The Information Content in the Term Structure of Commodity Prices

by

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Abstract

In this paper, we investigate the term structure of agricultural commodity prices. Using corn as an example, we demonstrate that commodity futures price curve can be well-approximated by three latent factors: level, slope, and curvature obtained from a dynamic latent factor model. Relating the three unobserved factors to observable economic fundamentals, we find that real economic activity and relative scarcity of the commodity play an important role in the evolution of the corn futures price curve. Using Granger causality tests, we find that all three unobserved factors of the futures price curve contain predictive information on real economic activity and the relative scarcity of the commodity. Consistent with the theory of storage, there is a forward-looking element embedded in the term structure of commodity prices that contain information regarding subsequent market fundamentals.

Keywords: *term structure, dynamic latent factor model, corn, real economic activity, stocks-to-use ratio, interest rate*

JEL Classification Codes*: C52, C53, G12, G13, Q13, Q14.*

Introduction

An issue of central interest in commodity markets is the extent to which futures price may serve as a reliable forecast of future spot price. With the recent heightened volatility in commodity markets, access to accurate price forecasts has become crucially important for market participants who wish to better manage their price risks. A common belief held by policymakers and practitioners is that commodity futures prices not only convey information regarding future supply and demand conditions, but also represent the best estimate of the future spot price. However, a recent study by Alquist and Kilian (2010) suggests that oil futures prices perform no better than a simple no-change forecast, casting doubt on the predictive information content of futures prices. Alquist and Kilian (2010) argue that the inferiority of futures-based forecast is driven by the variability of the futures price around the spot price as captured by future price spreads, which they show to be linked to a marginal convenience yield.

Traditionally, the question of whether futures prices and their term structure (i.e., the difference between futures prices of different maturities) contain information on future spot prices has been examined by the hypothesis-testing approach through regression analysis. Fama (1984) shows that when the market is efficient, the term structure of interest rate does contain useful information about future spot rate. Fama and French (1987) extend such application to a variety of commodity futures markets, and show that futures prices show forecast power or expected premiums depending on the specific market being examined. Despite numerous research on the information content of futures price and term structure (e.g. Fama 1990, Swanson and White 1995, Chernenko et al. 2004, McCallum and Wu 2005, etc.), little agreement has been reached on whether there exists a risk premium in commodity markets and whether futures prices provide a reliable forecast of future spot price.

In this paper, we take a different approach compared to the previous literature by modeling the shape of the futures price curve. Such an examination complements and expands on the traditional hypothesis-testing research as in Fama and French (1987) and the forecasting approach as in Alquist and Kilian (2010) in at least two ways. First, while futures prices of different maturities are considered separately in previous studies, prices of the entire collection of futures contracts are considered simultaneously when investigating the shape of the term structure. A complete examination of all prices available can certainly provide more information regarding the current market structure and future price behavior. Second, both hypothesis-testing and forecasting analyses focus primarily on the ability of futures prices to predict future spot prices, either on an in-sample or out-of-sample basis. Neither of these approaches pays much attention to how futures prices are determined, how they vary with shocks to economic fundamentals, and whether they contain information on subsequent changes of relevant economic variables. The analysis conducted in the present paper, by contrast, relates unobservable determinants of futures price curves to observable economic variables, showing not only that exogenous shocks to the fundamental supply-and-demand relationships can significantly affect the shape of the term structure, but also that information on these economic variables can be gleaned from the unobserved factors of the futures price curve.

Our analyses also differ significantly from most of the recent studies on commodity price behavior that focus primarily on either the spot price or the rolling nearby futures contract price. Much less attention has been paid to the profile of futures prices that contain information on contracts with longer maturities. Ignoring these prices may not only lead to significant information loss, but could potentially create counterproductive biases when drawing policy implications.

The purpose of this paper is to investigate the futures price curve of agricultural commodities using corn as an example. We seek to answer the following three questions: (1) How has the underlying price process changed over time in light of dramatic market changes? (2) How does the unobserved components of the futures price curve relate to observed economic variables? and (3) What does the futures price curve tell us about the market and its related economic fundamentals? Using a dynamic latent factor model over the period of January 1975 to March 2016, we find that corn futures price curves can be well-approximated by three unobserved elements: level, slope, and curvature. These three factors appear to be significantly affected by shocks to real economic activity and the relative scarcity of the commodity. Using Granger causality tests, we find that all three unobserved factors of the futures price curve contain predictive information on real economic activities and the relative scarcity of the commodity. Consistent with the theory of storage, there appear to exist forward-looking elements in the term structure of commodity prices that contain information on subsequent market fundamentals.

Related Literature

The term structure of commodities, or the futures price curve, refers to the collection of prices for all available futures contracts at a given point of time. As shown in figure 1, the relationship between futures prices to time-to-maturity may be described as either "contango" when contracts traded for more distant maturities are priced at a premium compared to contracts closer to maturity, or "backwardation" when futures contract price decreases as the time-to-maturity increases. The behavior of futures price curve may be best explained by Working's theory of storage, as shown in equation (1):

$$F(t,T) = S(t)e^{(r+c-y)(T-t)} \quad (1)$$

where $F(t,T)$ is the futures price at time *t* for contract maturing at T, $S(t)$ is the spot price at time *t*, *r* is the interest rate, c is the inventory cost for carrying commodity to a future time period, and y is the convenience yield representing the benefit of holding inventory at the current period to meet unexpected disruptions in consumption or production. Contango occurs when the full cost of carry exceeds convenience yield, or when $r + c - y > 0$. In the case of backwardation, futures contracts of more distant maturities are priced at a discount relative to contracts closer to maturity, or $r + c - y < 0$. In such circumstances, the marginal convenience yield is high as there is a great demand of holding physical commodity in hand compared to receiving at a future date.

Two approaches in the literature are typically used to model the term structure of commodity prices. The first approach uses principal component analysis (e.g., Alquist, Bauer, and Diez de los Rios, 2014). Findings generally indicate that the parallel shift of the term structure curve (or the level factor) accounts for most of the variations in commodity prices. The second and more popular method considers a set of underlying state variables that can be used to derive the futures price curve under no-arbitrage conditions. Recent applications of this method include Gibson and Schwartz (1990), Schwartz (1997), and Power and Turvey (2008), among others. These studies typically assume that commodity prices are driven by three stochastic factors: spot price, convenience yield, and interest rate.

Regarding factors affecting commodity term structure and its information content, Alquist, Bauer, and Diez de los Rios (2014) show that the term structure of crude oil contain in-sample predictive power over future inventory, production, global real economic activity, and the price of oil under a regression framework. In particular, they show the reason why inventories can be used to forecast the real price of oil as found in several recent studies (e.g. Baumeister, Guérin, and Kilian 2015) is related to the information contained in the convenience yield (y in equation (1)), which summarizes the relative scarcity of a commodity. Karstanje, Van der Wel, and Van Dijk (2015) examine the market-wide common level, slope, and curvature of 24 commodities, and find that the market-wide level term is related to economic output variables, exchange rates and hedging pressure, while the factors driving the slope of the futures price curve are related to inventory, hedging pressure, and interest rates.

In the present paper, we focus solely on the term structure of agricultural commodities, using corn as an example. We seek to not only model the futures price curve, but also understand how exogenous shocks to economic fundamentals can affect the profile of futures contract prices, and whether futures price curves contain predictive information on observed economic variables.

Econometric Procedures

We follow Karstanje, Van der Wel, and Van Dijk (2015) and use the dynamic latent factor approach of Diebold and Li (2006) to model the term structure of corn prices. The method is based on the static model proposed by Nelson and Siegel (1987) in which the term structure can be approximated by three unobserved components, as shown in equation (2):

$$(2)\qquad y(\tau) = \beta_1 + \beta_2\left[\frac{1 - exp(-\lambda\tau)}{\lambda\tau}\right] + \beta_3\left[\frac{1 - exp(-\lambda\tau)}{\lambda\tau} - exp(-\lambda\tau)\right]$$

where $y(\tau)$ is the set of prices at different contract maturity τ, β_1, β_2, and β_3 are level, slope, and curvature, respectively, and λ is a shape parameter that determines the slope and curvature of the futures price curve. The specific interpretation of the unobserved factors depends on their loadings. The loading on the first factor is a constant such that it affects futures contracts of all maturities in the same fashion, and is therefore a level factor. The loading on the second factor is a decreasing function of time to maturity, and as such can be considered as the slope of the futures price curve. In particular, if $\beta_2 > 0$, contracts closer to maturity are expected to have higher prices compared to contracts with more distant maturities, and hence the commodity market is in backwardation. On the other hand, a negative β_2 is an indication that the market is in contango. The loading on the third factor is a concave function of time to maturity, allowing the futures curve to exhibit a hump shape. β_3 can be interpreted as the curvature of the term structure of commodity prices.

Diebold and Li (2006) and Diebold, Rudebusch, and Aruoba (2006) extend the Nelson and Siegel (1987) model to a dynamic framework by allowing temporal variations in the estimated term structure. Specifically, equation (2) may be re-written as:

$$(3)\qquad y_t(\tau) = L_t + S_t\left(\frac{1 - exp(-\lambda\tau)}{\lambda\tau}\right) + C_t\left(\frac{1 - exp(-\lambda\tau)}{\lambda\tau} - exp(-\lambda\tau)\right) + \epsilon_t(\tau)$$

where L_t, S_t, and C_t are the level, slope, and curvature of the futures price curve at time *t*, respectively, and $\epsilon_t(\tau)$ is the error term with a covariance matrix $\sum_\varepsilon$. Compared to the static model of equation (2), the estimated term structure provides a more realistic fit to the observed futures price curve as the three unobserved factors are allowed to vary at different periods of time.

Diebold and Li (2006) and Diebold, Rudebusch, and Aruoba (2006) show that equation (3) can be rewritten in the state-space format for *N* contracts. The measurement equation, as shown in equation (4), relates to a set of *N* observed contracts of different maturities at time *t* to the three latent factors:

$$
(4) \qquad \begin{pmatrix} y_t(\tau_1) \\ y_t(\tau_2) \\ \vdots \\ y_t(\tau_N) \end{pmatrix} = \begin{pmatrix} 1 & \left(\frac{1-e^{-\lambda\tau_1}}{\lambda\tau_1}\right) & \left(\frac{1-e^{-\lambda\tau_1}}{\lambda\tau_1}\right)-e^{-\lambda\tau_1} \\ 1 & \left(\frac{1-e^{-\lambda\tau_2}}{\lambda\tau_2}\right) & \left(\frac{1-e^{-\lambda\tau_2}}{\lambda\tau_2}\right)-e^{-\lambda\tau_2} \\ \vdots & \vdots & \vdots \\ 1 & \left(\frac{1-e^{-\lambda\tau_N}}{\lambda\tau_N}\right) & \left(\frac{1-e^{-\lambda\tau_N}}{\lambda\tau_N}\right)-e^{-\lambda\tau_N} \end{pmatrix} \begin{pmatrix} L_t \\ S_t \\ C_t \end{pmatrix} + \begin{pmatrix} \varepsilon_t(\tau_1) \\ \varepsilon_t(\tau_2) \\ \vdots \\ \varepsilon_t(\tau_N) \end{pmatrix}
$$

where $\epsilon_t(\tau_i)$ for i=1,….N are measurement errors, or the deviations of the implied contract prices from the term structure model to the observed contract prices. In the transition equation, the three unobserved factors are assumed to follow a vector autoregression model of one lag, or VAR(1), as shown in equation (5):

$$
(5) \qquad \begin{pmatrix} L_t \\ S_t \\ C_t \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} * \begin{pmatrix} L_{t-1} \\ S_{t-1} \\ C_{t-1} \end{pmatrix} + \begin{pmatrix} \eta_t(L) \\ \eta_t(S) \\ \eta_t(C) \end{pmatrix},
$$

where $\eta_t(L)$, $\eta_t(S)$, and $\eta_t(C)$ are innovations to the autoregressive process of the latent factors. Following Diebold, Rudebusch, and Aruoba (2006), the innovations of the measurement and transition equations are assumed to be white noise and mutually uncorrelated. We use the Kalman filter to estimate all parameters associated with the model as well as the three latent factors, as in Koopman and Durbin (2012).

Data

We consider monthly futures prices for corn from January 1975 to March 2016, yielding 495 observations. Following Power and Turvey (2008), we limit our estimation to the six most recent nearby prices. Though contracts of more distant maturities are available, they are typically of low trading volume. Monthly prices refer to the close prices on the first trading day of the month. All prices are then transformed to its logarithmic format. Table 1 presents the summary statistics for average returns and volatility used in the paper. Higher average returns seem to be observed for more distant contracts. Consistent with the voluminous evidence reported in previous studies, we find futures prices to exhibit the so-called Samuelson effect (1965)—the volatility of futures prices increases as delivery date approaches.

Figure 2 shows the futures price curve for corn from 1975 to 2016. Two clear patterns emerge. First, corn prices have experienced several boom-and-bust cycles over the sample period. Large spikes are observed first in mid-1970s, and most recently in 2010-2012. Second, both contango and backwardation have occurred rather frequently in the corn market over the sample period. For instance, the futures curve between 1995 and 1997 are generally in backwardation, while mostly in contango between 1997 and 2002.

Estimation Results

The state-space representation of equation (3) as shown in equations (4)-(5) are estimated using the Kalman filter on monthly corn prices from January 1975 to March 2016. Before delving into the specific estimation results, it is useful to evaluate how well our model fits the actual data. Figure 3 shows the measurement errors from equation (4), i.e. the difference between the actual futures price and the estimated price at various time periods for various maturities. The residuals appear to be larger for nearby contracts and contracts at the most distant delivery. With few exceptions, the residuals are less than 10%. In particular, all residuals for the 4th and 5th nearby contracts are within 5% of the actual prices. Overall, the model appears to fit the data rather well.

Figure 4 shows the estimated level, slope, and curvature of the term structure over the sample period. As can be seen, the evolution of the level factor mirrors the overall price trends in corn prices, with the price reaching record highs in 2007-2008, and again in 2010-2012. There appears to be a clear structural break in the level factor between 2005 and 2007, when its value jumped almost 50% in less than 2 years. Our results are consistent with several previous studies that used 2005-2007 as a structural break when estimating the driving factors of corn prices (e.g. Carter, Rausser, and Smith 2016).

As noted earlier, a negative (positive) slope factor is an indication that the market is in contango (backwardation). The middle chart in figure 4 shows that the corn market has been in backwardation from 1983 to 1986, from 1995 to 1997, and again from 2010-2013. The remaining years in the sample period appear to have been mostly in contango. This is generally consistent with the pattern observed in figure 2. The last chart of figure 4 shows the estimated curvature factor, which appears to range between -1.0 and +1.0 for most of the sample.

Relating Unobserved Factors to Observed Economic Variables

In this section, we consider two key variables that could affect the shape of the term structure, namely global real economic activity and inventory.

Various studies suggest that the rapid economic growth in developing countries, notably China and India, was the main driver of commodity price spikes in the 2000's. If this argument is true, global economic growth should at least partially affect commodity price levels. The monthly index developed by Kilian (2009) is used to capture the effect of global economic activity on corn price behavior. The index is constructed based on dry cargo single voyage ocean freight rates. Recognizing that the demand for transport services is primarily determined by world economic growth, Kilian shows that this index captures shifts in the demand for industrial commodities driven by the global business cycle. Recent application of this index and similar measures based on dry cargo freight rates as a proxy for macroeconomic fluctuations include, among others, Carter, Rausser, and Smith. (2016), McPhail, Du, Muhammad. (2012), Qiu et al. (2012), and Wang et al. (2014).

The second variable is the relative scarcity of corn. The theory of storage (e.g., Working, 1948, 1949) states that firms earn a convenience yield by holding inventory at hand, which prevents disruptions in the flow of goods and services, and in turn reduces production uncertainty. The relationship between convenience yield and carrying cost essentially determines whether the shape of commodity futures price curve is upward- or downward-sloping. We use the ending stocks-to-use ratio to represent market-specific fundamentals. This variable scales inventory by total use to reflect the current market demand conditions. We obtain inventory data from the World Agricultural Supply and Demand Estimates (WASDE) report released by the USDA. Every month, the WASDE report provides an estimate of the US end-of-marketing-year and world end-of-year stocks and uses. The estimated ending stocks-to-use ratio measures the level of carryover stock as a percentage of the total demand to use, and thus dependably represents the tightness of the current supply-demand relationship in the corn market. Estimates are provided for both old and new crops in the WASDE reports, and the former is used to calculate the ending stock-to-use ratio in this study.

We consider a vector autoregression model (VAR) to estimate the effects of observed economic variables on the futures price curve, as shown in equation (6):

$$X_t = c + \sum_{i=1}^{p} V_i X_{t-1} + \varepsilon_t. \tag{6}$$

Here, X_t is a 5 by 1 vector of endogenous variables including real economic activity, inventory, level, slope, and curvature. Monthly dummies are added to the model to account for seasonal patterns commonly observed in commodity prices. We use the recursive ordering of the five variables to identify the VAR model. Real economic activity is placed as the first variable since the likelihood of real economic activity responding to changes in the remaining four commodity-specific variables is low at contemporaneous time. Inventory is placed as the second variable, and the three latent factors of term structure are placed as the third, fourth, and fifth variables, respectively.

Lag structure of the VAR model in equation (6) is determined by the Schwartz Bayesian Information Criteria (SBIC). The Lagrange Multiplier test is used to test for residual autocorrelation, and we fail to reject the null hypothesis of zero autocorrelation for any of the lags considered.

Table 2 shows the contemporaneous correlations between the five variables in the VAR system. The level factor is negatively correlated with the stocks-to-use ratio but positively correlated with real economic activity. The slope factor is negatively correlated with both real economic activity and stocks-to-use ratio. The curvature factor negatively correlates with stocks-to-use ratio, but not with real economic activity. However, contemporaneous correlations do not imply temporal causality between these variables.

Figures 5 show the impulse responses of level, slope, and curvature to an exogenous shock from other variables based on the estimated VAR model. Turning first to the level factor, a positive shock to the real economic activity significantly increases the level of the term structure, and this effect does not diminish even after 18 months. By contrast, the effect of ending stocks-to-use ratio, while mostly negative, disappears with a very short time horizon. Panel b of figure 5 shows the response of the slope factor to various exogenous shocks. When a positive shock occurs in the real economic activity, the slope factor increases for the first ten months, after which the response becomes statistically insignificant. A positive shock to the inventory will lead to a negative response in the slope factor for the first 5 months, after which the effect is virtually indistinguishable from zero. The increasing demand of corn due to expansion of global real economic activity in the current period is likely to pose upward pressure to corn prices in the nearby contracts relative to more distant contracts. Under such circumstances, the futures price curve of corn will be either more negatively-sloped (stronger backwardation) or less positively-sloped (weaker contango). An unexpected positive shock to the ending stocks-to-use ratio, on the other hand, has a mostly negative impact on the slope factor. When the ending stocks-to-use ratio increases, market participants will place higher value on corn for future delivery, leading to a less negatively-sloped (weaker backwardation) or more positively-sloped (stronger contango) futures price curve. Finally, an unexpected positive shock to real economic activity or stocks-to-use ratio will both significantly increase the curvature factor of corn futures price curves.

To investigate whether there is information contained in the term structure, we conduct Granger causality test to determine whether the lagged levels, slopes, and curvatures may be used predict the real economic activity and ending stocks-to-use ratio. As shown in table 3, the null hypothesis of zero predictability can be rejected at the 5% significance level in most of the cases. The lagged level and slope do contain predicative information on both real economic activity and ending stocks-to-use ratio. The curvature factor appears to only be useful for predicting real economic activity, not stocks-to-use ratio.

Conclusions

In this working paper, we show that corn futures price curves can be well-approximated by a dynamic latent factor model including three components: level, slope, and curvature. We show that both real economic activity and relative scarcity play an important role in the term structure of corn prices. In particular, a positive shock to real economic activity will significantly increase all three factors of the futures price curve. Consistent with the theory of storage, a positive shock to the stocks-to-use ratio will lead to a more positively-sloped (stronger contango) or less negatively-sloped (weaker backwardation) futures price curve. Using Granger causality tests, we also find that all three factors contain predictive information regarding real economic activities and stocks-to-use ratios in future periods. There clearly exists a forward-looking element in the term structure of commodity prices that contains information about subsequent market fundamentals.

Previous studies show that commodity futures price curves can also be affected by the hedging pressure in the market as the risk premium demanded by speculators for assuming price risks is correlated with subsequent prices. A possible expansion of the current analysis would be to investigate the effect of an exogenous shock to traders' positions in futures markets. It may also be interesting to investigate whether our forecast of real economic activity and stocks-to-use ratios might be improved using level, slope, and curvature in an out-of-sample context.

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Tables and Figures

Table 1. Summary Statistics of Corn Futures Prices, January 1975 to March 2016

	1st nearby	2nd nearby	3rd nearby	4th nearby	5th nearby	6th nearby
Average return	0.03%	0.03%	0.03%	0.05%	0.08%	0.07%
Volatility	7.86%	7.66%	6.93%	6.43%	6.18%	5.65%

Table 2. Contemporaneous Correlations between Variables Considered in the VAR Model

	level	slope	curvature	stocks/use	Real econ
level	1				
slope	-0.02	1			
curvature	-0.29***	0.57***	1		
stocks/use	-0.40***	-0.28***	-0.13***	1	
real econ	0.24***	-0.15**	0.04	-0.22***	1

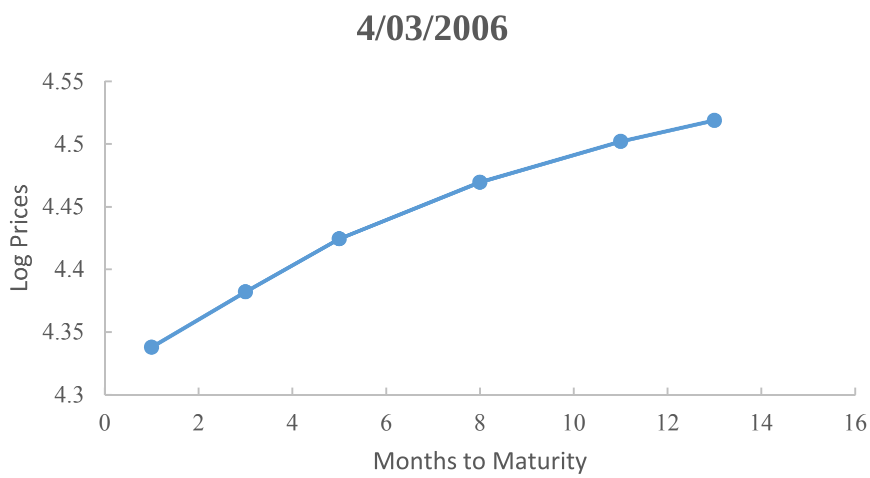
Note: *, **, and *** represent statistical significance at 10%, 5%, and 1%, respectively.

Table 3. Granger Causality Test Results

Panel A: Real Economic Activity Equation			
Independent variables	Chi2	df	Prob>Chi2
Stocks-to-use ratio	0.769	4	0.943
Level	14.269	4	0.006
Slope	10.467	4	0.033
Curvature	12.634	4	0.013
All variables	27.348	16	0.038

Panel B: Ending Stocks-to-Use Ratio			
Independent variables			
Stocks-to-use ratio	2.685	4	0.612
Level	18.374	4	0.001
Slope	44.474	4	0.000
Curvature	7.685	4	0.104
All variables	93.540	16	0.000

Panel A. Futures Price Curve for Corn Prices on 4/3/2006 (Contango)



Panel B. Futures Price Curve for Corn Prices on 2/1/1996 (Backwardation)

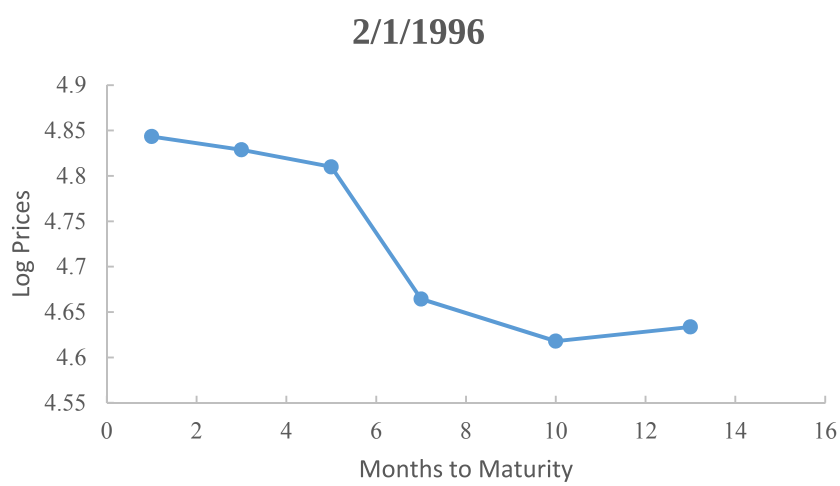


Figure 1. Contango vs. Backwardation

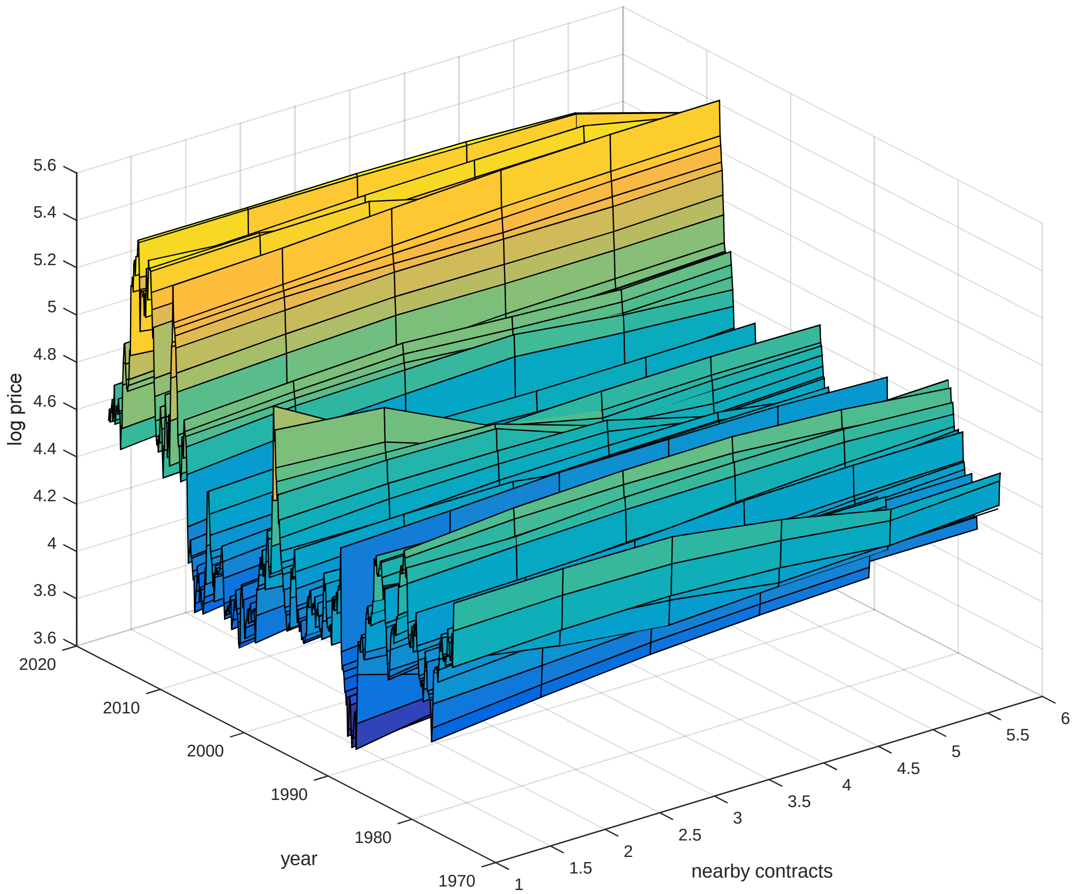


Figure 2. Futures Price Curve for Corn, January 1975-March 2016

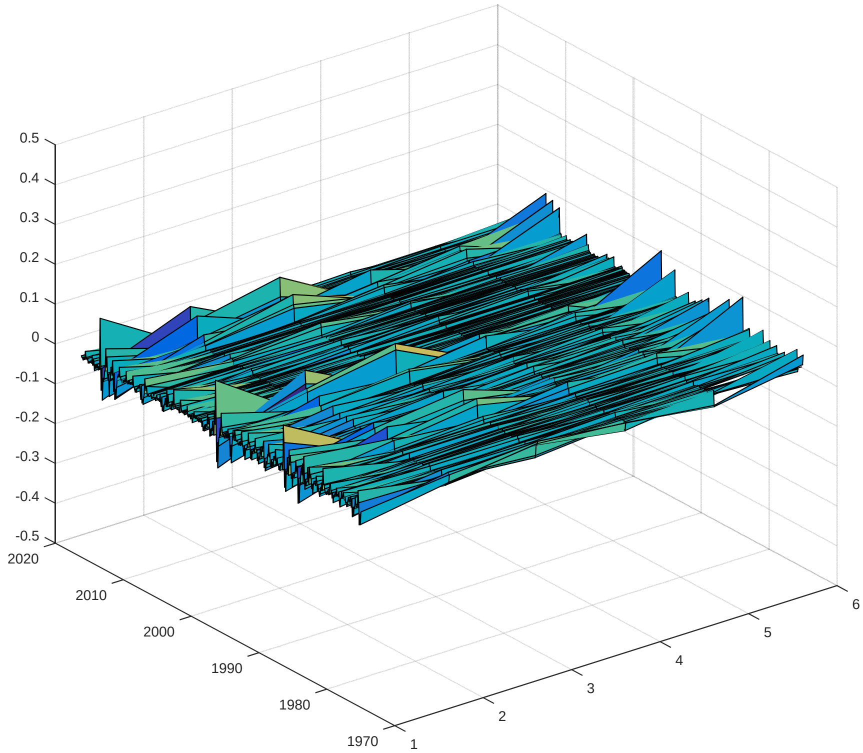
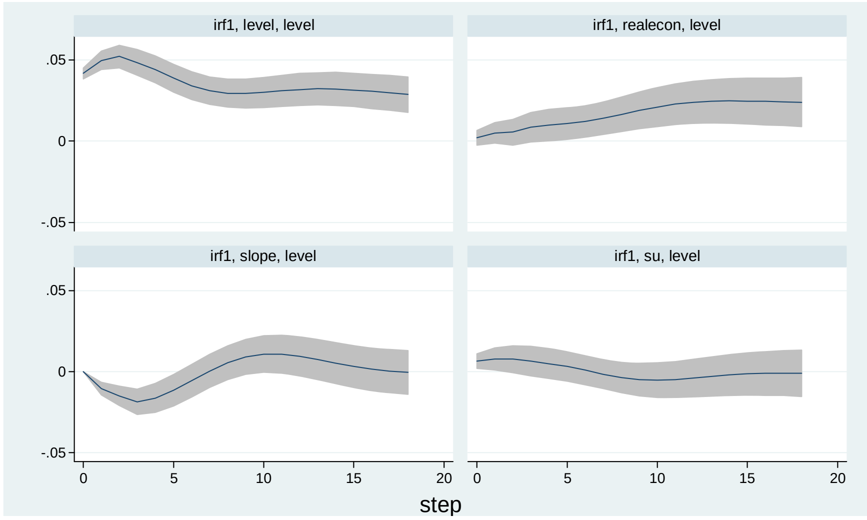


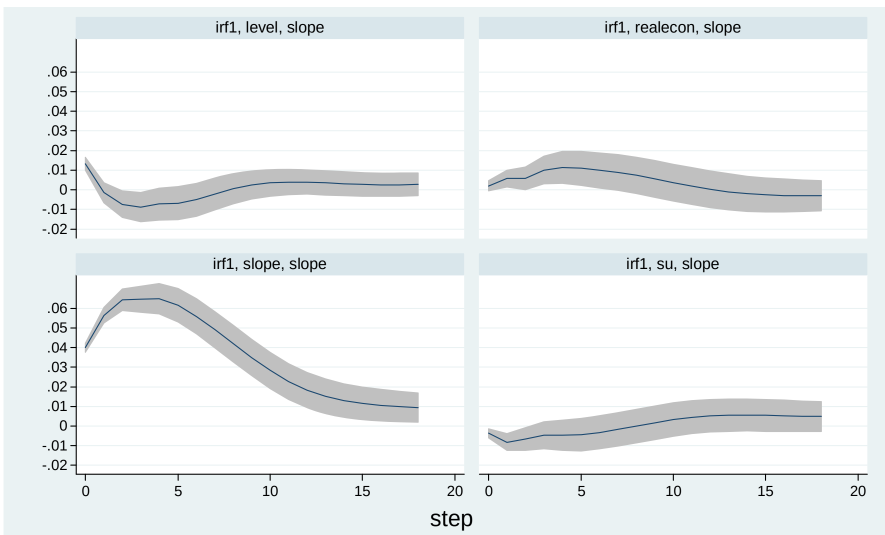
Figure 3. Residuals

Figure 4. Estimated Level, Slope, and Curvature for Corn Futures Price Curve, January 1975 to March 2016

Panel A. Response of Level to Exogenous Shocks



Panel B. Response of Slope to Exogenous Shocks



Panel C. Response of Curvature to Exogenous Shocks

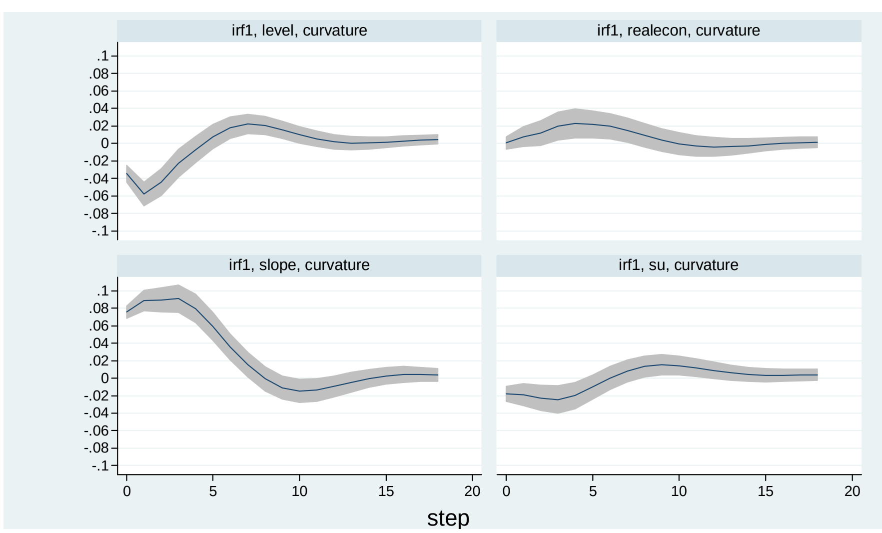


Figure 5. Impulse Response Functions