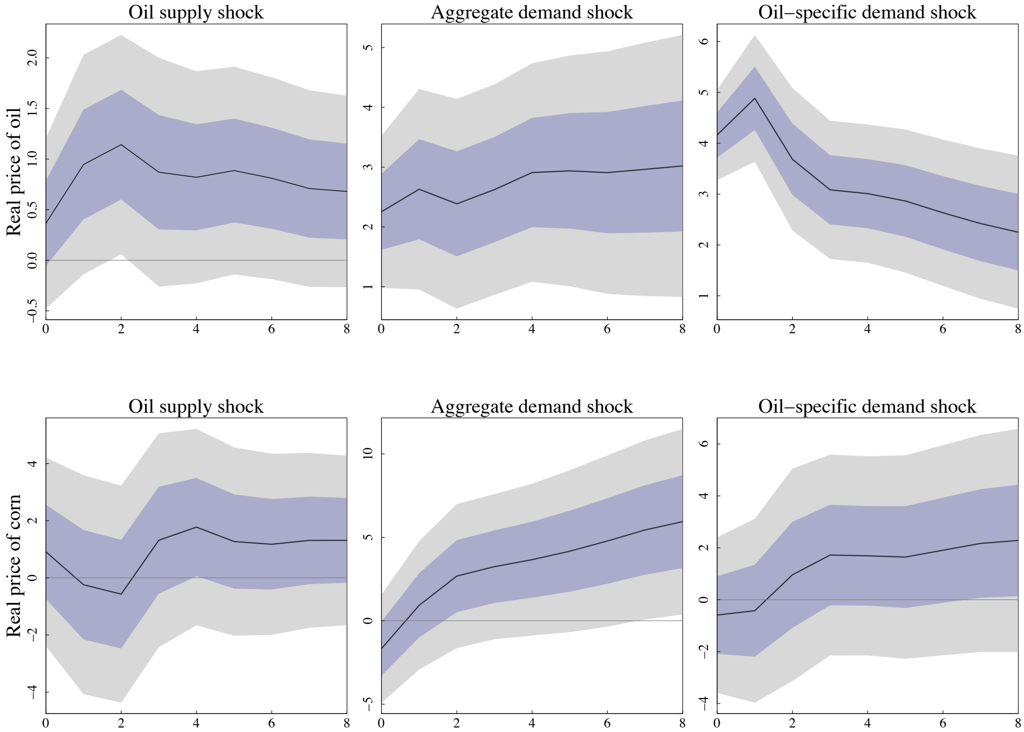

Figure 4. Responses of the real price of crude oil (upper panel) and the real price of corn (lower panel) to one-standard deviation structural shocks in the crude oil market: Point estimates with one- and two-standard error confidence bands.

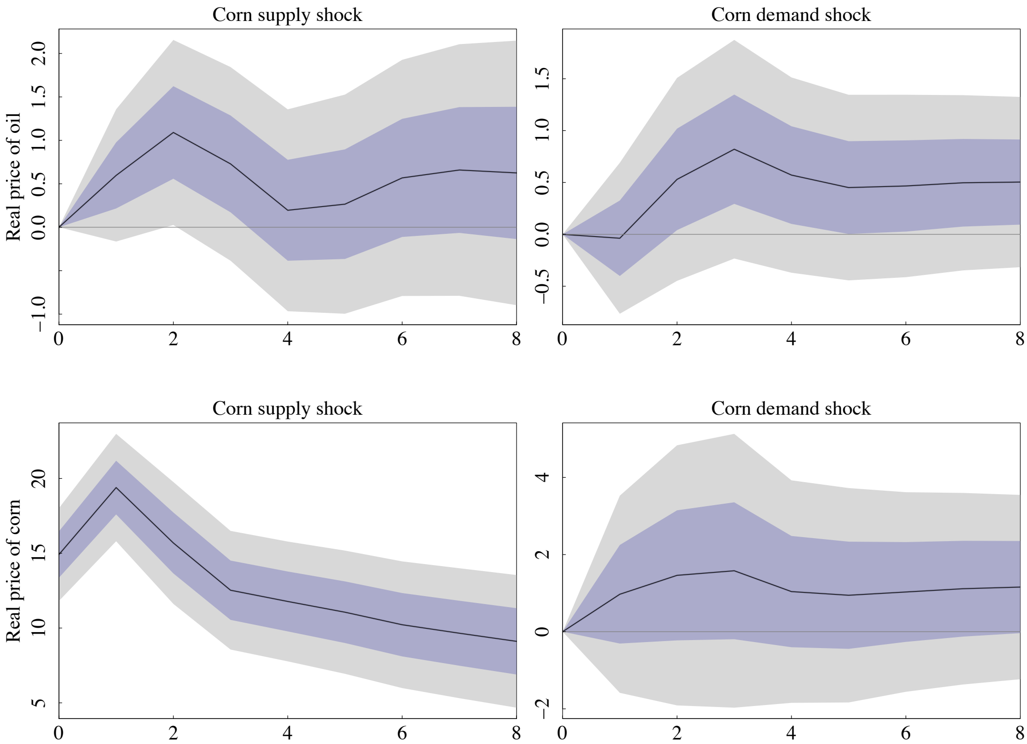

Figure 5. Responses of the real price of crude oil (upper panel) and the real price of corn (lower panel) to one-standard deviation structural shocks in the corn market: Point estimates with one- and two-standard error confidence bands.

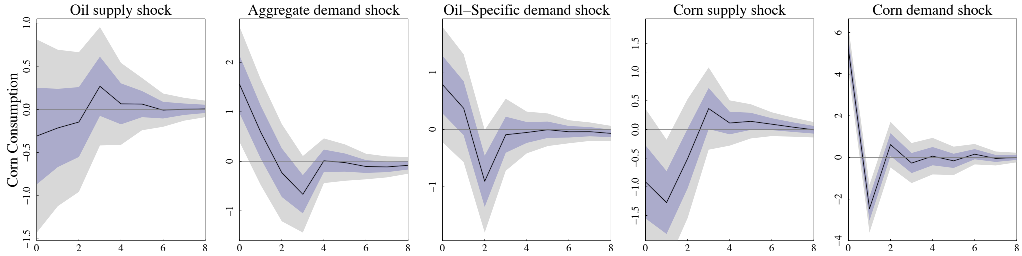

Figure 6. Responses of U.S. corn consumption to demand and supply shocks to one-standard deviation structural shocks in the corn market: Point estimates with one- and two-standard error confidence bands.

Table 1. Percent contribution of supply and demand shocks in the crude oil market to the overall variability of the real corn price.

	Shock				
Horizon	Oil supply	Aggregate demand	Oil-specific demand	Corn supply	Corn demand
1	0.37	1.22	0.15	98.26	0.00
2	0.15	0.60	0.09	99.01	0.16
3	0.14	1.25	0.17	98.08	0.36
15	0.94	17.55	2.27	78.41	0.83
∞	1.01	32.39	2.51	63.07	1.02

Note: Based on variance decompositions of the structural VAR model (1).

Table 2. Percent contribution of supply and demand shocks in the crude oil market to the overall variability of the growth rate of U.S. corn consumption.

	Shock				
Horizon	Oil supply	Aggregate demand	Oil-specific demand	Corn supply	Corn demand
1	0.31	7.74	1.96	2.70	87.30
2	0.36	7.00	1.90	6.28	84.47
3	0.40	6.87	3.83	6.67	82.23
15	0.58	7.93	3.80	6.96	80.73
∞	0.58	7.96	3.80	6.96	80.70

Note: Based on variance decompositions of the structural VAR model (1).

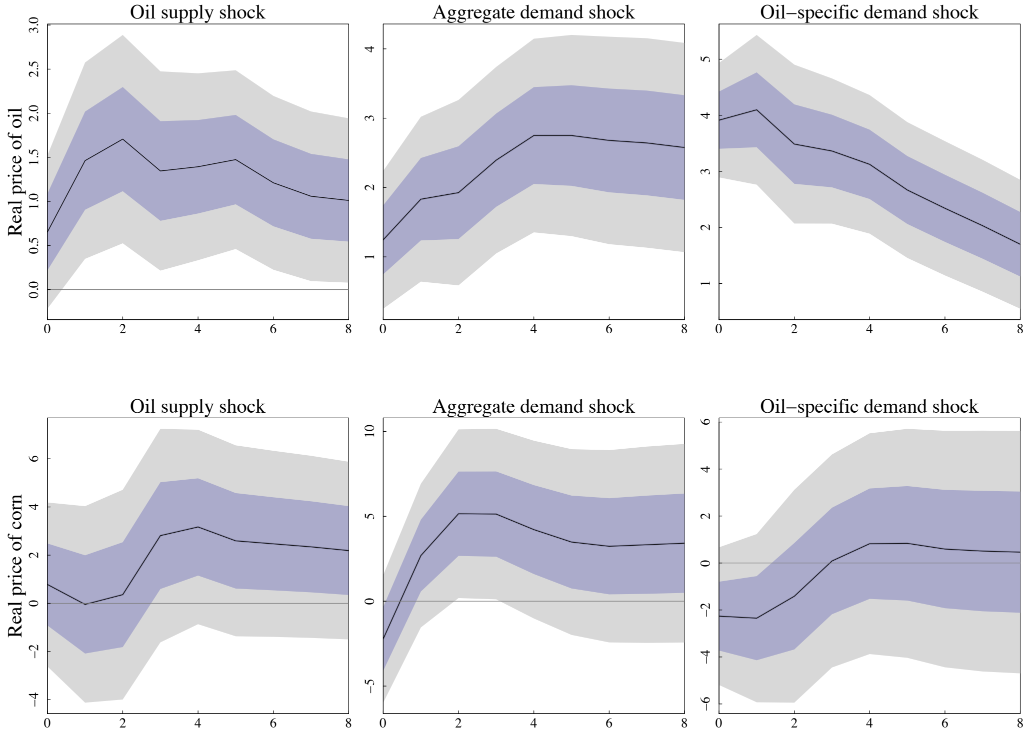

Figure 7. Responses of the real price of crude oil (upper panel) and the real price of corn (lower panel) to one-standard deviation structural shocks in the crude oil market: Point estimates with one- and two-standard error confidence bands, for the pre-ethanol mandate period.

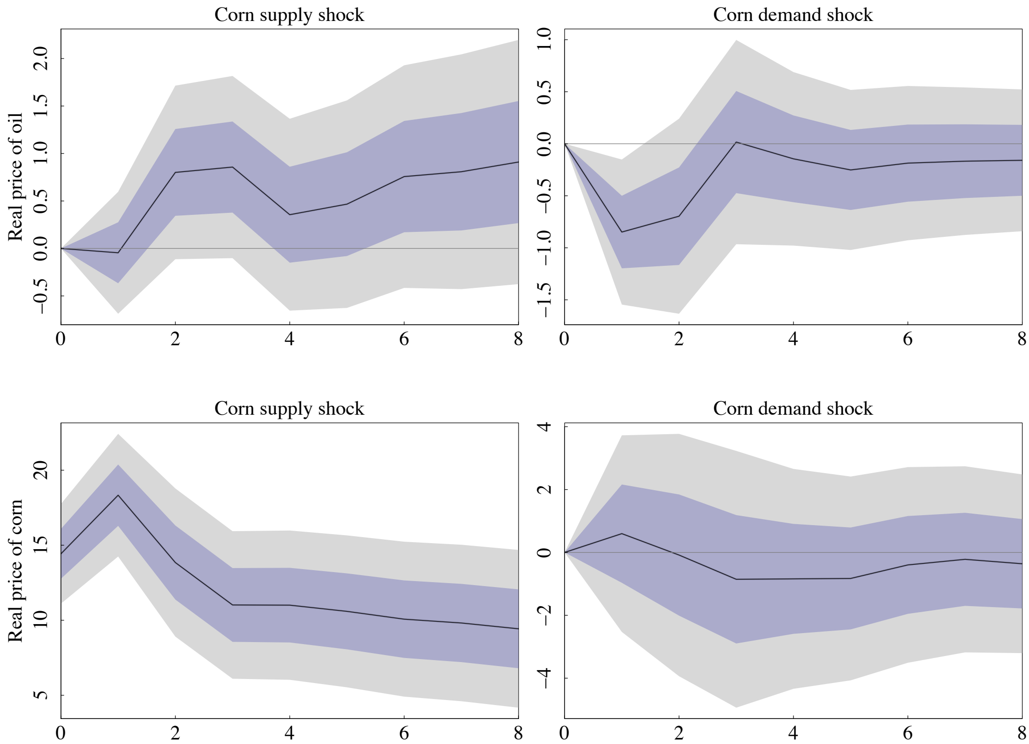

Figure 8. Responses of the real price of crude oil (upper panel) and the real price of corn (lower panel) to one-standard deviation structural shocks in the corn market: Point estimates with one- and two-standard error confidence bands, for the pre-ethanol mandate period.

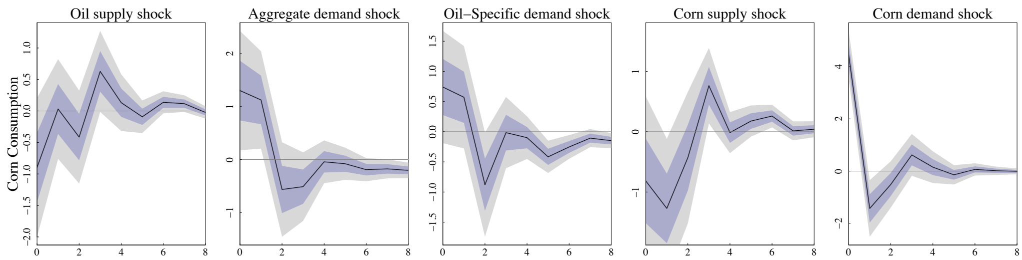

Figure 9. Responses of U.S. corn consumption to demand and supply shocks to one-standard deviation structural shocks in the corn market: Point estimates with one- and two-standard error confidence bands, for the pre-ethanol mandate period.

Table 3. Percent contribution of supply and demand shocks in the crude oil market to the overall variability of the real corn price, for the pre-ethanol mandate period.

	Shock				
Horizon	Oil supply	Aggregate demand	Oil-specific demand	Corn supply	Corn demand
1	0.28	2.25	2.34	95.13	0.00
2	0.11	2.14	1.87	95.82	0.06
3	0.09	4.91	1.60	93.35	0.05
15	3.17	9.42	0.81	86.43	0.18
∞	3.64	11.34	0.64	84.20	0.18

Note: Based on variance decompositions of the structural VAR model (1).

Table 4. Percent contribution of supply and demand shocks in the crude oil market to the overall variability of the growth rate of U.S. corn consumption, for the pre-ethanol mandate period.

	Shock				
Horizon	Oil supply	Aggregate demand	Oil-specific demand	Corn supply	Corn demand
1	3.42	7.21	2.33	2.83	84.21
2	2.80	10.30	3.04	7.92	75.94
3	3.20	10.77	5.40	8.09	72.54
15	4.37	11.57	5.98	9.65	68.44
∞	4.37	11.62	6.00	9.66	68.35

Note: Based on variance decompositions of the structural VAR model (1).