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The Convenience Yield Determinants of Corn Futures

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Christopher R. DeLong

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Dissertation Supervisor: Dr. W. Keener Hughen Signature:

Committee Member: Dr. I-Hsuan Ethan Chiang Signature:

Committee Member: Dr. Xin (Shane) Gao Signature:

The Convenience Yield Determinants of Corn Futures

Christopher DeLong

Abstract

This paper presents an in-depth analysis of the convenience yield determinants of corn futures. The estimated spot price and convenience yield are derived from Gibson and Schwartz's (1990) two-factor model, and a deterministic seasonal component is added to the convenience yield. Numerous potentially novel determinants are regressed against the convenience yield while controlling for the spot price. The spot price is highly significant in all univariate regressions and is the main driver of changes in convenience yield. This research confirms the theory of storage, provides conflicting results regarding net hedging pressure, shows significant results for novel determinants, and proves that drought influences the convenience yield determinants of corn futures.

JEL classification: G12, G13

Keywords: corn, commodity futures, convenience yield

1. Introduction

Corn is the most widely produced feed grain in the United States, accounting for more than 95% of total feed grain production (United States Department of Agriculture, 2020). When conditioned correctly, corn can be stored for an extended period, allowing the United States to maintain stocks in case of future production issues. Carrying physical grain is convenient for market participants because it assures them product in case of supply shocks. In addition, this practice can yield an additional financial benefit if the contango in the market is large enough to cover financing costs, insurance, wastage, and operating costs. The convenience yield is the net implied financial benefit of holding physical commodities.

This paper presents an in-depth analysis of the convenience yield determinants of corn futures and makes several contributions to the literature. First, it includes novel data proxies for the primary demand drivers of corn in the United States, which are feed and residual, ethanol, and export. Second, it examines the impacts of net hedging pressure, the theory of storage, volatility, and macroeconomic conditions on the convenience yield of corn after controlling for the spot price. Third, it examines the impact of drought on the determinants of the convenience yield of corn. The aim is to provide a full picture of the convenience yield determinants of corn futures, which is rarely the focus of research in the field.

The estimated spot price and convenience yield come from Gibson and Schwartz's (1990) two-factor model and a deterministic seasonal component added to the convenience yield, in line with Mirantes et al. (2013). The potential determinants are then regressed against the estimated convenience yield series. Pokopczuck and Wu (2015) used a similar methodology but did not control for spot price in the regressions of the potential determinants on the convenience yield. This research controls for spot price because the correlation with the convenience yield is so high. Not controlling for spot price on the determinants of convenience yield could lead to misleading results that inadvertently reveal spot price determinants. Alquist et al. (2014) found a similar relationship in crude oil futures in which the convenience yield contained information on the spot price.

In this paper, the disaggregated commitment of traders' reports is used as a proxy for commercial hedgers, speculators, swap dealers, and other large traders to show the impact on the convince yield. Cootner (1960) initially proposed that net hedging pressure by commercial hedgers during harvests provides profitable trading opportunities to speculators. The theory of net hedging pressure provides little supporting evidence after controlling for spot price in this research. Swap pressure is surprisingly significant and robust, while other types of pressure are not. The findings of this paper partially confirm those of Irwin et al. (2011), who found that speculators do not affect calendar spreads during the roll period.

This paper uses three separate measures of volatility: GARCH (1, 1), implied at-the money volatility for the spot contract, and implied-at-the money volatility for contracts with a 3-month duration. Milonas and Thomadakis (1997) wrote a seminal paper modeling the convenience yield after the Black–Scholes option-pricing model. They found strong support for modeling the convenience yield as a call option. Their inclusion of volatility warranted this research's revisiting of volatility and its relationship to convenience yield. In this paper, only the implied volatilities show significant results; however, it does not perform well on the various robustness tests.

This research confirms the theory of storage by using Chicago Mercantile Exchange (CME) deliverable stocks without supporting evidence from United States Department of Agriculture (USDA) ending stocks. Power and Turvey (2008) found similar results for corn futures using USDA ending stocks. The macroeconomic variables used in this research provide little to no explanation for the convenience yield, indicating that the state of the economy does not affect returns on physical corn. Bailey and Chan (1993) found similar results regarding the macroeconomic impacts on agricultural commodities.

The United States experienced low ending stocks from 2011 to 2014 caused by drought and high demand. Very few determinants show significance for the periods before and during the US drought. However, several novel demand determinants including live cattle, lean hog, Corn Belt ethanol margins, and Illinois ethanol margins show highly significant results for the period after the drought. The spot price is highly significant in all univariate regressions and is the main driver of changes in convenience yield. This research confirms the theory of storage, provides conflicting results regarding net hedging pressure and significant results for novel determinants, and proves that drought influences the convenience yield determinants of corn futures.

This paper provides background on convenience yield research (section 2), provides a model for estimating the convenience yield (section 3), describes potential determinants (section 4), shows the results of univariate regressions on the convenience yield and performs various robustness tests (section 5), and presents conclusions about the determinants of the convenience yield of corn futures (section 6).

2. Background

John Maynard Keynes was one of the first authors to write about commodity term structures in *A Treatise on Money* (1930). In it, Keynes describes his normal backwardation hypothesis, which occurs when the spot price exceeds the futures price. Backwardation occurs when there are adequate or inadequate inventories. Contango occurs when there is a large excess of inventories; the spot price will be less than the futures price. During the sample period of this research, the corn market was in a contango 89.7% of the time.

Nicholas Kaldor laid the foundation for convenience yield in *Speculation and Economic Stability* (1939). Convenience yield is the economic benefit of having a physical commodity when needed. This benefit is lost if the holder of the commodity sells that commodity for a forward position. In some markets, the convenience benefit outweighs the interest expense to finance inventory, storage costs, and wastage. This convenience yield helps explain why a commodity holder might want to be long in a normal backwardation market. The U.S. corn market experienced very large backwardations between 2010 and 2014 due to significantly reduced corn stocks caused by drought and high demand.

Working (1948) took Kaldor's ideas and empirically applied them in "Theory of the Inverse Carrying Charge in the Futures Market." Working's research found three key findings: (1) the spot and futures prices of a commodity are always connected; (2) inverse carrying charges indicate a shortage of the commodity; and (3) market participants are willing to hold a commodity in a backwardation market to ensure that they have appropriate production stock. The findings of the present analysis confirm confirms Working's (1948) first two findings.

In *The Theory of Price of Storage*, Working (1949) argues that the supply and demand for storage are the main factors driving wheat's term structure. If there are large carryovers of wheat, competition among wheat warehouses will be low, causing calendar spreads to show more carry (i.e., contango). If wheat carryovers are small, competition among wheat warehouses will be high, causing an inverse (i.e., backwardation). This paper confirms Working's (1949) stance, showing a strong negative relationship between stocks and the convenience yield of corn.

Tesler (1958) examined the relationship between inventories and calendar spreads and discovered that a seasonal pattern in inventories helped determine the price of a given calendar spread. The present research adds a seasonal component to the convenience yield and confirms the findings of Tesler (1958). During periods of low stocks, convenience yields tend to be at their highest. For example, in the corn market, the time before harvest, when stocks are at their lowest, provides the largest convenience yield. The following section provides an overview of corn futures data and describes the method for constructing the convenience yield.

3. Corn Futures Term Structure

The corn futures data used in this study comes from the CME Group. The frequency is daily, and the range is from 8/1/2001 to 3/19/2020. There is no reliable data for maturities greater than 1 year prior to 8/1/2001, which was needed for the estimation procedure of the convenience yield. Corn futures have five maturities in a calendar year: December, March, May, July, and September. To generate the respective corn futures series, the contracts are rolled to the next maturity at expiration.

The mean of the nearby contract during the sample period is 389.97 (cents/bushel), and the respective means of the other six durations are larger relative to the length of the duration. This indicates that the corn futures market is generally in a contango. During the sample period, the two most nearby contracts were in a contango 89.7% of the time. The standard deviation ranges from 150.79 to 120.52, with the most nearby durations having greater volatility. Corn future returns for the sample period show larger volatility for the nearby contracts as well. For full descriptive statistics on corn futures returns, see Table 4.

Corn futures exhibit contango, backwardation, and other term structures, depending on the given period, as shown in Figure 1. The most common term structure exhibited by corn futures is a contango. However, during periods of low supply generally caused by drought, the market can display an extreme backwardation. Modeling of the term structure or convenience yield is covered in the following section.

3.1 The Naïve Convenience Yield

Convenience yield is not readily observable and differs among market participants. The naïve convenience yield uses the risk-free rate and the nearest futures calendar spread to estimate the implied benefit of holding the physical commodity. The formula for determining the naïve spot price and convenience yield is as follows:

$$F(S,T) = Se^{(r-\delta)(T-t)} \quad (1)$$

$$\delta_{T-1,T} = r_{T-1,T} - 12ln[\frac{F(S,T)}{F(S,T-1)}] \quad (2)$$

where:

$\delta_{T-1,T}$ = T-1 periods ahead annualized 1-month forward convenience yield
$r_{T-1,T}$ = T-1 periods ahead annualized 1-month riskless forward interest rate
$F(S,T-1)$ = Spot contract (T1)
$F(S,T)$ = Forward futures contract (T2)

If the convenience yield is negative, the return on the given calendar spread is greater than that of financing costs. If the convenience yield is positive, the return on the given calendar spread is less than that of the financing costs. A positive convenience yield helps explain why a holder of physical inventories would carry them through a market in backwardation.

Use of the naïve convenience yield results in numerous issues. First, the true spot price is not observable. Second, the holder of physical corn can carry the product for much longer than two periods. Third, due to the Samuelson effect (Samuelson, 1965), nearby months are more volatile, and examining only these months could lead to misleading results. Figure 2 shows the realized volatility for corn futures with different contract expirations, confirming the Samuelson effect. Fourth, the equation does not include a seasonal component,[1] which is a readily observable phenomenon in agricultural markets.

The model for estimating the convenience yield should balance accuracy and the parsimony principle. Table 1 shows the results of a principal component analysis of the seven most nearby corn futures contracts. The first two principal components account for 99.51% of the total variation. For this reason, this analysis uses Gibson and Schwartz's (1990) two-factor model with an added deterministic seasonal component.

3.2 Gibson and Schwartz's (1990) Two-Factor Model

The Gibson and Schwartz (1990) two-factor model calculates spot price, S_t, and instantaneous convenience yield, δ_t. The original two-factor model does not include a deterministic seasonal component, but this paper adopts an extension by Mirantes et al. (2013), which includes a deterministic seasonal component in the convenience yield, $h(t)$. Adding this component to the convenience yield captures the variation in inventories due to harvest cycles better than the spot price. The different frequencies of seasonality are denoted as θ_i and ξ_i.

The instantaneous convenience yield is the sum of the stochastic part, $\overline{\delta_t}$, and the seasonal part, $h(t)$. The combined dynamics follow the equations below:

$$dS_t = (\mu_s - \delta_t)S_t dt + \sigma_s S_t dW_t^1 \tag{3}$$
$$\delta_t = \overline{\delta_t} + h(t) \tag{4}$$
$$h(t) = \sum_{i=1}^{n} \theta_i \sin(2i\pi(1 + \xi_i)) \tag{5}$$
$$d\overline{\delta_t} = k(\alpha - \delta_t)dt + \sigma_\delta dW_t^2 \tag{6}$$
$$dW_t^1 dW_t^2 = \rho_{s\delta} dt \tag{7}$$

where:

S_t = spot price at time *t*
δ_t = instantaneous convenience yield at time *t*
$\overline{\delta_t}$ =stochastic portion of convenience yield at time *t*

[1] Empirical evidence of seasonality in commodity futures is provided by Tesler (1958), Cootner (1960), Liu et al. (2005), Karali and Thurman (2010), and Wang and Garcia (2011).

$h(t)$ = deterministic seasonal component of convenience yield
μ_s-δ_t= drift of the spot price
σ_s= instantaneous volatility of the spot price return
α = long term mean of the convenience yield
k = speed of convergence of the convenience yield towards k
σ_δ= instantaneous volatility of the convenience yield
$\rho_{s\delta}$ = correlations between the two Brownian motions dW_t^1anddW_t^2
θ_i and ξ_i capture seasonality at different frequencies

W_t^1 and W_t^2 are two standard Brownian motions that have correlations with $\rho_{s\delta}$, σ_s, and σ_δ, which describe the volatilities of the spot price and instantaneous convenience yield. A geometric Brownian motion can describe the spot price, and μ_s governs the drift of the spot price. The stochastic portion of the convenience yield is an Ornstein–Uhlenbeck process with mean reversion, k, to the long-run equilibrium level, α.

The full estimation procedure is included in the appendix. The main portion of this paper uses the estimated spot price and convenience yield series from this estimation procedure. Figure 3 shows the naïve convenience yield and Gibson and Schwartz's estimated convenience yield. Table 2 provides the root mean squared errors between the actual futures prices and the modeled futures prices from the naïve estimation and the Gibson and Schwartz (1990) estimation. The lower root mean squared error for the Gibson and Schwatz (1990) estimation indicates it fits the data much better than the naïve estimation. The following section reviews the data used in this paper and the potential convenience yield determinants of corn futures.

3.3 Convenience Yield Estimated Series

The convenience yield estimation procedure uses the seven most nearby corn futures contracts, which are available starting from 8/1/2001 and have a 1-month treasury bill rate. Most nearby corn futures contracts have a greater positive skewness than deferred contracts. The corn futures data is also leptokurtic, meaning that it has fat tails.

The generated convenience yield and spot series can be seen in Figure 4. The convenience yield series ranges from -.42 to .34, with a mean of -.05. The convenience yield only has prolonged positive values from 2010 to 2013. The effects of the determinist seasonal component on the convenience yield series are visible, showing highs in June or July and lows in September or October.

4. Data and Methodology

This paper regresses the potential determinants against Gibson and Schwartz's (1990) estimated instantaneous convenience yield with a univariate regression. The basic equation is outlined below:

$$\delta_t = c + \beta_1 X + e \tag{8}$$

where:

δ_t = instantaneous convenience yield at time *t*
c = constant
β_1= coefficient of the respective independent variable
X = the independent variable
e = error term

The following sections provide an overview of the potential determinants that are regressed against the convenience yield. Table 3 provides the full descriptive statistics, transformations, sources for all variables used in this paper. Table 3 panel B shows the correlation coefficients for the data, it is worth noting that the spot price and some of the independent variables have a correlation coefficient greater than 0.7, which indicates a degree of collinearity.

4.1 Demand

Corn demand in the United States in 2020 was 38% feed and residual, 37% ethanol, 15% exports, and 10% food and industrial (United States Department of Agriculture, 2020). The following subsections provide an overview of the various proxies used for these demand factors.

Most of the proxies are novel and have not been regressed on the convenience yield of corn before. The expectation for the coefficient signs from the regressions is positive because as demand margins appreciate, so should the convenience of holding physical corn, which is the main input.

4.1.1 Feed and Residual

The proxies for feed and residual demand are the returns on feeder cattle, live cattle, and lean hogs. The prevailing idea of using livestock returns is that if the return on producing livestock is strong (weak), then the returns obtained by producing the primary feed input should also be strong (weak). The data for feeder cattle, live cattle, and lean hogs comes from the CME Group. The frequency is daily, and the range is from 8/1/2001 to 3/19/2020.

4.1.2 Ethanol

Distillates from West Texas Intermediate (WTI) are a substitute for or complement of ethanol. This paper includes WTI as a determinant to see if there was a transmission in price change to the convenience yield of corn. The price data is from the CME Group and covers the same period as the convenience yield series.

Ethanol margin data comes from the Reuters Data Stream for four different proxies: the Corn Belt (a proxy for the corn production area from Iowa to Indiana), Northwest Iowa, Northeast Iowa, and Illinois. Each market zone has a different set of dynamics, given its geographic location, competition for supply, demand for output, and transportation to end users. Ethanol margins show the gross profit for buying one corn unit and selling the ethanol and distiller-dried grains from one corn unit. The frequency is daily, and the start dates are 7/23/2007 for the two Iowa proxies, 7/28/2009 for Illinois, and 1/5/2010 for the Corn Belt. The price of ethanol comes from the CME Group, with a start date of 4/11/2005 and a daily frequency.

This paper uses two additional proxies for ethanol: ethanol stocks and ethanol production. Data for these proxies, which has a daily frequency and start date of 6/4/2010, comes from the Energy Information Administration (EIA).

4.1.3 Exports

Export announcements come from the USDA. These published announcements occur infrequently, depending on the announcements of that day. Sales of more than 100,000 tons must be reported to the USDA Foreign Agricultural Service. This helps ensure market transparency and better market discovery. The data has an irregular daily frequency, and the start date of the series is 1/6/2005.

4.2 The Theory of Storage

The theory of storage, introduced by Working (1949), proposes an inverse relationship between convenience yield and inventory levels. This inverse relationship is intuitive: if there are large inventories of a commodity, the return on holding inventories should be low. Working's findings have been confirmed by numerous authors (e.g., Brennan, 1958; Tesler, 1958; Fama & French, 1987; Prokopczuk & Wu, 2015).

This paper uses two separate proxies for inventory levels: USDA ending stocks and CME deliverable stocks. The USDA ending stocks, which estimate what the United States will carry over given the production and demand, come from the USDA Agricultural Marketing Service (AMS). They are published monthly and start on 9/5/2006.

CME deliverable stocks are registered stocks held by grain warehouses within the CME's physical delivery system. They play a vital role in the convergence of the futures market and the physical spot market for grain. This published data has a daily frequency and starts on 1/2/2014.

4.3 Net Hedging Pressure

Cootner (1960) outlined the relationship between commercial hedgers and speculators in the futures market. He proposed that net hedging pressure by commercial hedgers during harvest provides profitable trading opportunities to speculators. Cootner used commercial hedge positions and physical stocks to examine net hedging pressure in wheat futures. Hedging pressure was observable in wheat futures. Cootner (1960) concluded that net hedging effects go unobserved for non-harvested commodities.

Bessembinder et al. (1992) built on Cootner's idea of net hedging pressure by examining the impact of the commitment of traders data and its effect on commodity prices. They found that returns differed from zero when conditioned on signs of hedging. They concluded that a speculator positioned on the opposite side of hedging pressure could yield positive returns.

Research on how large traders impact the curve of the futures market has produced conflicting results. Huellen (2018) found that institutional investors contribute to "excessive calendar spread anomalies" in cocoa, coffee, and cotton. The analysis showed that index positions relative to hedging positions are associated with upward sloping, peaked futures curves, and, occasionally, wave-like patterns. Huellen (2018) concluded that the large presence of index traders caused the commodity futures curves to be misleading and uninformative for underlying supply and demand. However, Irwin et al. (2011) examined the effects of commodity index traders on agricultural futures during the roll period and found no statistical evidence that these funds distorted agricultural calendar spreads during this period. The results of the present study resemble those of Irwin et al. (2011).

4.4 Volatility

Milonas and Thomadakis (1997) modeled convenience yields as call options according to the Black–Scholes pricing model. The authors developed a new definition of convenience yield as "the benefit which accrues to inventory holders from the increased utility associated with the availability of periods in scarce supply." Their empirical models strongly supported price convenience yields as call options after the Black–Scholes option-pricing model. Pindyck (2001) found that changes in volatility could directly affect the marginal value of storage, the marginal cost of production, and the opportunity cost of production.

The present paper uses three separate proxies for volatility: at-the-money implied volatility, at-the-money implied volatility for contracts with a 3-month duration, and GARCH (1,1) volatility. At-the-money implied volatility and at-the-money implied volatility for contracts with a 3-month duration come from Reuters Data Stream. The rationale for analyzing 3-month implied volatility as well is that the spot contract is generally noisier due to the Samuelsson effect, which could lead to misleading results. The start date is 6/5/2007, and the data have a daily frequency. This paper also calculates GARCH (1,1) volatility from the spot series generated by Gibson and Schwartz's two-factor model.

4.5 Macroeconomic Conditions

Macroeconomic conditions affect the state of the whole economy. Pokopczuck and Wu (2013) used macroeconomic variables to determine the convenience yield for various commodities. They found significant results for industrial production and consumer price index

Bailey and Chan (1993) examined macroeconomic influences and the variability of futures basis for an array of commodities. For corn, they found significant results using the T-bill yield and the corporate dividend yield. However, other proxies of macroeconomic conditions did not provide much support.

The 5-year break-even inflation rate, 10- vs. 2-year constant maturity treasury yield, consumer price index, and industrial production time series all come from the Federal Reserve Economic Database. The published data have a monthly frequency, and the start date for: The 5-year break-even inflation rate, 10- vs. 2-year constant maturity treasury yield, consumer price index, and industrial production, is 4/11/2005,1/2/2014,and 1/2/2014 respectively. The expectation for the coefficient signs from the regressions is positive because the convenience of holding physical corn should be higher when the general economy performs better.

4.6 Unit Roots

An augmented Dickey–Fuller unit test was run at the level for all variables. Numerous variables showed a unit root and were non-stationary at level. Non-stationarity is common in financial data; thus, all the regressions were run at first difference. For the results of the unit root test, refer to Tables 3 and 4. Running the univariate regressions at first difference is a point of distinction compared to the work of Prokopczuk and Wu (2015), which ignored this fact.

The following section presents the results of the univariate regressions and the various robustness tests.

5. Results and Robustness Tests

5.1 At First Difference

The proxies for demand have significant coefficients for feeder cattle, live cattle, lean hog, WTI, and ethanol margins. However, EIA ethanol production and ethanol stock datadoes not have significant coefficient. These results reflect the work of Trujillo-Barrera et al. (2012), who found crude oil spillovers in the corn and ethanol markets. However, there is no observable volatility transmission from ethanol to the corn market.

At-the-money implied volatility and at-the-money implied volatility for a 3-month duration show highly significant results with positive coefficients, but the GARCH (1,1) volatility of corn spot prices does not. These results indicate that the convenience yield of corn should be priced as a real option if the model uses implied volatility.

Managed pressure and hedge pressure showed significant results and confirmed the theory of net hedging pressure. Interestingly, swap pressure showed highly significant results, while other reportable pressure did not. Swap dealers use the futures market to hedge their own risk from the swap transactions they perform with their counterparties to reduce risk. A possible economic justification for the significance of swap positions is that swap dealers act as a transmission channel for risk mitigation for the participants who hold the physical corn.

The 5-year break-even inflation rate shows slightly significant results. However, the 10-year vs. 2-year treasury yields, consumer price index (CPI), and the industrial production index show no explanatory power. Fama and French (1988) state that agricultural commodities are primarily influenced by seasonality and production and are less influenced by the state of the economy, which is supported by the present study.

USDA corn export announcements and ending stocks show no significance. These are heavily monitored figures within the corn industry, but numerous independent firms forecast these statistics in advance of the USDA's published data. This independent research could smooth the impact of these reports.

CME deliverable stocks are highly significant with negative coefficients and confirm the theory of storage. The inverse relationship between stocks and convenience yield is one of the most agreed-upon facts in commodity research. However, the USDA proxy for inventories show no significance. This paper's results indicate that stocks held by a CME deliverable warehouse determine the convenience yield, while stocks held elsewhere do not. For the full results, refer to Table 5.

5.2 Controlling for Spot Price

The spot price is the immediate price of the physical commodity, and the convenience yield is the implied return of holding the physical commodity. The correlation between the spot price and convenience yield of corn during this paper's sampling period is 65% at level. This correlation intuitively makes sense: if the spot's returns are high (low), the return of holding the physical commodity should also be high (low). As mentioned previously, not controlling for the spot price on the determinants of convenience yield could lead to misleading results that inadvertently reveal spot price determinants.

After controlling for the spot price, many determinants lose their explanatory power. In addition, the R^2 value increases significantly, indicating that changes in the spot price drive changes in the convenience yield. The determinants that still hold significance are feeder cattle, CME deliverable stocks, WTI, swap pressure, and CPI.

Live cattle, lean hog, ethanol margins, and 5-year break-even inflation lose their explanatory power after controlling for spot price. This indicates that the determinants only affect spot price changes. In addition, hedging pressure and managed money pressure lose their significance, which indicates that the theory of net hedging pressure applies only to the spot price of corn and not to the convenience yield. The coefficient signs for the remaining significant determinants are surprising. Feeder cattle, WTI, and ethanol all have negative coefficients, which is contrary to the notion that as demand margins increase, so should the convenience of holding physical corn, which is the main input or substitute for the various demand factors. CME deliverable stocks and at-the-money volatility of corn futures for a 3-month duration are positive, which confirms the theory of storage and the findings of Milonas and Thomadakis (1997). For the full results, refer to Table 5.

5.3 Robustness Test: Before, During, and After a US Drought

The United States experienced low carryout numbers from 2010 to 2014 due to record demand and, more importantly, production issues related to widespread drought across the Corn Belt. To check the robustness of the univariate regressions, the sample is split into three different periods: (1) before the drought, from 8/1/2001 to 8/31/2010; (2) during the drought, from 9/1/2010 to 8/31/2014; and (3) after the drought, from 9/1/2014 to 3/19/2020. The subsample univariate regressions are run by controlling for the spot price.

For the period before the drought, feeder cattle, live cattle, and WTI remain highly significant, and all other determinants show no significance. For the period during the drought, only hedge pressure show significant results. For the period after the drought, many of the determinants are significant: live cattle, lean hog, CME deliverable stocks, Corn Belt ethanol margins, Illinois ethanol margins, and swap pressure.

Interestingly, the R^2 value for the periods before and during the drought is higher when controlling for the spot price. This indicates the the goodness of fit for the convenience yield is model is better for the periods before and during the drought than after. The macroeconomic variables yield no significance for any of the subsample periods. For the full results, refer to Table 6.

An additional multiple regression for the significant variables from the univariate regressions for the period after the drought was run using a drought dummy variable. The dummy drought variable is regressed as its own series and is multiplied to the coefficients of the independent variables. The spot price, live cattle, CME delivery stocks, and swap pressure remain highly significant. The drought dummy and the drought dummy multiplied by live cattle are also significant. For Full results, refer to Table 7.

5.4 Robustness Test: Multiple Regression

Univariate regressions ignore any potential correlations between explanatory variables. For this reason, two multiple regressions were run. One multiple regression ran the significant determinants from the univariate regressions (Table 5) for feeder cattle, WTI, CME deliverable stocks, at-the-money implied volatilely for contracts with a 3-month duration, ethanol and swap pressure, revealing CME deliverable stocks and swap pressure to be highly significant. The negative and significant coefficient for CME deliverable stocks confirms the theory of storage. The multiple regression excludes CPI because it decreases the number of observations to 64. For the full results, refer to Table 8.

The significant determinants for the period after the drought (live cattle, lean hog, CME deliverable stocks, ethanol margins for Illinois and the Corn Belt, and swap pressure) were run with a multiple regression (Table 6). The coefficient signs for the demand factors show a positive coefficient, which makes economic sense except for the proxy for the ethanol margin in Illinois. Live cattle is the only significant demand factor; swap pressure also shows significance. Again, CME deliverable stocks confirmed the theory of storage. For full results, refer to Table 8.

5.5 Robustness Test: Non-Linear Regressions

Table 9 displays the results for non-linear regressions between the convenience yield, the determinant, and the spot price on the significant determinants from the univariate regressions. The first non-linear relationship examined is the determinant squared. Feeder cattle and at-the-money implied volatility show a small significance. The second non-liner relationship examined is the spot price squared which there is highlight significant results for CME deliverable stocks and swap pressure. An interaction term which is the spot price multiplied by the determinant is added to check if the sensitivity of the convenience yield to the determinant depends on the spot price. WTI, at-the-money implied volatility with a 3-month duration, and swap pressure all show highly significant results for the interaction term. The interaction term created an interesting result for WTI, which causes the linear coefficient to go from negative to positive. This added interaction term could be causing suppression or degree issues with WTI.

6. Conclusion

This paper performs an in-depth analysis of the determinants of convenience yield in corn futures. The estimated spot price and convenience yield come from Gibson and Schwartz's (1990) two-factor model, and a deterministic seasonal component adds to the convenience yield, in line with Mirantes et al. (2013). Numerous potentially novel determinants were regressed against the convenience yield while controlling for spot price.

This research confirms the theory of storage by using CME deliverable stocks without supporting evidence from USDA ending stocks. The theory of net hedging pressure provides little supporting evidence after controlling for spot price. Swap pressure is surprisingly significant and robust, while other types of pressure are not. Very few determinants show significance for the periods before and during the drought. However, numerous novel demand determinants—including live cattle, lean hog, Corn Belt ethanol margins, and Illinois ethanol margins—show highly significant results after the drought.

The macroeconomic variables used in this research provide little to no explanatory power for the convenience yield, indicating that the economy's state does not affect returns on physical corn. The spot price is highly significant in all univariate regressions and is the main driver of change in convenience yield. This research confirms the theory of storage, provides conflicting results regarding net hedging pressure and significant results for novel determinants, and proves that drought influences the convenience yield determinants of corn futures.

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8. Tables and Figures

Table 1: Principal Components Analysis

The two tables below show the results of the principal component anaylis for the seven most nearby corn futures contracts.

Eigenvalues:

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	6.90	6.84	0.99	6.90	0.9859
2	0.06	0.04	0.01	6.97	0.9951
3	0.02	0.01	0.00	6.99	0.9980
4	0.01	0.01	0.00	7.00	0.9993
5	0.00	0.00	0.00	7.00	0.9997
6	0.00	0.00	0.00	7.00	0.9999
7	0.00	---	0.00	7.00	1.0000

Eigenvectors :

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Corn Futures (t)	0.38	0.52	0.41	0.46	0.33	0.242445	0.21
Corn Futures (t+1)	0.38	0.43	0.13	-0.16	-0.35	-0.55983	-0.44
Corn Futures (t+2)	0.38	0.26	-0.28	-0.54	-0.30	0.399703	0.42
Corn Futures (t+3)	0.38	-0.03	-0.57	-0.04	0.59	0.072693	-0.42
Corn Futures (t+4)	0.38	-0.28	-0.36	0.49	-0.21	-0.39918	0.45
Corn Futures (t+5)	0.38	-0.44	0.21	0.22	-0.40	0.492026	-0.41
Corn Futures (t+6)	0.38	-0.46	0.48	-0.43	0.35	-0.24766	0.20

Table 2: Root Mean Squared Errors

This table provides the root mean squared errors between the actual futures prices and the modeled futures prices from the naive estimation and the Gibson and Schwartz (1990) estimation.

Full Name	Naive Estimation	Gibson and Schwartz (1990)
Corn Futures (t)	0.0437	0.0172
Corn Futures (t+1)	0.0925	0.0117
Corn Futures (t+2)	0.1582	0.0159
Corn Futures (t+3)	0.2321	0.0172
Corn Futures (t+4)	0.3015	0.0149
Corn Futures (t+5)	0.3763	0.0135
Corn Futures (t+6)	0.4515	0.0118
Corn Futures (t+7)	0.5340	0.0135
Corn Futures (t+8)	0.6178	0.0179

Table 3: Explanatory Variables: Descriptive Information, Statistics, Unit Roots , and Correlation Coefficients

This table provides the descriptive information for all variables used. The first column is the full name of the variable along with any transformation. The second column indicates the source of the data and the third column indicates the frequency. Columns four through seven show the descriptive statistics. Column eight shows the observations which some are irregular. Column nine and ten show the start and end date of the respective series. Columns eleven and twelve show the t-statistic for the Dickey-Fuller Unit root test ran and first differences and the probability, respectively. Banel B shows the correlation coefficients.

										Unit Root At First Diff	
Full Name	**Source**	**Frequency**	**Mean**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Observations**	**Start Date**	**End Date**	**t-Statistic**	**Prob.***
Log of Feeder Cattle	CME Group	Daily	4.82	0.26	0.3	2.66	4664	8/1/2001	3/19/2020	(63.58)	***
Log of Live Cattle	CME Group	Daily	4.63	0.22	0.01	2.32	4664	8/1/2001	3/19/2020	(65.45)	***
Log of Lean Hog	CME Group	Daily	4.24	0.22	0.08	3.39	4664	8/1/2001	3/19/2020	(65.88)	***
Log of WTI	CME Group	Daily	4.08	0.43	-0.48	2.59	4664	8/1/2001	3/19/2020	(71.87)	***
Log of Ethanol	CME Group	Daily	0.69	0.24	0.27	2.15	3742	4/11/2005	3/19/2020	(57.74)	***
5-Year Breakeven Inflation Rate	FRED	Daily	1.85	0.53	-1.32	7.83	206	1/2/2014	3/19/2020	(12.43)	***
10 - 2 Year Treasury Constant Maturity	FRED	Monthly	1.4	0.87	-0.23	1.81	224	9/5/2006	3/3/2020	(6.86)	***
Consumer Price Index	FRED	Monthly	0.17	0.38	-0.85	6.8	224	1/6/2005	3/19/2020	(10.57)	***
Industrial Production Index	FRED	Monthly	100.21	5.69	-0.24	2.22	224	8/2/2001	3/19/2020	(4.43)	***
Log of CME Corn Deliverable Stocks	CME Group	Daily	2.41	0.73	-0.70	2.29	1459	6/5/2007	3/19/2020	(35.27)	***
Log of USDA Ending Stocks Corn	USDA	Monthly	3.16	0.17	-0.75	2.26	161	1/5/2010	3/19/2020	(13.67)	***
Log of USDA Corn Export Announcements	USDA	Daily	5.80	0.34	-3.27	25.61	2035	7/28/2009	3/19/2020	(14.96)	***
GARCH (1,1) Vol	CME Group	Daily	0.00	0.00	2.38	10.55	4663	7/23/2007	3/19/2020	(41.51)	***
At-The-Money Implied Vol Corn Futures, Spot	Reuters Data Stream	Daily	26.49	9.56	0.76	3.52	2824	7/23/2007	3/19/2020	(71.18)	***
At-The-Money Implied Vol Corn Futures, 3 Mo.	Reuters Data Stream	Daily	27.89	8.77	0.44	2.42	3112	10/10/2007	3/19/2020	(60.61)	***
Ethanol Margins Corn Belt	Reuters Data Stream	Daily	0.2	0.29	2.53	13.82	2553	6/4/2010	3/19/2020	(53.21)	***
Ethanol Margins Illinois	Reuters Data Stream	Daily	0.13	0.29	1.30	4.83	2662	6/4/2010	3/20/2020	(25.97)	***
Ethanol Margins North East Iowa	Reuters Data Stream	Daily	0.16	0.25	1.55	7.89	3168	6/13/2006	3/17/2020	(21.74)	***
Ethanol Margins Northwest Iowa	Reuters Data Stream	Daily	0.18	0.25	1.62	8.32	3168	6/13/2006	3/17/2020	(21.38)	***
Log of EIA Ethanol Production	EIA	Daily	2.99	0.03	-0.77	3.04	1828	6/13/2006	3/17/2020	(23.64)	***
Log of EIA Ethanol Stocks	EIA	Daily	4.31	0.05	-0.61	2.46	1828	6/13/2006	3/17/2020	(19.80)	***
Managed Money Pressure	CFTC	Weekly	0.29	0.41	-0.01	1.69	711	2/1/2003	2/29/2020	(18.46)	***
Hedge Pressure	CFTC	Weekly	-0.29	0.12	0.11	2.55	711	8/1/2001	3/1/2020	(21.65)	***
Swap Pressure	CFTC	Weekly	0.87	0.11	-1.02	4.45	711	8/1/2001	3/1/2020	(20.15)	***
Other Pressure	CFTC	Weekly	0.30	0.14	-0.31	3.16	711	8/1/2001	3/1/2020	(29.54)	***

*** Significant at 1%

** Significant at 5%

* Significant at 10%

Table 3 Panel B: Correlation Coefficients

	Convenience Yield	Log Spot	Log of Feeder Cattle	Log of Live Cattle	Log of Lean Hog	Log of WTI	Log of Ethanol	5-Year Breakeven Inflation Rate	10 - 2 Year Treasury Constant Maturity	Consumer Price Index	Industrial Production Index	Log of CME Corn Deliverable Stocks	Log of USDA Ending Stocks Corn	Log of USDA Corn Export Announcements	GARCH (1,1) Vol	At-The-Money Implied Vol Corn Futures, Spot	At-The-Money Implied Vol Corn Futures, 3 Mo.	Ethanol Margins Corn Belt	Ethanol Margins Illinois	Ethanol Margins North East Iowa	Ethanol Margins Northwest Iowa	Log of EIA Ethanol Production	Log of EIA Ethanol Stocks	Managed Money Pressure	Hedge Pressure	Swap Pressure	Other Pressure
Convenience Yield	1.00	0.68	0.03	0.27	0.57	0.56	0.55	0.58	0.31	0.48	0.06	-0.30	-0.45	0.39	-0.67	-0.13	0.41	0.61	0.56	0.60	0.58	-0.08	-0.28	0.47	-0.43	0.18	0.10
Log Spot		1.00	0.28	0.28	0.87	0.93	0.86	0.48	0.46	0.48	0.43	0.23	-0.54	0.49	-0.05	0.52	0.65	0.88	0.82	0.86	0.84	-0.48	-0.59	0.82	-0.61	0.06	-0.16
Log of Feeder Cattle			1.00	0.89	0.52	0.06	0.30	-0.47	0.62	-0.19	-0.22	-0.24	-0.82	0.03	0.18	0.60	0.46	0.24	0.44	0.27	0.29	-0.76	-0.52	0.32	-0.23	0.39	-0.53
Log of Live Cattle				1.00	0.55	0.01	0.44	-0.44	0.78	-0.13	-0.50	-0.59	-0.92	-0.04	-0.12	0.34	0.34	0.39	0.54	0.42	0.44	-0.72	-0.59	0.22	-0.14	0.59	-0.45
Log of Lean Hog					1.00	0.68	0.80	0.24	0.58	0.53	0.14	0.07	-0.64	0.42	0.12	0.55	0.55	0.80	0.77	0.80	0.79	-0.57	-0.59	0.73	-0.46	0.11	-0.49
Log of WTI						1.00	0.81	0.65	0.37	0.36	0.52	0.45	-0.31	0.56	0.05	0.55	0.68	0.84	0.78	0.82	0.80	-0.29	-0.59	0.87	-0.73	0.08	0.11
Log of Ethanol							1.00	0.27	0.76	0.21	0.04	-0.01	-0.64	0.28	0.00	0.51	0.51	0.99	0.94	0.99	0.99	-0.58	-0.84	0.71	-0.54	0.42	-0.11
5-Year Breakeven Inflation Rate								1.00	-0.08	0.50	0.37	0.45	0.27	0.76	-0.14	0.06	0.48	0.38	0.33	0.37	0.33	0.51	-0.08	0.61	-0.63	-0.06	0.53
10 - 2 Year Treasury Constant Maturity									1.00	-0.22	-0.53	-0.36	-0.80	0.18	0.03	0.52	0.50	0.73	0.86	0.77	0.79	-0.58	-0.94	0.54	-0.50	0.85	-0.06
Consumer Price Index										1.00	0.41	0.23	0.09	0.50	-0.10	-0.04	0.17	0.29	0.10	0.26	0.23	0.19	0.23	0.26	0.05	-0.50	-0.19
Industrial Production Index											1.00	0.72	0.26	0.21	0.13	0.20	0.19	0.06	-0.09	0.00	-0.02	-0.02	0.28	0.26	-0.12	-0.73	-0.07
Log of CME Corn Deliverable Stocks												1.00	0.50	0.47	0.68	0.52	0.31	0.02	-0.01	0.00	-0.02	0.22	0.06	0.44	-0.36	-0.47	0.10
Log of USDA Ending Stocks Corn													1.00	0.00	0.25	-0.39	-0.46	-0.60	-0.70	-0.61	-0.63	0.82	0.69	-0.38	0.29	-0.55	0.35
Log of USDA Corn Export Announcements														1.00	0.14	0.49	0.82	0.38	0.47	0.40	0.38	0.32	-0.27	0.77	-0.69	0.13	0.38
GARCH (1,1) Vol															1.00	0.66	0.11	-0.03	0.02	-0.02	-0.01	-0.09	-0.18	0.25	-0.15	-0.13	-0.28
At-The-Money Implied Vol Corn Futures, Spot																1.00	0.75	0.49	0.63	0.51	0.52	-0.47	-0.68	0.76	-0.62	0.27	-0.15
At-The-Money Implied Vol Corn Futures, 3 Mo.																	1.00	0.55	0.73	0.58	0.57	-0.19	-0.61	0.88	-0.83	0.39	0.24
Ethanol Margins Corn Belt																		1.00	0.94	1.00	0.99	-0.49	-0.81	0.75	-0.57	0.41	-0.03
Ethanol Margins Illinois																			1.00	0.96	0.96	-0.50	-0.93	0.84	-0.74	0.61	0.03
Ethanol Margins North East Iowa																				1.00	1.00	-0.48	-0.84	0.76	-0.59	0.46	-0.01
Ethanol Margins Northwest Iowa																					1.00	-0.50	-0.86	0.75	-0.58	0.49	-0.02
Log of EIA Ethanol Production																						1.00	0.57	-0.23	0.08	-0.21	0.63
Log of EIA Ethanol Stocks																							1.00	-0.71	0.68	-0.76	-0.02
Managed Money Pressure																								1.00	-0.91	0.30	0.09
Hedge Pressure																									1.00	-0.44	-0.31
Swap Pressure																										1.00	0.35
Other Pressure																											1.00

Table 4: Corn Futures Returns: Descriptive Information, Statistics, and Unit Roots

This table provides the descriptive information for the returns for the seven most nearby corn futures contracts. The first column is the full name of the variable. The second column indicates the source of the data and the third column indicates the frequency. Column four shows the average days till maturity. Columns five through seven show the descriptive statistics. Column eight shows the observations , column nine and ten show the start and end date of the respective series. Columns eleven and twelve show the t-statistic for the Dickey-Fuller Unit root test ran and first differences and the probability, respectively.

										Unit Root At First Diff	
Full Name	Source	Frequency	Ave. Days Till Maturity	Mean	Std. Dev.	Skewness	Kurtosis	Observations	Start Date	t-Statistic	Prob.*
Corn Futures (t)	CME Group	Daily	25.7	0.000099	0.0183	-0.57	15.35	4663	8/2/2001	(28.76)	***
Corn Futures (t+1)	CME Group	Daily	76.5	0.000094	0.0173	0.01	7.02	4663	8/2/2001	(28.97)	***
Corn Futures (t+2)	CME Group	Daily	125.4	0.000094	0.0167	-0.21	8.67	4663	8/2/2001	(27.85)	***
Corn Futures (t+3)	CME Group	Daily	174.3	0.000095	0.0158	-0.14	7.65	4663	8/2/2001	(27.95)	***
Corn Futures (t+4)	CME Group	Daily	225.1	0.000095	0.0149	-0.25	8.12	4663	8/2/2001	(27.66)	***
Corn Futures (t+5)	CME Group	Daily	277.6	0.000094	0.0142	-0.19	7.43	4663	8/2/2001	(27.81)	***
Corn Futures (t+6)	CME Group	Daily	328.40	0.000091	0.01	-0.12	7.35	4663	8/2/2001	(22.55)	***

*** Significant at 1%

** Significant at 5%

* Significant at 10%

Table 5: Results of Univariate Regressions

This table displays the results for the univariate regressions without controlling for the spot price and after controlling for the spot price, ran at first differences

	Without Controlling For Spot				Controlling For Spot					
Independent Dependent Variable	**α Coef.**	**β1 Coef.**		**R-Squared**	**α Coef.**	**β1 Coef.**		**Log Spot Coef.**		**R-Square**
Log of Feeder Cattle	0.000	-0.070	***	0.7%	0.000	-0.020	***	0.482	***	83.7%
Log of Live Cattle	0.000	0.046	***	0.4%	0.000	-0.002		0.483	***	83.6%
Log of Lean Hog	0.000	0.011	**	0.1%	0.000	0.001		0.483	***	83.6%
Log of WTI	0.000	0.057	***	2.8%	0.000	-0.010	***	0.486	***	83.7%
Log of Ethanol	0.000	0.150	***	14.0%	0.000	-0.005	*	0.478	***	84.1%
Log of CME Corn Deliverable Stocks	0.000	0.004	***	0.4%	0.000	-0.001	**	0.518	***	80.7%
Log of USDA Ending Stocks Corn	0.001	-0.014		0.0%	-0.001	-0.052		0.592	***	57.8%
Log of USDA Corn Export Announcements	0.000	0.002		0.1%	0.000	0.000		0.505	***	81.2%
GARCH (1,1)	0.000	0.170		0.0%	0.000	0.408		0.483	***	83.0%
At-The-Money Implied Vol Corn Futures, Spot	0.000	0.000	***	1.6%	0.000	0.000		0.477	***	83.3%
At-The-Money Implied Vol Corn Futures, 3 Mo	0.000	0.002	***	4.5%	0.000	0.000	**	0.465	***	84.5%
Ethanol Margins Corn Belt	0.000	-0.032	***	7.7%	0.000	0.001		0.485	***	82.9%
Ethanol Margins Illinois	0.000	-0.012	***	1.2%	0.000	-0.001		0.480	***	83.6%
Ethanol Margins North East Iowa	0.000	-0.008	***	0.4%	0.000	0.000		0.467	***	84.4%
Ethanol Margins Northwest Iowa	0.000	-0.007	***	0.4%	0.000	0.000		0.467	***	84.4%
Log of EIA Ethanol Production	0.000	-0.010		0.0%	0.000	0.021		0.505	***	81.2%
Log of EIA Ethanol Stocks	0.000	0.028		0.0%	0.000	-0.003		0.505	***	81.2%
Managed Money Pressure	0.000	0.168	***	23.7%	0.000	0.010		0.508	***	69.1%
Hedge Pressure	0.000	-0.448	***	22.5%	0.000	0.021		0.526	***	69.1%
Swap Pressure	0.000	-0.260	***	3.8%	0.000	-0.081	***	0.512	***	69.4%
Other Pressure	0.000	0.037		0.4%	0.000	0.009		0.518	***	69.1%
5-Year Breakeven Inflation Rate	0.000	0.050	*	1.6%	-0.002	-0.024		0.661	***	56.8%
10- 2 Year Treasury Constant Maturity	0.001	0.022		0.1%	0.000	0.015		0.633	***	55.2%
Consumer Price Index	0.001	0.025		1.2%	0.001	-0.022	**	0.655	***	56.0%
Industrial Production Index	0.001	0.005		0.2%	0.000	0.003		0.633	***	55.2%

*** Significant at 1%
** Significant at 5%
* Significant at 10%

Table 6: Results of the univariate regressions before, during , and after the drought.

This table shows the results of the univariate regressions of the determinants on the convenience yield of corn, after controlling for the spot price, and ran at first differences for the periods 1) before the drought 8/1/2000 to 8/31/2010, 2) during the drought 9/1/2010 to 8/31/2014, and 3) after the drought 9/1/2014 to 3/19/2020

	8/1/2001 8/31/2010					9/1/2010 8/31/2014					9/1/2014 3/19/2020				
Independent Dependent Variable	**α Coef.**	**β1 Coef.**	**Log Spot Coef**	**R-Squared**	**Obs.**	**α Coef.**	**β1 Coef.**	**Log Spot Coef.**	**R-Squared**	**Obs.**	**α Coef.**	**β1 Coef.**	**Log Spot Co**	**R-Squared**	**Obs.**
Log of Feeder Cattle	0.000	-0.037 ***	0.480 ***	84.7%	2276	0.000	-0.021	0.467 ***	84.9%	1000	0.000	-0.002	0.515 ***	80.1%	1387
Log of Live Cattle	0.000	-0.011 *	0.481 ***	84.6%	2276	0.000	-0.015	0.469 ***	84.9%	1000	0.000 **	0.015 **	0.515 ***	80.2%	1387
Log of Lean Hog	0.000	-0.004	0.481 ***	84.6%	2276	0.000	0.001	0.468 ***	84.9%	1000	0.000	0.006 **	0.514 ***	80.2%	1387
Log of WTI	0.000	-0.016 ***	0.487 ***	84.8%	2276	0.000	-0.003	0.469 ***	84.9%	1000	0.000 **	-0.002	0.515 ***	80.1%	1387
Log of Ethanol	0.000	-0.012 **	0.464 ***	86.2%	1354	0.000	-0.002	0.469 ***	84.9%	1000	0.000 **	-0.003	0.517 ***	80.1%	1387
Log of CME Corn Deliverable Stocks						-0.001 ***	-0.001	0.501 ***	90.3%	166	0.000 *	-0.002 **	0.519 ***	80.0%	1283
Log of USDA Ending Stocks Corn	-0.004	-0.032	0.579 ***	63.0%	47	-0.004	-0.086	0.510 ***	59.9%	46	0.004	-0.082	0.757 ***	53.2%	65
Log of USDA Corn Export Announcements	0.000	0.007	0.465 ***	99.1%	5	-0.001 ***	0.000	0.464 ***	87.5%	246	0.000 *	-0.001	0.516 ***	80.2%	1374
GARCH (1,1)	0.000	0.834	0.481 ***	84.6%	2275	0.000	1.797	0.468 ***	84.9%	1000	0.000 **	-5.360	0.514 ***	80.1%	1387
At-The-Money Implied Vol Corn Futures, Spot	0.000	0.000	0.440 ***	86.6%	450	0.000	0.000	0.477 ***	85.5%	752	0.000 **	0.000	0.515 ***	80.1%	1385
At-The-Money Implied Vol Corn Futures, 3 Mo	0.001	0.000	0.440 ***	88.8%	725	0.000	0.000	0.467 ***	84.9%	1000	0.000 **	0.000	0.512 ***	80.1%	1387
Ethanol Margins Corn Belt	-0.001 ***	-0.003	0.445 ***	91.5%	165	0.000	-0.001	0.467 ***	84.9%	1000	0.000 ***	0.004 **	0.520 ***	80.2%	1387
Ethanol Margins Illinois	0.000	0.008	0.459 ***	91.3%	274	0.000	0.000	0.468 ***	84.9%	1000	0.000 **	-0.006 **	0.513 ***	80.2%	1387
Ethanol Margins North East Iowa	0.000	0.002	0.442 ***	88.4%	780	0.000	0.000	0.468 ***	84.9%	1000	0.000 **	-0.001	0.515 ***	80.1%	1387
Ethanol Margins Northwest Iowa	0.000	0.003	0.442 ***	88.4%	780	0.000	0.000	0.468 ***	84.9%	1000	0.000 **	0.000	0.515 ***	80.1%	1387
Log of EIA Ethanol Production						-0.001 ***	0.020	0.466 ***	87.4%	250	0.000 *	0.020	0.516 ***	80.2%	1374
Log of EIA Ethanol Stocks						-0.001 ***	0.042	0.464 ***	87.5%	250	0.000 *	-0.009	0.516 ***	80.2%	1374
Managed Money Pressure	-0.001	0.009	0.476 ***	72.2%	217	0.000	-0.020	0.533 ***	70.0%	205	0.001	0.010	0.590 ***	66.4%	288
Hedge Pressure	-0.001	0.046	0.497 ***	72.2%	217	0.000	0.092 *	0.547 ***	70.4%	205	0.001	0.019	0.620 ***	66.4%	288
Swap Pressure	-0.001	0.044	0.482 ***	72.2%	217	0.000	-0.013	0.516 ***	69.9%	205	0.001	-0.116 ***	0.568 ***	67.5%	288
Other Pressure	-0.001	-0.007	0.483 ***	72.2%	217	0.000	0.020	0.519 ***	70.0%	205	0.001	0.015	0.603 ***	66.4%	288
5-Year Breakeven Inflation Rate	-0.004	-0.030	0.595 ***	63.7%	48	0.000	0.065	0.515 ***	56.0%	48	0.004	0.081	0.743 ***	54.6%	67
10- 2 Year Treasury Constant Maturity	-0.004	0.018	0.571 ***	62.8%	48	0.001	0.076	0.537 ***	56.4%	48	0.004	-0.002	0.753 ***	53.0%	67
Consumer Price Index	-0.004	-0.017	0.600 ***	63.1%	48	0.000	0.002	0.523 ***	54.6%	48	0.004	-0.008	0.749 ***	53.1%	67
Industrial Production Index	-0.004	-0.001	0.572 ***	62.7%	48	-0.003	0.017	0.530 ***	55.2%	48	0.004	0.002	0.751 ***	53.1%	67

*** Significant at 1%
** Significant at 5%
* Significant at 10%

Table 7: Multiple Regression For Significant Variables After Drought Using Dummy Drought Variable

This table shows the results of $\delta_t = c + \beta_1 X_{kt} + \beta_2 D + \beta_3 X_{kt} D + e_t$ where δ_t is the convenience yield , X_{kt} are the significant determinants from the univariate regression for the period after the drought, D is a dummy variable for the period during the drought, X_t D is the dummy variable multiplied by the determinant , and e_t is the error term . This regression is ran at first differences regressed in a multiple regression.

Full Name	Coefficient	Prob.
Log Spot	0.570	***
Log of Live Cattle	0.058	**
Log of Lean Hog	0.015	
Log of CME Corn Deliverable Stocks	-0.007	**
Ethanol Margins Illinois	0.008	
Ethanol Margins Corn Belt	-0.004	
Swap Pressure	-0.120	***
Drought Dummy	-0.006	**
(Log Spot *Drought Dummy)	0.094	
(Log of Live Cattle * Drought Dummy)	-0.163	*
(Log of Lean Hog * Drought Dummy)	0.002	
(Log of CME Corn Deliverable Stocks * Drought Dummy)	0.001	
(Ethanol Margins Illinois * Drought Dummy)	-0.009	
(Ethanol Margins Corn Belt * Drought Dummy)	0.003	
(Swap Pressure * Drought Dummy)	0.275	
Constant	0.001	
R-squared	71.3%	
Adjusted R-squared	69.7%	
S.E. of regression	0.014	
Sum squared resid	0.051	
Log likelihood	847.853	
F-statistic	45.654	

*** Significant at 1%

** Significant at 5%

* Significant at 10%

Table 8 : Multiple Regression

This table shows the results of $\delta_t = c + \beta\, X_{kt} + e_t$ where δ_t is the convenience yield , X_{kt} are the significant determinants from the univariate regressions, and e_t is the error term . This regression is ran at first differences regressed in a multiple regression.

Full Name	**Coefficient**	**Prob.**
Log Spot of Corn (GS Est)	0.569	***
Log of Feeder Cattle	-0.033	
Log of WTI	-0.019	
Log of CME Corn Deliverable Stocks	-0.007	**
Swap Pressure	-0.101	***
Log of Ethanol	0.002	
At-The-Money Implied Vol Corn Futures, 3 Mo.	0.001	
Constant	0.000	
R-squared	69.7%	
Adjusted R-squared	69.1%	
S.E. of regression	0.014	
Sum squared resid	0.054	
Log likelihood	840.255	
F-statistic	109.473	
Prob(F-statistic)	0.000	

*** Significant at 1%
** Significant at 5%
* Significant at 10%

Table 9: Non-Linear Regressions

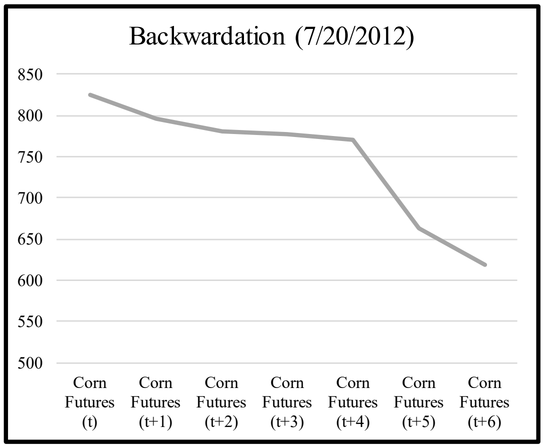
This table shows the results of $\delta_t = c + \beta_1 X_t + \beta_2 X_t^2 + \beta_3 S_t + \beta_3 S_t^2 + \beta_4 X_t * S_t \;\; e_t$ *where* δ_t *is the convenience yield ,* X_t *are the significant determinants from the univariate regression,* S_t *is the spot price, and* e_t *is the error term . This regression is ran at first differences.*

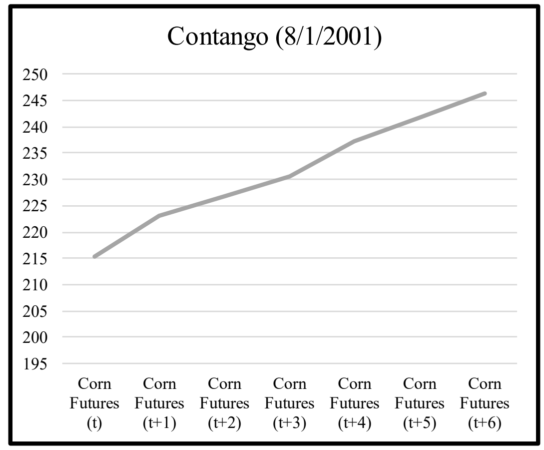
Variable	α Coef.	β1 Coef.	β1 Coef. ^2	Log Spot	Log Spot ^2	X * Log Spot	R-squared
Log of Feeder Cattle	0.000024	-0.01988 ***		0.48237 ***	-0.11182		83.7%
Log of Feeder Cattle	0.000020	-0.02022 ***	-0.22685	0.48215 ***			83.7%
Log of Feeder Cattle	0.000044	-0.02045 ***	-0.21535	0.48218 ***	-0.10152		83.7%
Log of Feeder Cattle	0.000048	-0.07812	-0.25456 *	0.43493 ***	-0.09848	0.00990	83.7%
Log of WTI	0.000020	-0.00982 ***		0.48651 ***	-0.10463		83.7%
Log of WTI	0.000000	-0.00990 ***	-0.01021	0.48646 ***			83.7%
Log of WTI	0.000025	-0.00993 ***	-0.00841	0.48651 ***	-0.10216		83.7%
Log of WTI	0.000025	0.10444 ***	-0.00398	0.57069 ***	-0.12172	-0.01977 ***	83.8%
Log of Ethanol	-0.000043	-0.00236 *		0.47761 ***	-0.05997		84.1%
Log of Ethanol	-0.000049	-0.00312 **	-0.00557	0.47846 ***			84.1%
Log of Ethanol	-0.000035	-0.00311 **	-0.00536	0.47843 ***	-0.05216		84.1%
Log of Ethanol	-0.000033	0.02001	-0.00627	0.48728 ***	-0.05196	-0.00393	84.2%
Log of CME Corn Deliverable Stocks	0.000337 ***	-0.00033		0.51461 ***	-1.80378 ***		81.3%
Log of CME Corn Deliverable Stocks	0.000085	-0.00111	-0.00049	0.51862 ***			80.7%
Log of CME Corn Deliverable Stocks	0.000338 ***	-0.00076	0.00069	0.51368 ***	-1.88204 ***		81.3%
Log of CME Corn Deliverable Stocks	0.000340 ***	-0.04134	0.00058	0.49718 ***	-1.89437 ***	0.00690	81.4%
At-The-Money Implied Vol Corn Futures, 3 Mo	0.000064	0.00014 **		0.46523 ***	-0.12502		84.5%
At-The-Money Implied Vol Corn Futures, 3 Mo	0.000048	0.00013 **	-0.00002 *	0.46524 ***			84.5%
At-The-Money Implied Vol Corn Futures, 3 Mo	0.000072	0.00014 **	-0.00002 *	0.46509 ***	-0.09275		84.5%
At-The-Money Implied Vol Corn Futures, 3 Mo	0.000078	0.00295 ***	-0.00002 *	0.48020 ***	-0.10714	-0.00046 ***	84.6%
Swap Pressure	0.000509	-0.08368 ***		0.51137 ***	-0.28372 **		69.6%
Swap Pressure	-0.000118	-0.08047 ***	0.04682	0.51186 ***			69.4%
Swap Pressure	0.000472	-0.08259 ***	0.09927	0.51140 ***	-0.28828 **		69.6%
Swap Pressure	0.000433	-1.01841 **	0.12720	0.37756 ***	-0.28599 **	0.15381 **	69.8%
Consumer Price Index	0.013041 **	-0.06499 ***		0.63862 ***	-0.22873		63.0%
Consumer Price Index	-0.001130	-0.01641	0.01273	0.60976 ***			56.9%
Consumer Price Index	0.000035	-0.01971	0.02240	0.60940 ***	-0.17870		57.1%
Consumer Price Index	-0.000159	-0.12513	0.02280	0.60706 ***	-0.16900	0.01749	57.1%

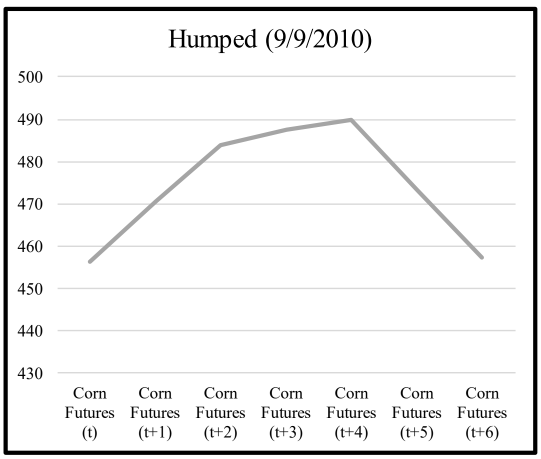
*** Significant at 1%
** Significant at 5%
* Significant at 10%

Figure (1)

The four charts below show a backwardation, contango, humped, and irregular curve structures for the seven most nearby corn futures contracts. The dates of these different structures are included next to the curve structure name.







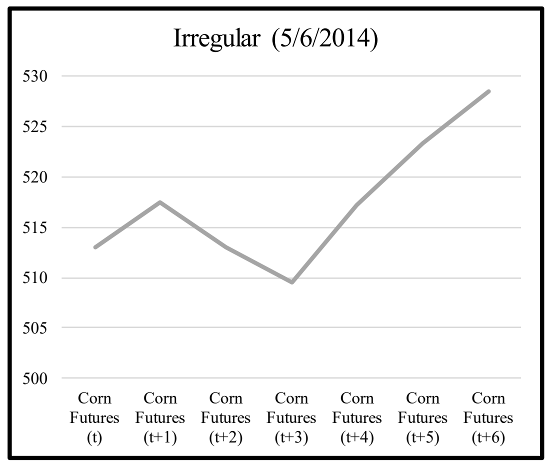


Figure (2)

The chart below shows the annualized realized volatility for the seven most nearby corn futures contracts.

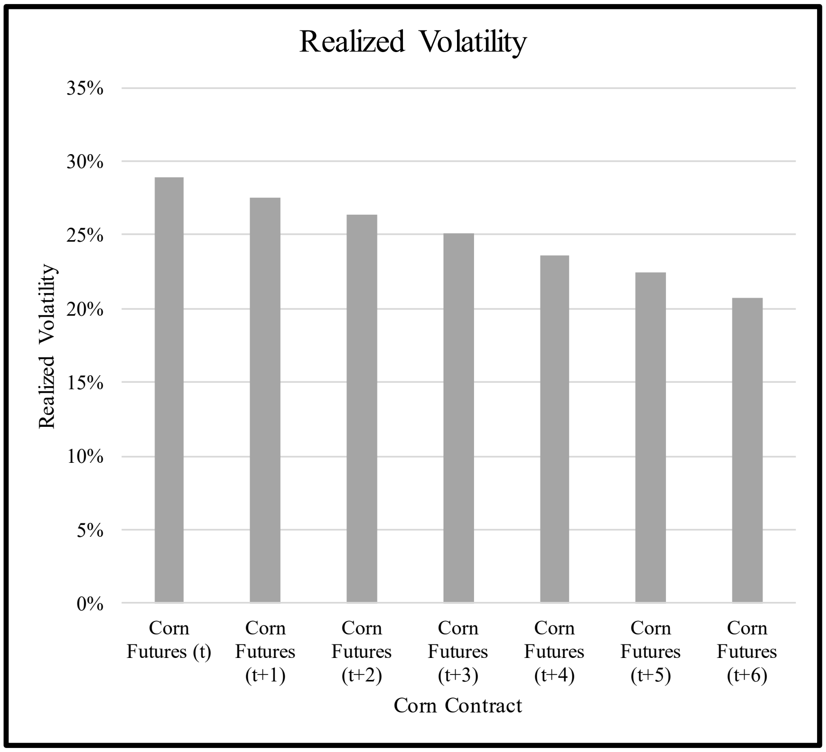


Figure (3)
The figure below shows the Gibson and Schwartz (1990) estimated series for convenience yield and the naive convenience yield for corn futures.

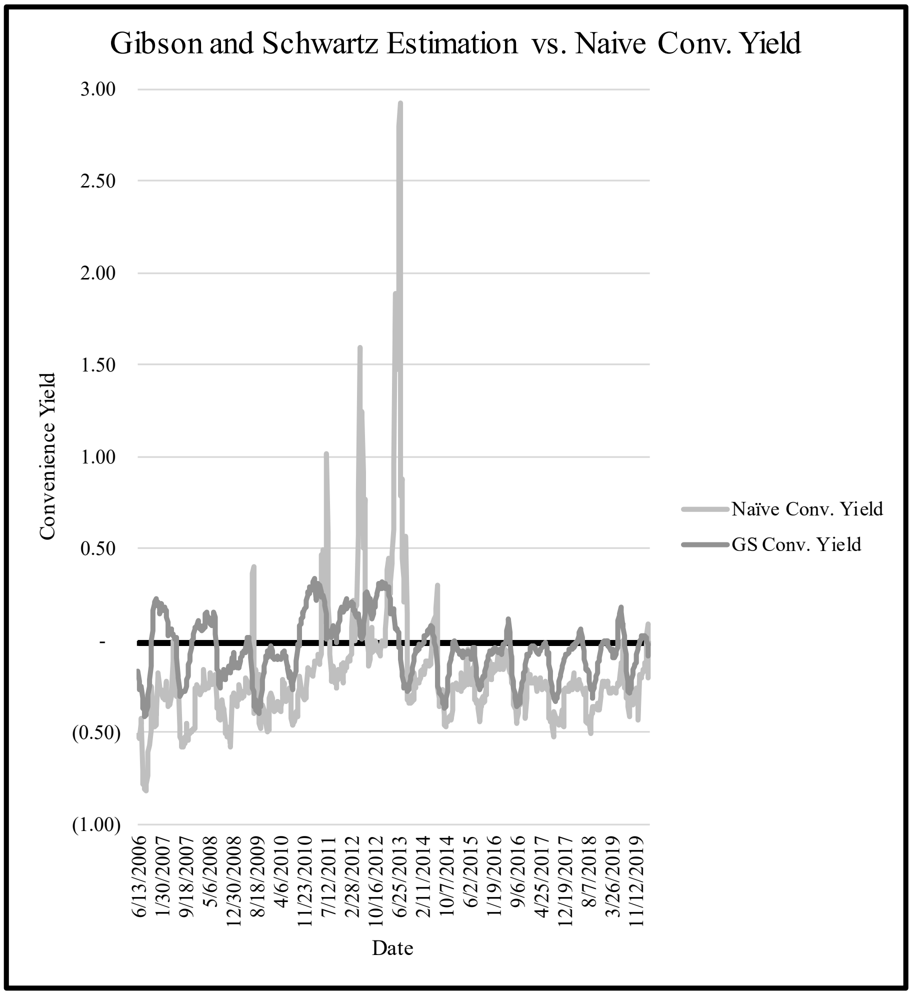
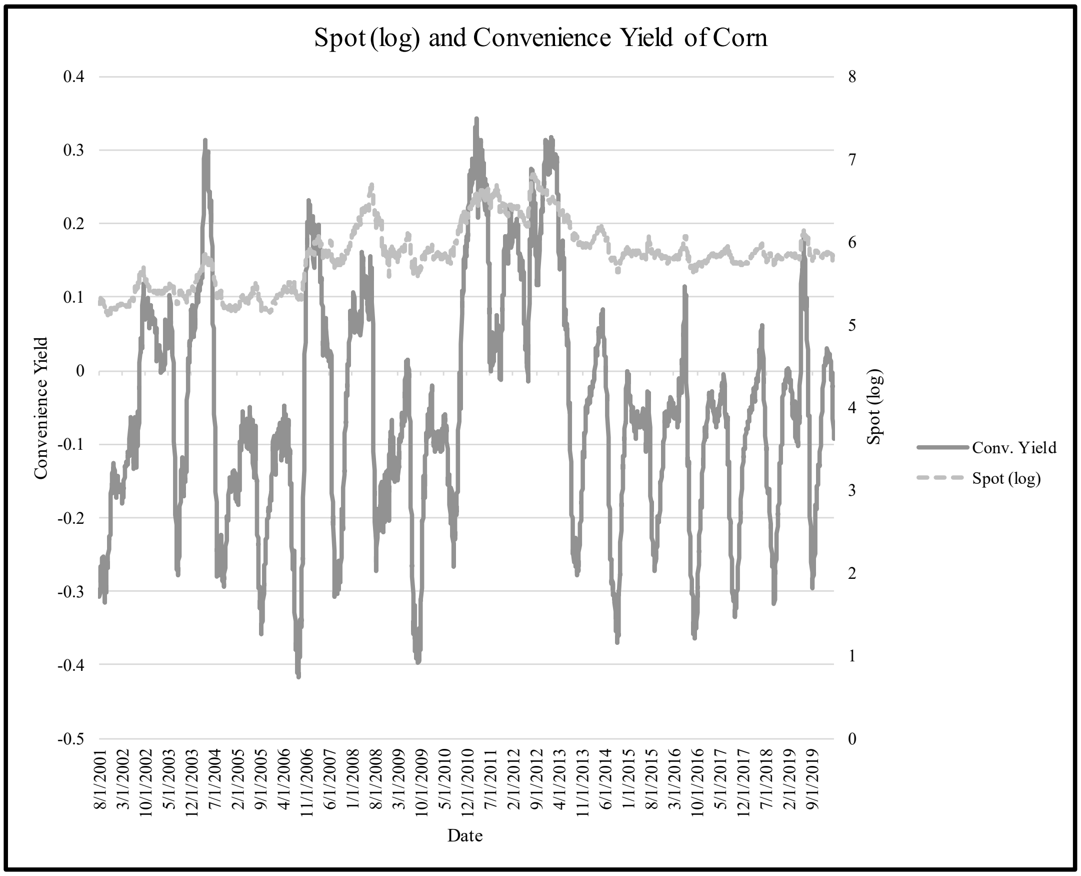


Figure (4)
The figure below shows the spot and convenience yield series from the Gibson and Schwartz (1990) estimation



9. Appendix

9.1 Estimation Procedure

Assuming no arbitrage opportunities and risk-neutral pricing, the combined dynamics follow the joint stochastic process:

$$dS_t = (r_t - \delta_t)S_t dt + \sigma_s S_t dW_t^1 \tag{9}$$
$$d\overline{\delta}_t = k(\hat{\alpha} - \delta_t)dt + \sigma_\delta dW_t^2 \tag{10}$$

where r is the interest rate assumed to be constant. Also, $\hat{\alpha} = \alpha - \frac{\lambda\sigma_2}{k}$, where λ is the market price of risk for the convenience yield. The futures prices and forward prices can be assumed to be equal and satisfy a partial differential equation with a definitive solution:

$$F(t,T) = s(t)e^{-\delta(t)\,\frac{1-e^{-kT}}{k}} + A(T) \tag{11}$$

$$A(T) = \sum_{i=1}^{n} \frac{\theta_i}{2i\pi}\cos(2i\pi(s+\xi_i))\left(r - \hat{\alpha} + \frac{\sigma_2^2}{2k^2} - \rho\frac{\sigma_1\sigma_2}{k}\right)T + \frac{\sigma_2^2}{4}\frac{1-e^{-2kT}}{k^3} + (\hat{\alpha}k +$$
$$\rho\sigma_1\sigma_2 - \frac{\sigma_2^2}{k})\frac{1-e^{-kT}}{K^2} \tag{12}$$

This paper applies the Kalman filter (Kalman, 1960) to estimate the term structure of corn futures. This is an optimal recursive estimator that minimizes the mean square error of the estimated parameters. It requires the specified model to be in a state-space form with a transition equation and a measurement equation. The transition equation of the unobserved state variables is given by the discrete-time versions of equations (3) and (6), as follows:

$$\begin{bmatrix} X_t \\ \overline{\delta}_t \end{bmatrix} = \begin{bmatrix} (\mu - \frac{1}{2}\sigma_1^2)\Delta t \\ k\alpha\Delta t \end{bmatrix} + \begin{bmatrix} 1 & -\Delta t \\ 0 & 1 - k\Delta t \end{bmatrix} \begin{bmatrix} X_{t-1} \\ \overline{\delta}_{t-1} \end{bmatrix} + \omega_t, \tag{13}$$

where Δt denotes the intervals between observations and ω_t represents serially uncorrelated and normally distributed innovations with

$$\mathbb{E}[\omega_t] = 0, Var[\omega_t] = W = \begin{bmatrix} \sigma_1^2 \Delta t & \sigma_1 \sigma_2 \rho_1 \Delta t \\ \sigma_1 \sigma_2 \rho_1 \Delta t & \sigma_2^2 \Delta t \end{bmatrix} \quad (14)$$

The measurement equation joins the state variables in the observable series of corn futures prices with different maturities, as shown in equation (11). *N* denotes the number of observed durations of commodity futures prices. The measurement equation is as follows:

$$\begin{bmatrix} \ln F(\tau_1) \\ \vdots \\ \ln F\ (\tau_{N1}) \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1-e^{-kT_1}}{k} \\ \vdots & \vdots \\ 1 & \frac{1-e^{-kT_{N_1}}}{k} \end{bmatrix} \begin{bmatrix} X_t \\ \overline{\delta_t} \end{bmatrix} + \begin{bmatrix} A\ (\tau_1) \\ \vdots \\ A(\tau_{N1}) \end{bmatrix} + \varepsilon_t \quad (15)$$

where ε_t represents serially uncorrelated measurement errors with $\mathbb{E}[\varepsilon_t] = 0$ and $Var[\varepsilon_t] = H_t$.