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Costs of Futures Hedging in Corn and Soybean Markets

Ruoding Shi and Olga Isengildina Massa

This study develops a comprehensive framework to measure, explain, and anticipate the costs of futures hedging. Using historical futures prices and margin requirements, we simulate hedging costs for corn and soybeans over 2004–2018. Empirical distributions derived from the simulation results provide unconditional estimates of the costs of hedging as well as the probability of hedging failure. Conditional estimates assess the impact of margin requirements, price volatility, and price changes as well as seasonal patterns using quantile regressions. Our findings demonstrate that price volatility is a main driver of the costs of hedging and can be used to anticipate future hedging costs.

Key words: futures trading, hedging, risk management

Introduction

Global commodity markets have experienced substantial volatility growth over the past decade, making price risk management increasingly important. Commodity futures are widely used as a risk management tool to offset price movements in the spot markets. However, maintaining an account to meet margin calls is consistently quoted as the main impediment to using futures markets by agricultural producers (Farm Credit Services of America, 2017). While some argue that correctly implementing a hedge allows losses in futures positions to be directly offset by gains in cash markets (Coffey, Tonsor, and Schroeder, 2018), large margin calls may lead to a liquidity crisis that often results in premature termination of a hedge or even bankruptcy. Some of the most notorious examples include the Metallgesellschaft debacle (Mello and Parsons, 1995) and bankruptcies of several cotton merchant firms in 2008 (Carter and Janzen, 2009). Further, Mello and Parsons (1995) point out that offsetting between cash and futures price changes requires the maturity of futures positions always to match the spot positions as well as the convergence of futures and spot prices. If there is mismatched maturity in the hedge or nonconvergence problems (Garcia, Irwin, and Smith, 2015), unfavorable movements of futures prices make hedgers vulnerable to liquidity crises. Therefore, it is essential to understand the costs of maintaining a futures hedge and their implications on hedgers' liquidity (Lence, 1996).

Despite this evidence, only a few studies have evaluated the costs of maintaining a futures hedge. Riley and Anderson (2010) estimated that the average margin requirement for corn was $0.13/bu in 2007, much higher than $0.04/bu as in previous years. Alexander, Prokopczuk, and Sumawong (2013) considered transaction costs (i.e., commission fee and bid–ask spread) and margin costs (measured as the borrowing cost of financing the initial margin plus interest on losses and gains of daily cash flow from margin accounts) in evaluating the performance of different hedging ratios for

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Online Supplement: Costs of Futures Hedging in Corn and Soybean Markets

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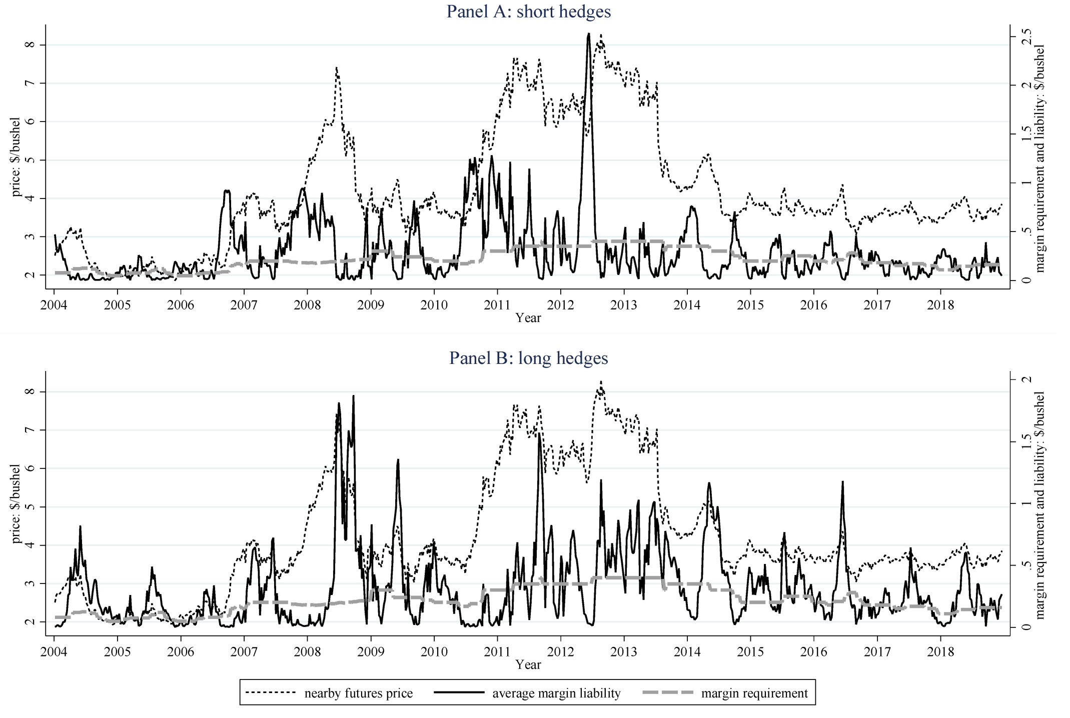

Figure S1. Prices of Nearby Futures, Margin Requirements, and Average Margin Liabilities for 3-Month Corn Hedges, 2004–2018

Notes: The scale of the left vertical axis shows the values for futures prices, and the scale of the right vertical axis shows the values for margin liabilities and margin requirements. All values are measured in $/bu.

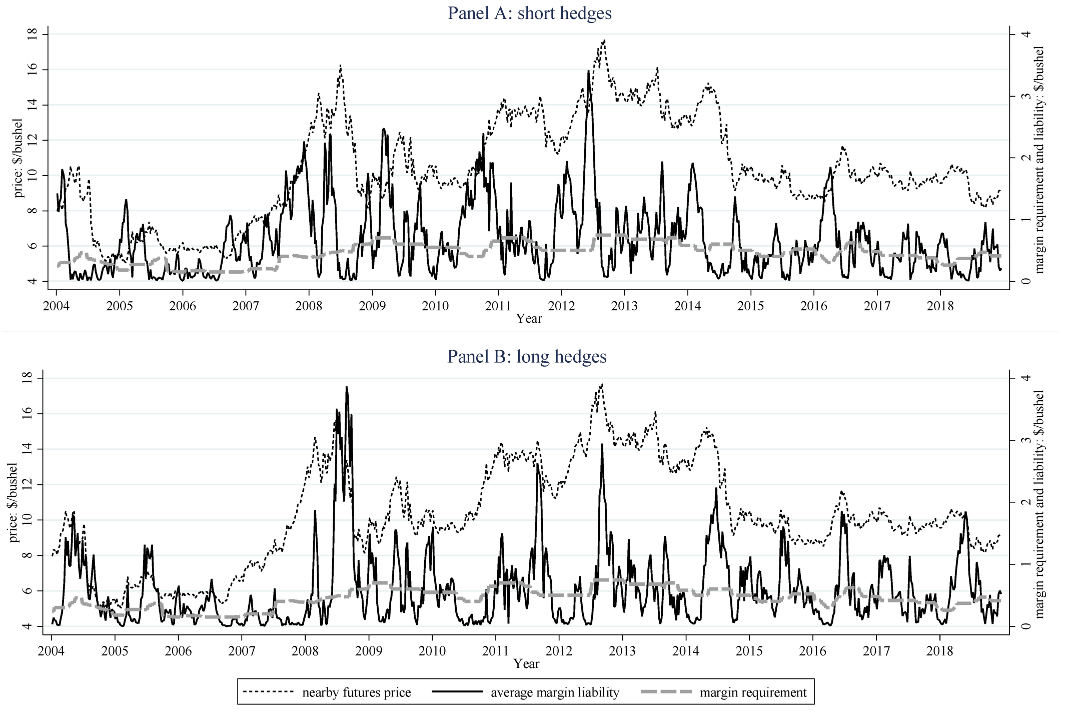

Figure S2. Prices of Nearby Futures, Margin Requirements, and Average Margin Liabilities for 3-Month Soybean Hedges, 2004–2018

Notes: The scale of the left vertical axis shows the values for futures prices, and the scale of the right vertical axis shows the values for margin liabilities and margin requirements. All values are measured in $/bu.

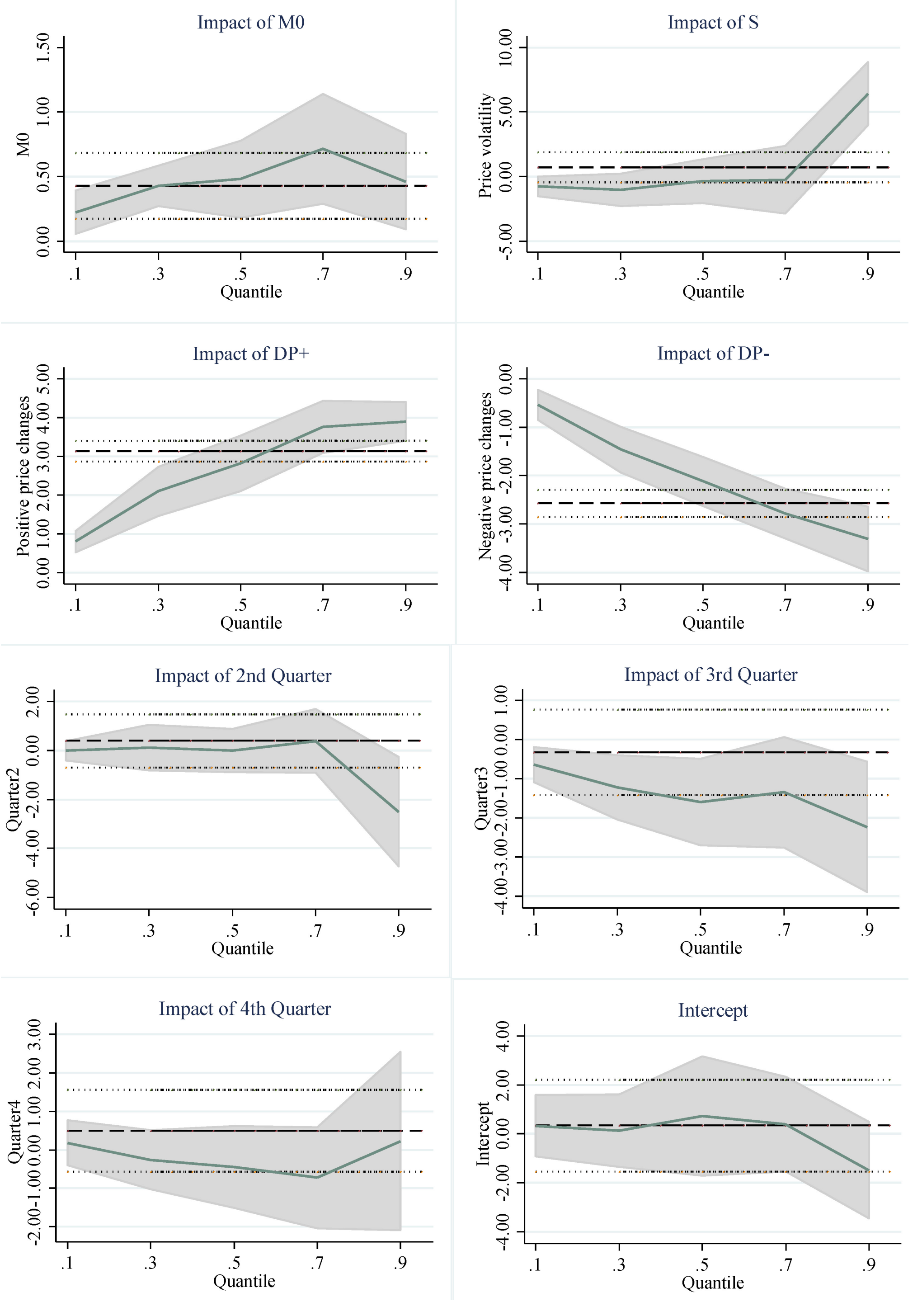

Figure S3. Quantile Regression Estimates and Least Squares Estimates for 3-Month Corn Short Hedge Model

Notes: The solid horizontal line indicates the marginal effect of each determinant on the conditional mean cost, and two dashed lines indicate the 95% confidence interval of least squares estimates. The coefficients of quantile regressions are plotted by the solid curve, surrounded by 95% confidence intervals in the shaded area.

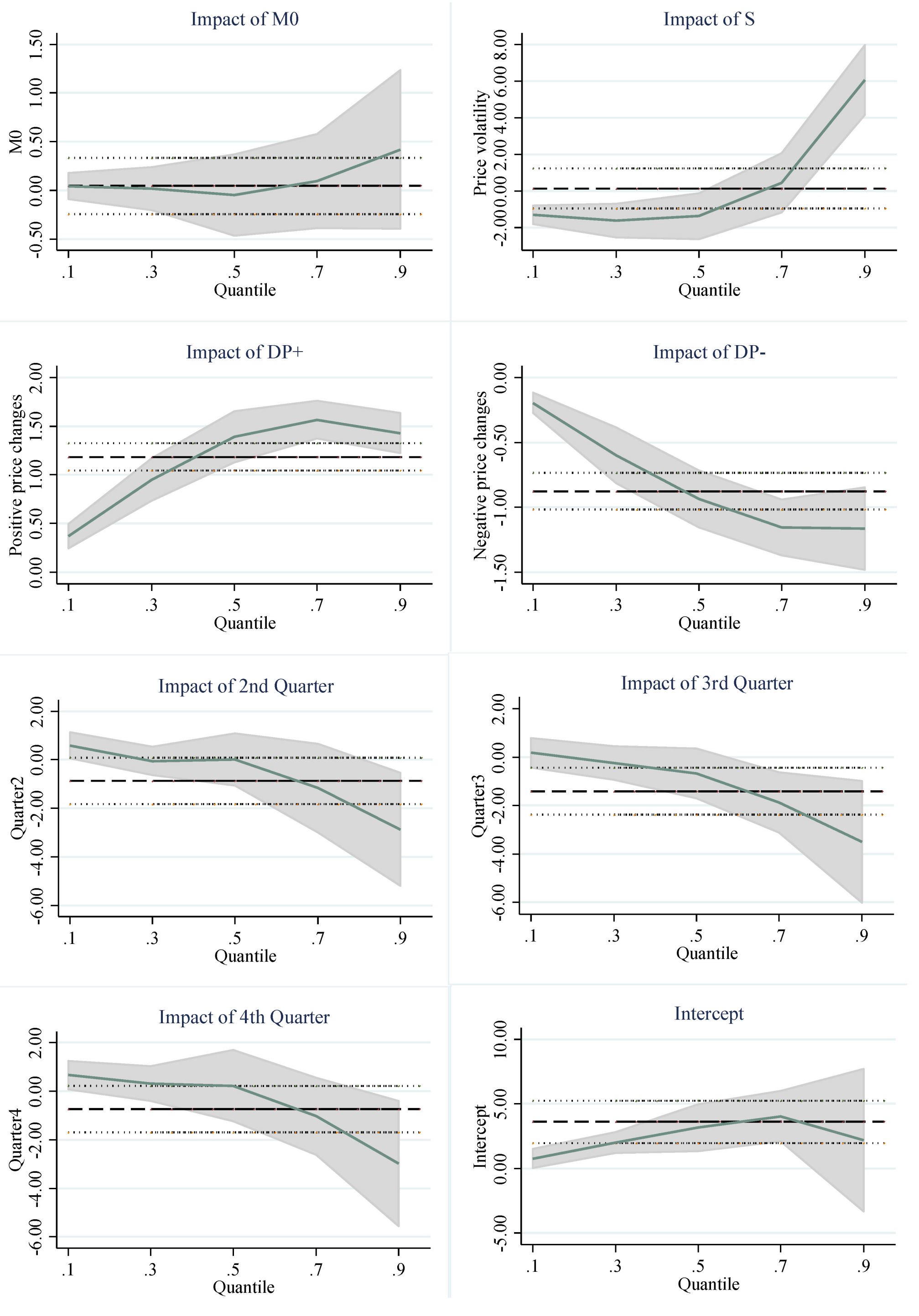

Figure S4. Quantile Regression Estimates and Least Squares Estimates for 3-Month Soybean Short Hedge Model

Notes: The solid horizontal line indicates the marginal effect of each determinant on the conditional mean cost, and two dashed lines indicate the 95% confidence interval of least squares estimates. The coefficients of quantile regressions are plotted by the solid curve, surrounded by 95% confidence intervals in the shaded area.

Table S1. Estimated Conditional Maximum Margin Liability for 3-Month Corn Hedges

Panel A. Long

Quantile	OLS	$Q(0.1)$	$Q(0.3)$	$Q(0.5)$	$Q(0.7)$	$Q(0.9)$
M_w^0	0.817***	1.043***	1.088***	0.923***	0.791***	0.650***
(Mean=4.99)	[0.143]	[0.103]	[0.127]	[0.148]	[0.170]	[0.224]
S_w	7.399***	0.010	3.492***	5.262***	8.134***	10.136***
(Mean=1.65)	[0.648]	[0.929]	[1.136]	[1.220]	[0.866]	[0.979]
DP_w^+	−2.836***	−1.282***	−2.167***	−2.665***	−3.025***	−3.545***
(Mean=5.59)	[0.154]	[0.192]	[0.239]	[0.196]	[0.184]	[0.193]
DP_w^-	2.522***	1.439***	2.140***	2.568***	2.848***	3.077***
(Mean=5.70)	[0.156]	[0.188]	[0.254]	[0.196]	[0.279]	[0.289]
$Quart_2$	4.185***	2.291***	4.034***	5.025***	4.778***	7.689***
(Mean=0.25)	[0.612]	[0.807]	[1.071]	[0.723]	[1.071]	[0.984]
$Quart_3$	3.409***	1.598**	1.571**	3.587***	4.152***	4.301***
(Mean=0.25)	[0.609]	[0.634]	[0.796]	[0.657]	[0.643]	[0.780]
$Quart_4$	0.736	−0.092	0.567	0.767	1.305**	−1.002
(Mean=0.25)	[0.600]	[0.377]	[0.580]	[0.623]	[0.542]	[0.840]
Intercept	−2.223**	0.358	−1.495	−1.013	−2.023**	1.957
	[1.049]	[0.841]	[0.968]	[1.389]	[0.926]	[1.671]
R^2	0.519	0.208	0.233	0.304	0.359	0.493
$\widehat{L_w}$ (%)	14.711	7.582	11.350	14.398	17.276	22.454
$\widehat{L_w}$ ($/bu)	0.623	0.321	0.481	0.610	0.731	0.951

Panel B. Short

Quantile	OLS	$Q(0.1)$	$Q(0.3)$	$Q(0.5)$	$Q(0.7)$	$Q(0.9)$
M_w^0	0.349*	0.836***	0.761***	0.616***	0.621***	0.226
(Mean=4.99)	[0.202]	[0.131]	[0.113]	[0.180]	[0.206]	[0.363]
S_w	4.453***	−0.573	2.221***	3.317***	5.365***	16.172***
(Mean=1.65)	[0.919]	[0.693]	[0.800]	[1.155]	[1.202]	[3.300]
DP_w^+	5.145***	1.596***	3.394***	4.708***	5.746***	5.911***
(Mean=5.59)	[0.218]	[0.339]	[0.295]	[0.448]	[0.384]	[0.559]
DP_w^-	−4.484***	−1.122***	−2.860***	−3.835***	−4.540***	−5.454***
(Mean=5.70)	[0.222]	[0.348]	[0.236]	[0.319]	[0.275]	[0.482]
$Quart_2$	3.936***	1.492**	2.047***	2.999***	2.914***	1.401
(Mean=0.25)	[0.868]	[0.760]	[0.656]	[0.864]	[0.824]	[2.092]
$Quart_3$	0.559	−0.395	−1.621***	−1.626*	−0.592	−0.364
(Mean=0.25)	[0.864]	[0.495]	[0.565]	[0.925]	[0.772]	[1.673]
$Quart_4$	0.869	−0.169	−0.376	−0.573	−0.906	2.637
(Mean=0.25)	[0.851]	[0.596]	[0.573]	[0.680]	[0.775]	[1.880]
Intercept	1.623	0.813	0.635	0.765	−0.788	−5.488*
	[1.487]	[1.145]	[0.913]	[1.264]	[1.101]	[3.290]
R^2	0.512	0.130	0.206	0.273	0.358	0.446
$\widehat{L_w}$ (%)	15.263	6.800	10.781	13.972	17.771	25.221
$\widehat{L_w}$ ($/bu)	0.646	0.288	0.456	0.592	0.752	1.068

Notes: Table S1 reports the estimation coefficients of the quantile regression described in equation (**??**) with maximum margin liability as the dependent variable. Single, double and triple asterisks (*,**,***) indicate statistical significance at the 10%, 5%, and 1% level, and standard errors are shown in square brackets. Ordinary least squares (OLS) estimates are presented with adjusted R^2, and pseudo-R^2 are reported for quantile regressions. For a hedge opened in week w, M_w^0 is the initial margin requirement and S_w is the price volatility, which is measured as the standard deviation of daily absolute return ($|\log(\frac{p_t}{p_{t-1}}) \cdot 100|$) over a hedge horizon. The positive price change, DP_w^+, is calculated as the sum of daily positive prices divided by the total number of days which have higher settlement prices than the previous day $DP_w^+ = \frac{\sum_{t=1}^{T} D(\Delta p_t > 0) \cdot \Delta p_t}{\sum_{t=1}^{T} D(\Delta p_t > 0)}$. The negative price change, DP_w^-, is the average absolute price reduction calculated in the similar manner: DP_w^-, is the average absolute price reduction calculated in the similar manner: $DP_w^- = \frac{\sum_{t=1}^{T} D(\Delta p_t < 0) \cdot |\Delta p_t|}{\sum_{t=1}^{T} D(\Delta p_t < 0)}$. Three seasonal dummy indicators ($Quart_2$, $Quart_3$, $Quart_4$) represent the second, third, and fourth quarters, respectively. $\widehat{L_w}$ indicates the in-sample predicted value at the sample mean reported in the first column, measured in percentage of opening price and $/bu.

Table S2. Estimated Conditional Maximum Margin Liability for 3-Month Soybean Hedges

Panel A. Long

Quantile	OLS	Q(0.1)	Q(0.3)	Q(0.5)	Q(0.7)	Q(0.9)
M_w^0	0.869***	1.129***	1.016***	0.937***	0.847***	1.155***
(Mean=4.45)	[0.158]	[0.144]	[0.184]	[0.256]	[0.267]	[0.277]
S_w	7.534***	1.156*	4.823***	8.250***	8.880***	8.237***
(Mean=1.43)	[0.602]	[0.606]	[0.805]	[1.122]	[0.809]	[1.072]
DP_w^+	−1.304***	−0.445***	−0.899***	−1.277***	−1.465***	−1.595***
(Mean=11.20)	[0.078]	[0.079]	[0.102]	[0.124]	[0.107]	[0.109]
DP_w^-	1.172***	0.448***	0.823***	1.071***	1.351***	1.513***
(Mean=11.42)	[0.077]	[0.093]	[0.105]	[0.122]	[0.118]	[0.098]
$Quart_2$	1.332**	0.043	0.890	1.569**	1.243	2.153**
(Mean=0.25)	[0.527]	[0.534]	[0.648]	[0.785]	[1.059]	[0.937]
$Quart_3$	2.540***	0.032	1.282***	1.556**	1.490*	2.248***
(Mean=0.25)	[0.535]	[0.456]	[0.481]	[0.733]	[0.889]	[0.861]
$Quart_4$	0.157	0.040	0.242	0.174	−0.937	−1.673**
(Mean=0.25)	[0.525]	[0.398]	[0.378]	[0.620]	[0.738]	[0.677]
Intercept	−2.526***	−1.125	−2.552**	−3.123*	−1.488	1.540
	[0.893]	[0.924]	[1.153]	[1.713]	[1.336]	[1.332]
R^2	0.523	0.140	0.185	0.249	0.350	0.484
$\widehat{L_w}$ (%)	11.908	5.710	8.804	11.604	14.456	18.562
$\widehat{L_w}$ ($/bu)	1.204	0.577	0.890	1.173	1.462	1.877

Panel B. Short

Quantile	OLS	Q(0.1)	Q(0.3)	Q(0.5)	Q(0.7)	Q(0.9)
M_w^0	−0.420*	0.409*	0.099	−0.403	−0.444	−0.850
(Mean=4.45)	[0.228]	[0.216]	[0.234]	[0.364]	[0.467]	[0.591]
S_w	3.723***	−1.085	0.715	1.813	5.842***	12.169***
(Mean=1.43)	[0.871]	[0.718]	[0.876]	[1.311]	[1.795]	[1.679]
DP_w^+	1.983***	0.762***	1.572***	2.059***	2.445***	2.355***
(Mean=11.20)	[0.112]	[0.110]	[0.151]	[0.175]	[0.172]	[0.287]
DP_w^-	−1.565***	−0.448***	−1.112***	−1.530***	−1.933***	−1.886***
(Mean=11.42)	[0.111]	[0.093]	[0.122]	[0.177]	[0.182]	[0.189]
$Quart_2$	−0.977	0.734	1.397**	0.334	−0.609	−4.980***
(Mean=0.25)	[0.763]	[0.482]	[0.664]	[0.940]	[1.306]	[1.531]
$Quart_3$	−2.190***	0.135	0.157	−0.547	−2.142*	−4.716***
(Mean=0.25)	[0.774]	[0.508]	[0.748]	[1.138]	[1.187]	[1.387]
$Quart_4$	−1.470*	0.452	0.566	−0.035	−2.079*	−3.556**
(Mean=0.25)	[0.759]	[0.477]	[0.706]	[0.900]	[1.154]	[1.612]
Intercept	7.722***	2.339**	2.936***	6.478***	6.860**	9.177**
	[1.293]	[0.961]	[1.065]	[1.587]	[3.162]	[4.325]
R^2	0.355	0.104	0.166	0.213	0.269	0.325
$\widehat{L_w}$ (%)	14.338	6.355	9.827	12.795	17.322	24.291
$\widehat{L_w}$ ($/bu)	1.450	0.643	0.994	1.294	1.752	2.456

Notes: Table S2 reports the estimation coefficients of the quantile regression described in equation (**??**) with maximum margin liability as the dependent variable. Single, double and triple asterisks (*,**,***) indicate statistical significance at the 10%, 5%, and 1% level, and standard errors are shown in square brackets. Ordinary least squares (OLS) estimates are presented with adjusted R^2, and pseudo-R^2 are reported for quantile regressions. For a hedge opened in week w, M_w^0 is the initial margin requirement and S_w is the price volatility, which is measured as the standard deviation of daily absolute return $(|\log(\frac{p_t}{p_{t-1}}) \cdot 100|)$ over a hedge horizon. The positive price change, DP_w^+, is calculated as the sum of daily positive prices divided by the total number of days which have higher settlement prices than the previous day$DP_w^+ = \frac{\sum_{t=1}^T D(\Delta p_t > 0) \cdot \Delta p_t}{\sum_{t=1}^T D(\Delta p_t > 0)}$. The negative price change, DP_w^-, is the average absolute price reduction calculated in the similar manner: DP_w^-, is the average absolute price reduction calculated in the similar manner: $DP_w^- = \frac{\sum_{t=1}^T D(\Delta p_t < 0) \cdot |\Delta p_t|}{\sum_{t=1}^T D(\Delta p_t < 0)}$. Three seasonal dummy indicators ($Quart_2$, $Quart_3$, $Quart_4$) represent the second, third, and fourth quarters, respectively. $\widehat{L_w}$ indicates the in-sample predicted value at the sample mean reported in the first column, measured in percentage of opening price and $/bu.

crack spread delta hedging. Other studies have examined the liquidity implications of maintaining a futures hedge by assessing the cash flow risk (Dahlgran, 2005; Dahlgran and Liu, 2011), imposing financial constraints (Deep, 2002; Lien, 2003), or including costs of borrowing funds to meet margin calls (Arias, Brorsen, and Harri, 2000). However, these previous studies often used hypothetical costs as an influencing factor or evaluation criterion to develop optimal hedging strategies while providing little guidance on how to anticipate the amount of funds needed to maintain a given hedging strategy.

This study aims to fill the gap in estimating the costs of hedging. First, we develop a conceptual framework to measure the costs of maintaining a margin account for a futures hedge. Extending previous literature, this framework incorporates direct (e.g., margin liability and borrowing costs) and indirect costs (e.g., probability of hedging failure). Under this framework, the costs of hedging can be assessed empirically and compared across various commodities. We simulate these costs using corn and soybean futures prices and historical margin requirements from the Chicago Mercantile Exchange (CME) Group. Changes in these costs are measured across three subperiods: 2004–2006, 2007–2013, and 2014–2018 and compared to the costs of forward contracting. Second, this study examines the empirical distribution of hedging costs and estimates the impacts of its determinants at different parts of the cost distribution. Finally, this study shows how *ex ante* information can be used to anticipate potential hedging costs and provides suggestions for futures market hedgers.

Understanding the costs of hedging, their changes over time, and their predictability is essential for successfully implementing risk management programs involving futures hedging. We measure the costs of hedging by average margin liability (i.e., the average amount of funds that should be deposited in the margin account over the hedging period) and the maximum margin liability, describing the maximum margin deposit requirements. Our study provides both unconditional and conditional estimates of these hedging costs. Unconditional estimates are based on the results of hedging simulations over 2004–2018 and demonstrate the average amount of funds required to maintain 1-, 3-, and 6-month hedges over 90% of the time. Conditional estimates evaluate the impact of the main drivers on the costs of hedging. Our results reveal that price volatility is a main driver of hedging costs, which explains a sharp increase in these costs during the 2007–2013 subperiod. Other driving factors include margin requirements and price changes (which we decompose into positive and negative changes as well as seasonality). Our out-of-sample forecasts of hedging costs based on conditional quantiles cover the actual 2018 hedging costs most of the time. A better understanding of hedging costs by financial institutions may improve access to credit for hedgers and decrease the risk of hedging failure caused by credit constraints.

Conceptual Framework

This study assesses the costs of hedging via the amount and the cost of capital required to maintain the margin account.[1] Specifically, the amount of capital illustrates the access to funds required to maintain the margin account, and the cost of capital reflects borrowing costs. Liquidity problems may arise when the required funds exceed hedgers' borrowing constraints associated with either borrowing costs or credit limits.

Margin Liability

Our framework extends the cash flow generation process developed by Dahlgran and Liu (2011). First, to open a futures position, a trader has to post an initial margin required by the exchange. The initial margin requirements are stipulated by the exchange on a per contract basis and serve the purpose of a performance bond. Futures hedging offers a great deal of liquidity since margin

[1] Other studies (e.g., Alexander, Prokopczuk, and Sumawong, 2013) also included transaction costs, which are not considered in our study since transaction costs are known in advance and are not likely to change within the hedging horizon.

requirements represent only a small portion of the position value (about 2%–10%). Thus, the per unit balance in the margin account (B) starts with an initial margin: $B_0 = M^0 \equiv \frac{\$\ initial\ margin}{size\ of\ a\ contract}$. The value of the margin account balance changes every day as futures prices change. Using the futures settlement price p, we compute the daily changes in margin account balance before marking to market as

$$(1) \qquad B_t = B_{t-1} + \Delta p_t, t = 1, 2, \ldots, T,$$

where T is a hedging horizon and the daily price change is calculated as $\Delta p_t = p_{t-1} - p_t$ for a short position and $\Delta p_t = p_t - p_{t-1}$ for a long position. The margin account balance is then compared to the maintenance margin requirement,[2] $M^m \equiv \frac{\$\ maintenance\ margin}{size\ of\ a\ contract}$, to determine whether a margin call is required:

(i) If $B_t < M^m$, a cash deposit (also called a margin call or the variation margin) is required to bring the margin account level back to the initial margin, generating a negative cash flow for the hedger, equivalent to $M^0 - B_t$.

(ii) If $B_t > M^0$, the hedger is allowed to withdraw the extra margin money in excess of the initial margin, equivalent to $B_t - M^0$. The extra margin money goes into daily cash flow, defined below, and can be used in future cash deposits.[3]

If the maintenance margin is equal to the initial margin and these margin requirements do not change over the hedging horizon, the size of these per unit daily cash flows is equivalent to Δp_t. After the deposits and withdrawals are made at the end of every day, the account's balance will return to the initial margin level, as outlined by Dahlgran and Liu (2011). On the other hand, if the maintenance margin requirement changes at day t by $\Delta M_t = M^m_{t-1} - M^m_t$, the cash flow is

$$(2) \qquad CF_t = \underbrace{\Delta p_t}_{futures\ price\ change} + \underbrace{\Delta M_t.}_{maintenance\ margin\ change}$$

Therefore, at the end of day t, the cumulative gain (or loss) in excess of the initial margin generated by the margin account (π_t) is the sum of previous daily cash flows:

$$(3) \qquad \pi_t = -M^0 + \sum_{j=1}^{t} CF_j, \text{ for } t = 1, 2, \ldots, T.$$

Taking two simulated 3-month corn hedges as an example, we illustrate cash flows ($CF_t = \Delta p_t$) and π_t from short and long positions opened on August 1, 2017. In Figure 1, the dashed line represents π_t, the cumulative margin gain (or loss) in excess of the initial margin, which is affected by the initial margin and daily cash flows (black bars). In this example, the initial margin is \$850 per contract or \$0.17/bu; $\pi_1 = -\$0.17$/bu indicates the minimum amount of money needed to open a long or short hedge position on August 1, 2017. For the long hedge, the cumulative price change is $-\$0.28$/bu, and the dashed line representing π_t remains negative, illustrating cumulative losses for the entire hedging horizon. For the short hedge, π_t becomes positive as the cumulative price change of +\$0.28/bu exceeds the initial margin requirement of \$0.17/bu.

[2] Initial margin is usually set as 110% of maintenance margin for speculative participants and 100% of maintenance margin for hedgers.

[3] An alternative strategy for the hedger is to leave all extra margin in the margin account and only deposit if the cumulative balance is below the maintenance margin level. Compared to daily deposit/withdraw, this deposit-only strategy helps to reduce margin calls. However, a hedger forfeits the opportunity cost of funds in this case because the margin account balance is often kept higher than needed during the hedge horizon, leading to a slightly higher costs of hedging. Therefore, this study assumes that any extra margin will become positive cash flow that can be used in future investment activities, which generates a conservative measure of hedging costs.

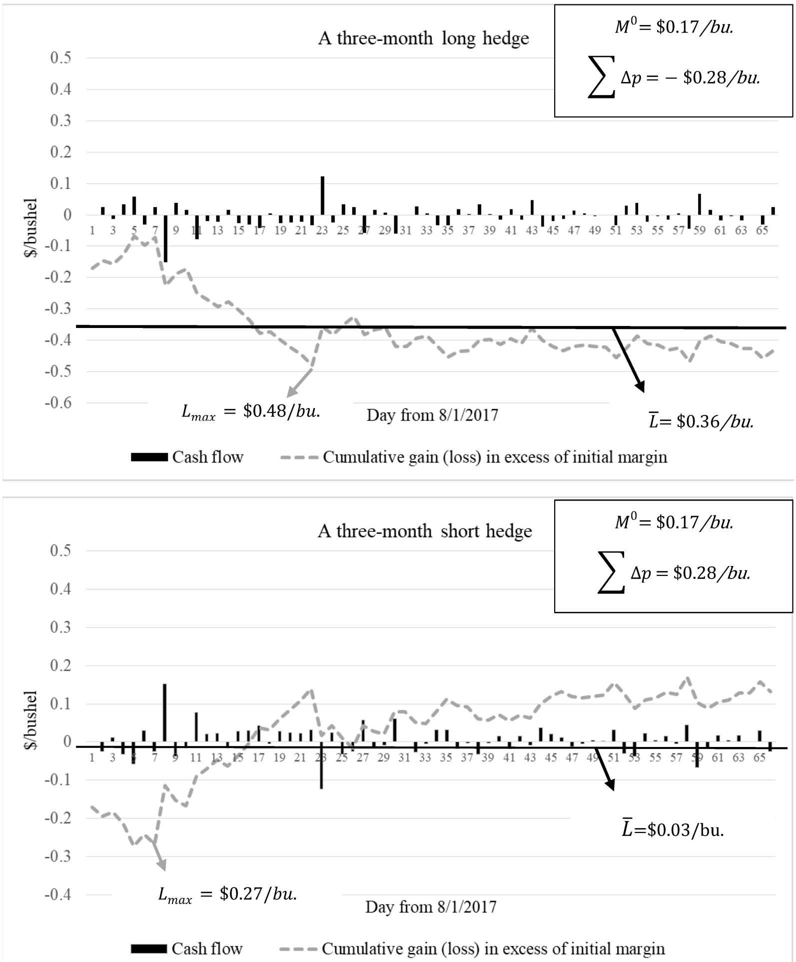

Figure 1. Daily Cash Flows, Cumulative Gains (or losses), and Margin Liabilities for Long and Short 3-Month Corn Hedges Initiated on August 1, 2017

Notes: Figure 1 shows simulated daily cash flows, cumulative gains/losses in excess of initial margin, average margin liability ($\bar{L}$), and maximum margin liability (L_{max}) for a 3-month hedge from long and short sides. It also reports the initial margin requirement (M^0) and cumulative price changes ($\sum \Delta p$) during the hedge period. All values are measured in $/bu.

Dahlgran and Liu (2011) used the variance of cash flows as a measure of hedging risk. Their implicit assumption may not be realistic for most hedgers' concerns because volatile cash flow is usually considered a risk only if the margin account balance falls below the maintenance level. Instead, the cumulative losses generated by the margin account provide a better measure of hedging costs than the variance of cash flows because these losses reflect the funds that have to be deposited to maintain a hedge. Thus, we concentrate on cumulative losses in this study and define them as the margin liability of a hedge. At day t, the margin liability is

$$L_t = -\pi_t \cdot D(\pi_t < 0), t = 1, \ldots, T, \tag{4}$$

where π_t is defined in equation (3) and the binary indicator function $D(.)$ returns to 1 if $\pi_t < 0$ and 0 otherwise. Thus, L illustrates periods in Figure 1 when the dashed line representing π_t is negative. Then, the average margin liability over a hedging horizon is defined as

$$\bar{L} = \frac{1}{T}\sum_{t=1}^{T} L_t = \frac{1}{T}\sum_{t=1}^{T} -\pi_t \cdot D(\pi_t < 0). \tag{5}$$

$\bar{L}$, our primary measure of hedging costs, is a convenient measure to compare the costs of hedging across various horizons because it adjusts the costs of hedging by the number of days within the hedging horizon. In Figure 1, $\bar{L}$ is \$0.36/bu because of mostly negative π_t in the long hedge. For the short hedge, $\bar{L}$ is \$0.03/bu because π_t was negative only at the beginning of the hedge. The average margin liability reflects the average amount of money that has to be deposited in the margin account over the hedging horizon to maintain a hedge. It can also be expressed as a percentage of futures price to allow for comparison across commodities and price levels.

Borrowing Costs

After defining the average margin liability, we can calculate a borrowing cost of hedging, which is used in previous studies on direct hedging costs (Arias, Brorsen, and Harri, 2000; Alexander, Prokopczuk, and Sumawong, 2013). We assume that the hedger has to borrow the margin liability, L_t, defined in equation (4). The total borrowing costs over a hedging horizon are then calculated as

$$BC = \sum_{t=1}^{T} L_t \cdot r = \bar{L} \cdot T \cdot r, \tag{6}$$

where r is the daily interest rate. Therefore, margin liability and interest rates will directly affect the borrowing costs. BC is an aggressive measure of borrowing costs as it does not include interest gains on the extra margin. Since this setting appears to be the case in many margin accounts, we use BC to measure the borrowing cost in our main set of results.[4]

Probability of Hedging Failure

In addition to the direct costs of maintaining a margin account, this framework can be used to assess the risk of hedging failures. A hedging failure occurs when a hedger cannot generate enough funds to deposit into the margin account when a margin call arises, in which case a hedge would be terminated (at least partially according to the shortfall). Failure to generate funds to sustain a hedge may result from excessive borrowing costs or credit limits. We illustrate the maximum credit required to maintain a hedge with a term called maximum margin liability, L_{max}, which reflects the largest cumulative loss in the margin account:

$$L_{\max} = \max\left(L_1, L_2, \ldots L_T\right), t = 1, \ldots, T. \tag{7}$$

For instance, Figure 1 suggests that a hedger had to finance a margin call of as much as \$0.48/bu to avoid premature termination of the long position on day 22 of the hedge. Following Deep (2002) and Lien (2003), we assume a capital constraint, C. If L_{max} exceeds this constraint, a hedger will be forced to abandon the futures position before the expected ending day. Thus, the probability of hedging failure is approximated empirically as a proportion of simulated hedges in which L_{max} exceeds a capital constraint, C:

$$\text{Prob}\left(L_{\max} > C\right) = \frac{1}{N}\sum_{i=1}^{N} D_i\left(L_{\max} > C\right) \times 100\%, \; i = 1, 2, \ldots, N. \tag{8}$$

For hedge i, the binary indicator function $D_i(L_{\max} > C)$ returns to 1 if the maximum daily liability exceeds the capital constraint (i.e., premature termination) and 0 otherwise. Equation (8) suggests that a more restrictive borrowing constraint increases the probability of premature termination of a hedge. The liquidity risk is likely to be a crucial concern for many small

[4] Additional results for an alternative measure of borrowing costs that includes interest paid on negative cash flows and earned on positive cash flows is available from the authors upon request.

producers who have insufficient credit lines. Within this framework, the proposed direct and indirect measures of hedging costs allow us to compare hedging costs across commodities and evaluate their distributions empirically.

Simulation of the Costs of Hedging

To calculate the costs of hedging, we simulated weekly short and long hedges for a single contract using historical futures prices and margin requirements from 2004 to 2018.[5] On Tuesday of each week,[6] a short (and a long) position was initiated with a target ending day 22, 66, and 130 days later (1-, 3-, and 6-month hedging horizons). The simulations employed the futures contract closest to maturity but still actively trading on the hedge ending day. Thus, for our example in Figure 1, the target ending day for a 3-month corn hedge opened on August 1, 2017, was November 1, 2017, and December 2017 corn futures was used as the underlying contract. That is, this hedge was simulated using daily settlement prices and margin requirements of December 2017 corn for the entire 3-month period. The hedge placed switched to the next maturity when the target ending day of a hedge reached the first day of the delivery month. For instance, the 3-month hedge opened on September 1, 2017, was simulated using settlement prices and margin requirements of March 2018 corn over the hedge horizon.

Table 1 shows the summary statistics for market conditions and the costs of hedging. During the period of study (2004–2018), the average price of nearby corn futures was \$4.16/bu with a standard deviation of \$1.52/bu. Corn prices increased sharply from the average of \$2.40/bu during 2004–2006 to \$5.22/bu during 2007–2013 and moderated to \$3.76/bu during 2014–2018. The volatility of corn prices changed even more dramatically, increasing from a standard deviation of \$0.46/bu to \$1.49/bu between the first two subperiods before dropping back to \$0.37/bu in the third subperiod. A similar pattern was observed in soybean prices (and volatility): a sharp increase from \$6.52/bu (SD = \$1.37/bu) to \$11.91/bu (SD = \$2.47/bu) between the first two subperiods and moderation to \$10.18/bu (SD = \$1.57/bu) in the third subperiod.

The mean margin requirement during the period of study was \$0.22/bu for corn and \$0.45/bu for soybeans. For corn futures, the margin requirements were steady at around \$0.09/bu or 4% of the nearby futures price before 2007. From 2007 to 2013, the margin requirements had increased to \$0.28/bu (5.4% of the nearby price). This observation was consistent with Riley and Anderson (2010), who found that the average corn margin requirement in 2007 was much higher than in previous years. After 2013, the exchange gradually reduced the margin requirements but still kept the values above the level in 2004–2006, roughly at \$0.21/bu (5.6% of the nearby price). In the soybean futures market, the margin requirements increased from \$0.24/bu to \$0.55/bu (i.e., from 3.7% to 4.6% of the nearby price) in 2007–2013 and decreased back to \$0.45/bu (4.4% of the nearby price) in 2014–2018.

Table 1 reports the medians of the average daily margin liability ($\bar{L}$).[7] About half of the time from 2004 to 2018, the average margin liability for 1-month hedges exceeded \$0.20/bu for corn and \$0.40/bu for soybeans, and the subperiod median values ranged from \$0.07/bu to \$0.28/bu for corn and from \$0.20/bu to \$0.61/bu for soybeans. The higher cost of hedging corn and soybeans in 2007–2013 was mainly due to higher prices and higher price volatility. In the 2014–2018 subperiod, average daily margin liability went down considerably for short hedges but not much for long hedges because of a decreasing trend in futures price movements after 2013 (see Figures S1 and S2 in the online supplement at www.jareonline.org).

[5] Futures prices were obtained from Barchart's *Market Data APIs* (https://www.barchart.com/ondemand/free-market-data-api). Margin requirements were collected from CME Group's *List of Historical Margins by Name* (https://www.cmegroup.com/ clearing/risk-management/historical-margins.html). We assumed that the initial margin was 100% of the maintenance margin.

[6] We selected to open the hedges on Tuesdays to avoid weekend effects.

[7] We focus on the medians of $\bar{L}$ to allow comparison with results in Table 3 and the following quantile regression estimates.

Table 1. Simulated Average Daily Margin Liability and Borrowing Costs Assuming No Interest Gain on Excess Margin

		Nearby Futures Price		Initial Margin Requirement		Average Margin Liability Long		Average Margin Liability Short		Borrowing Cost Long	Borrowing Cost Short
		($/bu)	($/bu)	($/bu)	($/bu)	($/bu)	(% of $\bar{p}$)	($/bu)	(% of $\bar{p}$)	(cents/bu)	
Year Period	***N***	**Mean**	**SD**	**Mean**	**SD**	**Median**	**Median**	**Median**	**Median**	**Mean**	**Mean**
Corn hedges											
1-month											
2004–2018	772	4.16	1.52	0.22	0.10	0.21	5.33	0.19	4.87	0.08	0.08
2004–2006	155	2.40	0.46	0.09	0.03	0.09	3.69	0.07	3.09	0.05	0.05
2007–2013	359	5.22	1.49	0.28	0.08	0.28	5.64	0.27	5.96	0.11	0.11
2014–2018	258	3.76	0.37	0.21	0.06	0.22	5.56	0.17	4.68	0.06	0.05
3-month											
2004–2018	772	4.16	1.52	0.22	0.10	0.23	5.98	0.17	4.48	0.30	0.28
2004–2006	155	2.40	0.46	0.09	0.03	0.11	4.32	0.07	3.01	0.19	0.21
2007–2013	359	5.22	1.49	0.28	0.08	0.33	6.93	0.28	5.77	0.40	0.41
2014–2018	258	3.76	0.37	0.21	0.06	0.23	6.09	0.16	4.29	0.22	0.15
6-month											
2004–2018	762	4.16	1.52	0.22	0.10	0.27	7.08	0.17	4.43	0.72	0.70
2004–2006	155	2.40	0.46	0.09	0.03	0.13	5.24	0.10	4.04	0.46	0.57
2007–2013	359	5.22	1.49	0.28	0.08	0.38	7.90	0.29	5.76	0.96	1.06
2014–2018	248	3.76	0.37	0.21	0.06	0.28	7.47	0.14	3.62	0.55	0.25
Soybean hedges											
1-month											
2004–2018	774	10.26	2.85	0.45	0.16	0.39	4.25	0.44	4.64	0.15	0.17
2004–2006	155	6.52	1.37	0.24	0.09	0.25	3.94	0.20	3.13	0.13	0.11
2007–2013	361	11.91	2.47	0.55	0.15	0.44	4.04	0.61	5.28	0.18	0.23
2014–2018	258	10.18	1.57	0.45	0.09	0.45	4.54	0.43	4.30	0.13	0.12
3-month											
2004–2018	774	10.26	2.85	0.45	0.16	0.42	4.26	0.51	5.10	0.55	0.65
2004–2006	161	6.52	1.37	0.24	0.09	0.25	4.31	0.20	3.42	0.49	0.46
2007–2013	361	11.91	2.47	0.55	0.15	0.44	3.61	0.80	6.52	0.62	0.92
2014–2018	258	10.18	1.57	0.45	0.09	0.48	4.97	0.41	4.22	0.48	0.38
6-month											
2004–2018	764	10.26	2.85	0.45	0.16	0.39	4.50	0.59	5.62	1.22	1.63
2004–2006	161	6.52	1.37	0.24	0.09	0.29	4.74	0.23	3.66	1.12	1.08
2007–2013	361	11.91	2.47	0.55	0.15	0.35	2.96	0.95	8.85	1.33	2.49
2014–2018	248	10.18	1.57	0.45	0.09	0.56	5.93	0.36	3.90	1.13	0.74

Notes: Table 1 reports summary statistics of nearby futures prices, simulated average margin liability, and borrowing costs from 2004 to 2018. N is the number of hedges simulated for each subperiod, SD is standard deviation, and $\bar{p}$ is average futures price over the simulated hedge horizon. For the columns of average margin liability, all numbers reported are medians to be comparable with Table 3. Borrowing costs are calculated as the total borrowing cost of a hedge defined in equation (6). The percentage of $\bar{p}$ is calculated by dividing average margin liability or borrowing costs over the average futures price ($\bar{p}$) during a hedge period.

Further, we found that average margin liability increased as the hedging horizon expanded. From 2004 to 2018, the sample median of 1-month $\bar{L}$ was \$0.21/bu for long hedges (about 5.33% of the average price), and it increased by 9.5% (or \$0.02/bu) if the hedge was extended to a 3-month horizon and by 28.6% (or \$0.06/bu) if extended to a 6-month horizon. Thus, using margin requirements to represent costs of hedging may result in considerable underestimation, especially for longer-horizon hedges.

These estimates may be combined with effective interest rates to calculate the costs of borrowing these funds over the hedging horizon. According to the *Agricultural Finance Databook* (Kansas

City Fed, 2020), effective interest rates on operating loans made to farmers varied from 3.9% to 8.5% during the period of study, with the highest interest rates reported in 2006 and 2007. The borrowing costs calculated using equation (6) may be compared to the implied costs of forward contracting (Etienne, Mallory, and Irwin, 2017),[8] which is defined as the difference between week w's forward price with the spot price at delivery in December for corn and in November for soybeans. Specifically, we compare the cost of forward contracting in late May (week 20) with the borrowing cost of 6-month long hedges because of similar hedging length. The results show that the costs of borrowing were consistently lower than the costs of forward contracting inferred in their study. Our findings for 6-month corn hedges show that the cost of borrowing changed from about $0.0046/bu prior to 2007 to about $0.0096/bu during 2007–2013, compared to the cost of forward contracting that changed from $0.0374/bu to $0.164/bu in the same time periods. In soybeans, our results show that the cost of borrowing for 6-month hedges changed from $0.0112/bu prior to 2007 to $0.0133/bu over 2007–2013, compared to changes in forward contracting that increased from $0.0626/bu to $0.1562/bu during the same time. Our findings can be interpreted as the potential costs for grain merchants who issue the forward contracts and usually use futures markets to manage the risk. The substantial differences between these borrowing costs and the costs of forward contracting can be caused by several factors, including higher interest rates on larger loan amounts, challenges with obtaining additional credit, and overall uncertainty with futures margin liability in highly volatile markets.

Table 2 shows the means of maximum margin liability (L_{max}) and its ranges defined by the maximum and minimum L_{max} in square brackets. To maintain a corn futures position for 1 month, a long hedger needed a credit line averaging $0.45/bu (11% of the price), but it could reach as high as $2.16/bu during the period of study. In contrast, maintaining 6-month hedges nearly doubled the required credit line to avoid premature termination to $0.83/bu (20% of the price), and as high as $5.02/bu. Thus, the maximum margin liability was higher for longer hedging horizons in each subperiod. Simulation results also exhibited different patterns across subperiods. For example, the mean L_{max} for 1-month long corn hedges increased from $0.21/bu (9% of the price) to $0.62/bu (12% of the price) between 2004–2006 to 2007–2013, mainly because of an increase in price and volatility in these markets. Our findings demonstrate that % of price was a more stable measure of L_{max} as it differed much less across subperiods when adjusted by changing price levels.

Based on simulated maximum margin liabilities and capital constraints (C), we calculated the probability of hedging failure as the percentage of hedges with $L_{max} > C$ in a year using equation (8). The capital constraints were set at 20% (C_1) and 30% (C_2) of the average price over a hedge horizon to be comparable between commodities. These two thresholds were chosen based on the average leverage ratios of hedging firms in commodity markets reported by Acharya, Lochstoer, and Ramadorai (2013), who found that hedgers have an average debt load of 20%–30% compared to their total assets. Mean capital constraints and probabilities of hedging failure shown in Table 2 suggest that 2007–2013 was the riskiest subperiod. When the constraint was set as 20% of the average price (C_1), almost one-half of the 6-month corn hedges had to be terminated before maturity in 2007–2013. In the 2004–2006 subperiod, the corresponding probability of hedging failure was only around 35%. Moreover, the probability of failure increased as hedge length increased. Finally, Table 2 suggests that hedging corn was riskier than hedging soybeans in the recent decade, holding the subperiod and hedging length the same.

Figure 2 shows the frequency distribution of $\bar{L}$ for 3-month corn hedges over 2004 to 2018. The average margin liability was measured in percentage of the opening price. $Q(0.5) = 4\%$ for short hedges, meaning that the average margin liability did not exceed 4% of the opening price half of the

[8] Since the position is temporary and a hedger can borrow margin loans from the broker to cover fund deficits, the borrowing cost (i.e., interest expense) is the amount of money a hedger eventually spends on using futures hedging and therefore is more comparable with the cost of forward contracting than margin liabilities. Reported interest rates on operating loans in Table A.5 of the *Agricultural Finance Databook* were used for each year of calculations.

Table 2. Simulated Maximum Margin Liability and Probabilities of Hedging Failure under Liability Constraints

Panel A. Corn hedges

	Maximum Margin Liability				Probabilities of Hedging Failure					
	Long		Short		C_1	Long	Short	C_2	Long	Short
Year Period	($/bu)	(% of $\bar{p}$)	($/bu)	(% of $\bar{p}$)	($/bu)	(%)	(%)	($/bu)	(%)	(%)
1-month										
2004–2018	0.45	11	0.43	10	0.84	7.8%	4.7%	1.26	1.7%	0.9%
	[0.05, 2.16]	[2, 43]	[0.05, 2.8]	[3, 42]						
2004–2006	0.21	9	0.22	8	0.49	3.9%	3.9%	0.74	0	1.3%
	[0.05, 0.7]	[2, 28]	[0.05, 0.97]	[3, 32]						
2007–2013	0.62	12	0.59	12	1.04	11.7%	7%	1.57	3.3%	1.4%
	[0.15, 2.16]	[3, 43]	[0.2, 2.8]	[3, 42]						
2014–2018	0.37	10	0.33	9	0.76	4.7%	1.9%	1.13	0.4%	0
	[0.11, 1.25]	[3, 33]	[0.13, 1.06]	[3, 26]						
3-month										
2004–2018	0.66	15	0.65	15	0.84	24.7%	21.6%	1.26	8.7%	7.0%
	[0.06, 3.26]	[3, 71]	[0.06, 3.71]	[3, 53]						
2004–2006	0.33	13	0.38	14	0.51	21.9%	16.1%	0.76	9.0%	7.7%
	[0.06, 1.15]	[3, 46]	[0.06, 1.55]	[3, 52]						
2007–2013	0.89	18	0.92	18	1.05	30.9%	31.5%	1.57	9.5%	11.7%
	[0.17, 3.26]	[3, 71]	[0.2, 3.71]	[3, 53]						
2014–2018	0.53	14	0.43	11	0.76	17.8%	11.2%	1.14	7.4%	0
	[0.11, 1.9]	[3, 45]	[0.14, 1.13]	[4, 27]						
6-month										
2004–2018	0.83	20	0.89	20	0.85	38.0%	36.7%	1.27	15.7%	18.8%
	[0.06, 5.02]	[2, 95]	[0.08, 3.64]	[4, 59]						
2004–2006	0.44	18	0.56	20	0.52	32.3%	37.4%	0.78	12.9%	17.4%
	[0.06, 1.37]	[2, 57]	[0.08, 2.07]	[4, 59]						
2007–2013	1.10	22	1.32	25	1.05	46.2%	50.4%	1.57	20.6%	32.9%
	[0.17, 5.02]	[3, 95]	[0.2, 3.64]	[4, 59]						
2014–2018	0.70	18	0.49	13	0.76	29.8%	17.1%	1.15	10.5%	0
	[0.15, 2.17]	[4, 55]	[0.14, 1.09]	[4, 27]						

Panel B. Soybean hedges

	Maximum Margin Liability				Probabilities of Hedging Failure					
	Long		Short		C_1	Long	Short	C_2	Long	Short
Year Period	($/bu)	(% of $\bar{p}$)	($/bu)	(% of $\bar{p}$)	($/bu)	(%)	(%)	($/bu)	(%)	(%)
1-month										
2004–2018	0.90	9	0.94	9	2.04	4.3%	2.5%	3.06	0.4%	0.1%
	[0.15, 3.99]	[2, 39]	[0.15, 3.68]	[2, 31]						
2004–2006	0.58	9	0.56	9	1.29	5.8%	2.6%	1.93	0	0
	[0.15, 2.62]	[2, 30]	[0.15, 1.83]	[2, 28]						
2007–2013	1.09	9	1.21	10	2.37	5.5%	4.2%	3.56	0.8%	0.3%
	[0.16, 3.99]	[2, 39]	[0.2, 3.68]	[3, 31]						
2014–2018	0.82	8	0.80	8	2.02	1.6%	0	3.03	0	0
	[0.26, 2.36]	[2, 22]	[0.26, 1.9]	[3, 19]						
3-month										
2004–2018	1.24	12	1.43	14	2.03	15.9%	21.3%	3.05	4.0%	5.2%
	[0.15, 7.17]	[2, 59]	[0.15, 5.66]	[3, 43]						
2004–2006	0.84	13	0.89	13	1.28	21.3%	23.2%	1.92	7.7%	4.5%
	[0.15, 3.07]	[2, 44]	[0.15, 2.91]	[3, 33]						

Continued on next page...

Table 2. – continued from previous page

	Maximum Margin Liability				Probabilities of Hedging Failure					
	Long		Short		C_1	Long	Short	C_2	Long	Short
Year Period	($/bu)	(% of $\bar{p}$)	($/bu)	(% of $\bar{p}$)	($/bu)	(%)	(%)	($/bu)	(%)	(%)
2007–2013	1.48	13	1.93	16	2.38	15.0%	31.0%	3.57	5.0%	8.0%
	[0.16, 7.17]	[2, 59]	[0.34, 5.66]	[4, 43]						
2014–2018	1.15	12	1.07	11	2.00	14.0%	6.6%	3.00	0.4%	1.6%
	[0.26, 3.52]	[3, 33]	[0.26, 3.4]	[3, 34]						
6-month										
2004–2018	1.48	15	1.94	19	2.03	21.7%	36.4%	3.04	8.4%	19.6%
	[0.15, 9.01]	[2, 81]	[0.17, 6.85]	[3, 60]						
2004–2006	1.02	16	1.16	18	1.26	27.7%	40.0%	1.89	14.2%	14.8%
	[0.15, 2.98]	[2, 48]	[0.17, 2.69]	[3, 42]						
2007–2013	1.71	15	2.78	23	2.39	19.9%	53.7%	3.59	7.5%	31.0%
	[0.17, 9.01]	[2, 81]	[0.47, 6.85]	[4, 60]						
2014–2018	1.44	15	1.23	13	1.97	20.5%	10.1%	2.96	6.2%	6.6%
	[0.3, 3.88]	[3, 36]	[0.37, 3.54]	[4, 36]						

Notes: Table 2 reports summary statistics of simulated maximum margin liability and probabilities of hedging failure at different capital constraints from 2004 to 2018. All numbers above square brackets are means with maximum and minimum values in square brackets. Percentage of $\bar{p}$ is calculated by dividing L_{max} over the average futures price ($\bar{p}$) during a hedge period. The probability of hedging failure is calculated as the percentage of weeks when L_{max} exceeds a capital constraint over a given study period. The capital constraints, C_1 and C_2, are calculated as 20% and 30% of the average futures price ($\bar{p}$) during a hedge horizon, respectively.

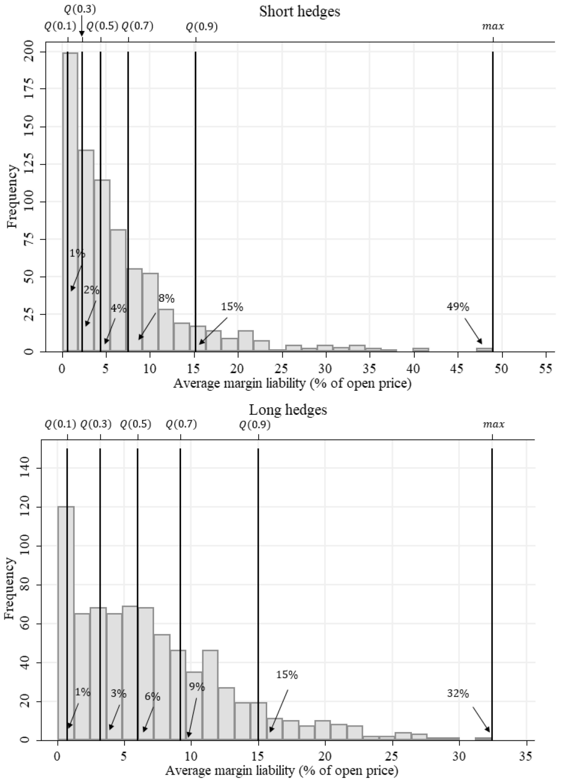

Figure 2. Histogram of Average Margin Liability for 3-Month Corn Hedges with Sample Quantiles at $\theta = 0.1, 0.3, 0.5, 0.7$, and 0.9

Notes: Figure 2 illustrates frequency distribution of average margin liability for 3-month corn hedges over 2004–2018. The average margin liability is measured in percentage of the opening price.

Table 3. Estimates of Unconditional Average Margin Liability for Corn and Soybean Hedges

Panel A. Long

	Q(0.1)		Q(0.3)		Q(0.5)		Q(0.7)		Q(0.9)	
	($/bu)	(%)	($/bu)	(%)	($/bu)	(%)	($/bu)	(%)	($/bu)	(%)
Corn hedges										
1-month										
2004–2018	0.04	1.2	0.11	3.4	0.21	5.3	0.31	7.3	0.53	10.8
2004–2006	0.02	0.7	0.05	2.1	0.09	3.7	0.14	5.8	0.24	10.0
2007–2013	0.06	1.1	0.14	3.3	0.28	5.7	0.42	8.1	0.67	12.1
2014–2018	0.07	2.1	0.15	4.0	0.22	5.5	0.27	6.9	0.41	10.4
3-month										
2004–2018	0.03	0.7	0.11	3.2	0.23	5.9	0.40	9.1	0.72	14.9
2004–2006	0.01	0.4	0.05	1.9	0.11	4.3	0.18	7.9	0.39	14.7
2007–2013	0.03	0.6	0.14	3.2	0.33	6.8	0.54	10.4	0.88	15.9
2014–2018	0.07	1.8	0.15	3.9	0.23	6.0	0.33	8.2	0.60	14.6
6-month										
2004–2018	0.02	0.7	0.14	3.8	0.27	7.0	0.47	10.9	0.87	17.9
2004–2006	0.01	0.4	0.07	2.7	0.13	5.3	0.22	8.9	0.52	17.9
2007–2013	0.01	0.3	0.13	2.8	0.38	8.0	0.65	12.1	1.08	18.4
2014–2018	0.09	2.4	0.19	4.8	0.28	7.2	0.41	10.2	0.74	16.8
Soybean hedges										
1-month										
2004–2018	0.09	0.9	0.22	2.4	0.39	4.2	0.63	6.3	1.02	9.4
2004–2006	0.05	0.8	0.15	2.3	0.25	3.9	0.37	5.8	0.69	10.3
2007–2013	0.09	0.8	0.22	2.0	0.44	4.1	0.75	6.3	1.20	9.7
2014–2018	0.14	1.4	0.31	3.2	0.45	4.5	0.62	6.3	0.92	9.0
3-month										
2004–2018	0.05	0.5	0.20	2.2	0.42	4.3	0.70	6.8	1.33	12.9
2004–2006	0.02	0.4	0.12	1.8	0.25	4.2	0.48	7.6	1.13	15.3
2007–2013	0.04	0.4	0.17	1.6	0.44	3.7	0.75	6.2	1.45	12.2
2014–2018	0.08	0.8	0.28	3.0	0.48	4.9	0.74	7.5	1.38	12.4
6-month										
2004–2018	0.04	0.4	0.19	2.1	0.39	4.5	0.78	7.5	1.54	14.9
2004–2006	0.02	0.4	0.15	2.5	0.29	4.7	0.53	8.2	1.26	18.6
2007–2013	0.03	0.3	0.13	1.2	0.35	3.1	0.74	6.2	1.62	12.8
2014–2018	0.12	1.3	0.31	3.1	0.56	5.9	0.94	8.9	1.62	14.7

Panel B. Short

	Q(0.1)		Q(0.3)		Q(0.5)		Q(0.7)		Q(0.9)	
	($/bu)	(%)	($/bu)	(%)	($/bu)	(%)	($/bu)	(%)	($/bu)	(%)
Corn hedges										
1-month										
2004–2018	0.04	1.1	0.11	3.0	0.19	4.8	0.29	6.7	0.48	10.6
2004–2006	0.02	0.6	0.04	1.6	0.07	3.1	0.13	4.8	0.20	8.0
2007–2013	0.06	1.3	0.18	3.8	0.27	6.0	0.39	8.1	0.61	12.1
2014–2018	0.07	1.7	0.13	3.4	0.17	4.6	0.23	6.3	0.36	9.2
3-month										
2004–2018	0.03	0.6	0.09	2.3	0.17	4.4	0.31	7.5	0.68	15.1
2004–2006	0.01	0.3	0.03	1.2	0.07	2.9	0.13	6.2	0.40	12.7
2007–2013	0.03	0.8	0.15	2.9	0.28	5.4	0.52	9.9	0.90	20.0
2014–2018	0.07	0.8	0.09	2.3	0.16	4.2	0.24	6.4	0.38	9.9

Continued on next page…

Table 3. – continued from previous page

	Q(0.1)		Q(0.3)		Q(0.5)		Q(0.7)		Q(0.9)	
Panel B. Short	**($/bu)**	**(%)**	**($/bu)**	**(%)**	**($/bu)**	**(%)**	**($/bu)**	**(%)**	**($/bu)**	**(%)**
6-month										
2004–2018	0.02	0.4	0.09	2.1	0.17	4.3	0.31	7.9	0.99	22.4
2004–2006	0.01	0.3	0.04	1.6	0.10	4.0	0.18	7.4	0.59	19.4
2007–2013	0.01	0.5	0.12	2.5	0.29	5.6	0.67	14.2	1.40	31.0
2014–2018	0.09	0.5	0.08	2.0	0.14	3.5	0.21	5.6	0.32	8.8
Soybean hedges										
1-month										
2004–2018	0.09	1.1	0.26	2.7	0.44	4.6	0.66	6.5	1.05	9.6
2004–2006	0.05	0.7	0.11	1.8	0.20	3.1	0.33	5.3	0.64	9.1
2007–2013	0.09	1.4	0.40	3.6	0.61	5.3	0.87	7.8	1.26	11.0
2014–2018	0.14	1.4	0.28	2.7	0.43	4.3	0.57	5.8	0.83	8.1
3-month										
2004–2018	0.05	0.7	0.24	2.6	0.51	5.1	0.84	8.2	1.52	15.0
2004–2006	0.02	0.4	0.09	1.4	0.20	3.4	0.42	7.2	0.93	15.4
2007–2013	0.04	1.1	0.48	4.1	0.80	6.6	1.14	10.4	1.78	16.5
2014–2018	0.08	0.7	0.21	2.0	0.41	4.2	0.60	6.3	1.06	10.2
6-month										
2004–2018	0.04	0.6	0.27	2.7	0.59	5.7	0.95	10.4	2.00	19.0
2004–2006	0.02	0.4	0.10	1.5	0.23	3.7	0.63	9.1	0.96	16.1
2007–2013	0.03	1.2	0.62	5.1	0.95	9.3	1.53	14.5	2.43	24.4
2014–2018	0.12	0.5	0.18	1.8	0.36	3.8	0.56	5.9	1.11	11.3

Notes: Table 3 reports sample quantiles of average margin liabilities simulated from 1-, 3-, and 6-month hedges, measured in $/bu as well as perentage of the opening price. The results of corn and soybean hedges are calculated for the entire study period and for each subperiod.

time. However, in 10% of the simulated hedges, $\bar{L}$ could be as high as 15% of the opening price ($Q(0.9) = 15\%$), reaching 49% at the worst time. The distribution of long $\bar{L}$ had similar values of sample quantiles but was more concentrated on the left side. The 0.7 quantile of long $\bar{L}$ indicated there was a 30% chance that the cost exceeded 9% of the opening price.

Table 3 reports detailed information on cost distribution for various hedging horizons across study subperiods. These findings can be interpreted as unconditional estimates of hedging costs by commodity market participants. Our results indicate that for short corn hedges, funds in the amount of 10.6% for 1-month, 15.1% for 3-month, and 22.4% for 6-month hedges were sufficient to cover costs of maintaining a margin account in about 90% of the time over the study period. During a relatively calmer 2014–2018 subperiod, funds in the amount of 8.8%–9.9% were sufficient to maintain a margin account for corn short hedges over 90% of the time. Similar patterns were observed for short soybean hedges, with average marginal liability increasing from 9.6% to 15% and 19% for 1-, 3-, and 6-month hedges 90% of the time, respectively, over the whole study period. These costs declined to between 8.1% and 11.3% (or $0.83/bu to $1.11/bu) in the last subperiod. These empirical distributions closely follow the median values of average margin liability reported in Table 1.

What Explains Changes in Hedging Costs?

Model Specification

Given how much hedging costs vary over time, it is useful to explore the conditions under which these costs change and how these changes affect various parts of cost distribution. The quantile regression approach, initially developed by Koenker and Bassett (1978), provides a useful

Table 4. Estimates of Conditional Average Margin Liability for 3-Month Corn Hedges

Panel A. Long

Quantile	OLS	$Q(0.1)$	$Q(0.3)$	$Q(0.5)$	$Q(0.7)$	$Q(0.9)$
M_w^0	0.631***	0.422***	0.703***	0.698***	0.828***	1.004***
(Mean=4.99)	[0.115]	[0.079]	[0.140]	[0.178]	[0.201]	[0.261]
S_w	3.159***	−0.697*	−0.213	1.413*	3.110***	5.839***
(Mean=1.65)	[0.521]	[0.386]	[0.538]	[0.823]	[0.721]	[1.138]
DP_w^+	−2.071***	−0.634***	−1.253***	−1.966***	−2.262***	−2.671***
(Mean=5.59)	[0.124]	[0.084]	[0.191]	[0.218]	[0.166]	[0.140]
DP_w^-	1.691***	0.596***	1.180***	1.818***	2.035***	2.123***
(Mean=5.70)	[0.126]	[0.079]	[0.207]	[0.273]	[0.206]	[0.267]
$Quart_2$	2.518***	2.114***	1.919***	2.206***	3.706***	5.858***
(Mean=0.25)	[0.491]	[0.323]	[0.535]	[0.835]	[0.923]	[0.935]
$Quart_3$	2.957***	1.078*	1.658***	3.850***	3.540***	3.754***
(Mean=0.25)	[0.489]	[0.565]	[0.560]	[0.792]	[0.627]	[0.744]
$Quart_4$	0.624	0.004	0.438	1.083*	0.733	0.098
(Mean=0.25)	[0.482]	[0.256]	[0.455]	[0.610]	[0.490]	[0.759]
Intercept	−0.821	0.376	0.152	−0.519	−0.818	−0.954
	[0.842]	[0.467]	[0.545]	[1.024]	[1.122]	[1.730]
R^2	0.362	0.124	0.176	0.197	0.253	0.371
$\widehat{L_w}$ (%)	7.152	1.993	4.047	6.480	9.430	13.333
$\widehat{L_w}$ ($/bu)	0.303	0.084	0.171	0.274	0.399	0.564

Panel B. Short

Quantile	OLS	$Q(0.1)$	$Q(0.3)$	$Q(0.5)$	$Q(0.7)$	$Q(0.9)$
M_w^0	0.429***	0.224***	0.430***	0.482***	0.715***	0.461***
(Mean=4.99)	[0.129]	[0.077]	[0.085]	[0.123]	[0.187]	[0.171]
S_w	0.708	−0.772**	−1.008**	−0.349	−0.255	6.412***
(Mean=1.65)	[0.588]	[0.340]	[0.472]	[0.578]	[0.854]	[1.215]
DP_w^+	3.132***	0.799***	2.095***	2.817***	3.755***	3.898***
(Mean=5.59)	[0.140]	[0.157]	[0.173]	[0.300]	[0.346]	[0.211]
DP_w^-	−2.573***	−0.535***	−1.463***	−2.118***	−2.782***	−3.311***
(Mean=5.70)	[0.142]	[0.144]	[0.158]	[0.213]	[0.260]	[0.222]
$Quart_2$	0.391	−0.012	0.106	0.004	0.387	−2.502**
(Mean=0.25)	[0.555]	[0.303]	[0.337]	[0.515]	[0.795]	[1.010]
$Quart_3$	−0.321	−0.640**	−1.216***	−1.594***	−1.343*	−2.227***
(Mean=0.25)	[0.552]	[0.269]	[0.360]	[0.557]	[0.730]	[0.807]
$Quart_4$	0.494	0.182	−0.262	−0.446	−0.725	0.227***
(Mean=0.25)	[0.544]	[0.287]	[0.388]	[0.481]	[0.699]	[0.907]
Intercept	0.335	0.331	0.129	0.727	0.396	−1.490
	[0.951]	[0.534]	[0.679]	[0.870]	[0.998]	[1.197]
R^2	0.449	0.074	0.165	0.224	0.296	0.421
$\widehat{L_w}$ (%)	6.622	1.469	3.634	5.713	8.254	13.175
$\widehat{L_w}$ ($/bu)	0.280	0.062	0.154	0.242	0.349	0.558

Notes: Table 4 reports the estimation coefficients of the quantile regression described in equation (9) with average margin liability as the dependent variable. Single, double and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, and standard errors are shown in square brackets. Ordinary least squares (OLS) estimates are presented with adjusted R^2, and pseudo-R^2 are reported for quantile regressions. For a hedge opened in week w, M_w^0 is the initial margin requirement and S_w is the price volatility, which is measured as the standard deviation of daily absolute return $(|\log(\frac{p_t}{p_{t-1}}) \cdot 100|)$ over a hedge horizon. The positive price change, DP_w^+, is calculated as the sum of daily positive prices divided by the total number of days which have higher settlement prices than the previous day $DP_w^+ = \frac{\sum_{t=1}^T D(\Delta p_t > 0) \cdot \Delta p_t}{\sum_{t=1}^T D(\Delta p_t > 0)}$. The negative price change, DP_w^-, is the average absolute price reduction calculated in the similar manner: DP_w^-, is the average absolute price reduction calculated in the similar manner: $DP_w^- = \frac{\sum_{t=1}^T D(\Delta p_t < 0) \cdot |\Delta p_t|}{\sum_{t=1}^T D(\Delta p_t < 0)}$. Three seasonal dummy indicators ($Quart_2$, $Quart_3$, $Quart_4$) represent the second, third, and fourth quarters, respectively. $\widehat{L_w}$ indicates the in-sample predicted value at the sample mean reported in the first column, measured in percentage of opening price and $/bu.

nonparametric approach for modeling various parts of the distribution of hedging costs. This approach is chosen because the estimated impacts of factors on the upper tail of the cost distribution are much more crucial to hedgers than the impacts on the conditional mean obtained from a least squares model.

Based on our conceptual framework, we consider the following drivers of costs of hedging: initial margin requirement (M_w^0), price volatility (S_w), and price changes, which are further decomposed into positive (DP_w^+) and negative changes (DP_w^-) to capture asymmetric effects on short and long hedges; quarterly dummy variables (*Quart*) are added to model the seasonality in price changes. The conditional quantile model is specified as

$$Q(\theta \mid \boldsymbol{x}_w) = \alpha_0(\theta) + \alpha_1(\theta) \cdot M_w^0 + \alpha_2(\theta) \cdot S_w + \alpha_3(\theta) \cdot DP_w^+ + \alpha_4(\theta) \cdot DP_w^- + \sum_{k=2}^{4} \alpha_{k+3}(\theta) \cdot Quart_k, \tag{9}$$

where $Q(\theta \mid \boldsymbol{x}_w)$ is the θth conditional quantile of $\bar{L}_w$, measured in percentage of the opening price. Initial margin requirement, M_w^0, which determines the frequency and amount of margin calls, is also measured in percentage of the opening price. An increase of the margin requirement is expected to increase the average margin liability, so $\alpha_1(\theta)$ is expected to be positive. For a hedge opened in week w, the price volatility, S_w, is constructed as the standard deviation of daily futures returns (R_t) over the hedge horizon, where $R_t = \ln(\frac{p_t}{p_{t-1}}) \times 100$. Over a hedge horizon, the positive price changes, DP_W^+, are calculated as an average of positive daily changes in the futures price, and DP_W^- is the absolute value of average daily negative price changes. The same model specification (equation 9) can be used to estimate the impacts of these drivers on the maximum margin liability.

Empirical Results

Our models estimate changes in hedging costs with respect to changes in determinants at different parts of the cost distribution (i.e., θ = 0.1, 0.3, 0.5, 0.7, and 0.9). Conditional mean results estimated using ordinary least squares (OLS) methods are also included for comparison. The results presented here are for the average margin liability models based on the 3-month hedges over 2004–2018, additional results for other hedging horizons are available from the authors upon request. As with unconditional results, the focus of our discussion is on the upper parts of the cost distribution when θ = 0.7 or 0.9.

As shown in Table 4, the pseudo-R^2 of quantile regressions ranged from 0.253 to 0.371 for corn long models and from 0.296 to 0.421 for corn short models at the upper parts of the cost distribution. The estimated coefficients had expected signs and magnitudes (see Figure S3 in the online supplement for the varying coefficients across quantiles). The OLS and $Q(0.5)$ estimates are very similar; any differences reflect the differences between the mean (OLS) and the median ($Q = 0.5$) of the cost distribution. The coefficient estimates can be combined with sample means of independent variables (reported in the first column) to form long-term expectations of conditional quantiles of $\bar{L}_w$, which can be compared with unconditional results reported in Table 3 and median values of average margin liability reported in Table 1. These findings illustrate that while about $0.24/bu (5.71% of the opening price) were sufficient to cover the costs of 3-months short corn hedging in half of the time, about $0.56/bu (13.18% of the opening price) were needed to cover these costs in 90% of cases. The impact of most variables was relatively higher at the upper quantiles of the cost distribution. For example, the impact of a 1 cent/bu increase in the standard deviation of futures returns in the 90th decile would increase $\bar{L}_w$ by 6.412% relative to 0.708% at the conditional mean. The dominant role of price volatility in explaining the costs of hedging is consistent with previous studies that state that hedging costs mainly depend on price volatility because high price volatility increases the opportunity cost of funds associated with maintaining a margin account

Table 5. Estimates of Conditional Average Margin Liability for 3-Month Soybean Hedges

Panel A. Long

Quantile	OLS	Q(0.1)	Q(0.3)	Q(0.5)	Q(0.7)	Q(0.9)
M_w^0	0.655***	0.307***	0.727***	0.654***	0.926***	1.207***
(Mean=4.45)	[0.123]	[0.101]	[0.152]	[0.181]	[0.213]	[0.250]
S_w	3.942***	−0.204	1.310**	2.802***	4.491***	5.273***
(Mean=1.43)	[0.468]	[0.339]	[0.524]	[0.832]	[0.918]	[0.995]
DP_w^+	−0.991***	−0.204***	−0.605***	−0.982***	−1.134***	−1.245***
(Mean=11.20)	[0.060]	[0.048]	[0.087]	[0.108]	[0.093]	[0.073]
DP_w^-	0.787***	0.188***	0.490***	0.858***	0.983***	1.014***
(Mean=11.42)	[0.060]	[0.045]	[0.078]	[0.114]	[0.089]	[0.107]
$Quart_2$	0.774*	0.258	0.457	0.863	1.090**	0.837
(Mean=0.25)	[0.410]	[0.295]	[0.444]	[0.574]	[0.538]	[0.689]
$Quart_3$	2.207***	0.433**	0.946**	1.697**	1.805**	1.568**
(Mean=0.25)	[0.416]	[0.210]	[0.422]	[0.706]	[0.706]	[0.769]
$Quart_4$	0.19	0.174	0.062	0.241	0.007	−1.558***
(Mean=0.25)	[0.408]	[0.165]	[0.330]	[0.482]	[0.468]	[0.600]
Intercept	−1.648**	−0.171	−1.291	−1.175	−2.192**	0.209
	[0.695]	[0.372]	[0.803]	[1.055]	[1.066]	[1.162]
R^2	0.393	0.060	0.116	0.170	0.273	0.406
$\widehat{L_w}$ (%)	5.591	0.978	3.009	5.248	7.609	10.974
$\widehat{L_w}$ ($/bu)	0.565	0.099	0.304	0.531	0.769	1.110

Panel B. Short

Quantile	OLS	Q(0.1)	Q(0.3)	Q(0.5)	Q(0.7)	Q(0.9)
M_w^0	0.0454	0.045	0.015	−0.050	0.095	0.420
(Mean=4.45)	[0.147]	[0.092]	[0.128]	[0.193]	[0.231]	[0.349]
S_w	0.145	−1.298***	−1.601***	−1.368**	0.437	6.049***
(Mean=1.43)	[0.560]	[0.302]	[0.416]	[0.632]	[1.012]	[1.158]
DP_w^+	1.184***	0.368***	0.950***	1.391***	1.565***	1.428***
(Mean=11.20)	[0.072]	[0.070]	[0.123]	[0.121]	[0.075]	[0.167]
DP_w^-	−0.876***	−0.196***	−0.601***	−0.937***	−1.157***	−1.164***
(Mean=11.42)	[0.071]	[0.048]	[0.096]	[0.096]	[0.095]	[0.187]
$Quart_2$	−0.869*	0.595**	−0.050	0.003	−1.165	−2.871**
(Mean=0.25)	[0.490]	[0.241]	[0.361]	[0.599]	[0.956]	[1.159]
$Quart_3$	−1.412***	0.176	−0.242	−0.681	−1.865**	−3.504***
(Mean=0.25)	[0.498]	[0.267]	[0.494]	[0.663]	[0.798]	[1.240]
$Quart_4$	−0.745	0.663**	0.308	0.228	−1.034	−2.979***
(Mean=0.25)	[0.488]	[0.296]	[0.414]	[0.540]	[0.684]	[0.905]
Intercept	3.606***	0.762*	1.997***	3.160***	4.046***	2.182
	[0.831]	[0.416]	[0.519]	[0.775]	[1.467]	[2.129]
R^2	0.285	0.085	0.144	0.178	0.218	0.277
$\widehat{L_w}$ (%)	6.506	1.347	3.553	5.741	8.380	13.037
$\widehat{L_w}$ ($/bu)	0.658	0.136	0.359	0.581	0.847	1.318

Notes: Table 5 reports the estimation coefficients of the quantile regression described in equation (9) with average margin liability as the dependent variable. Single, double and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level, and standard errors are shown in square brackets. Ordinary least squares (OLS) estimates are presented with adjusted R^2, and pseudo-R^2 are reported for quantile regressions. For a hedge opened in week w, M_w^0 is the initial margin requirement and S_w is the price volatility, which is measured as the standard deviation of daily absolute return $(|\log(\frac{p_t}{p_{t-1}}) \cdot 100|)$ over a hedge horizon. The positive price change, DP_w^+, is calculated as the sum of daily positive prices divided by the total number of days which have higher settlement prices than the previous day $DP_w^+ = \frac{\sum_{t=1}^{T} D(\Delta p_t > 0) \cdot \Delta p_t}{\sum_{t=1}^{T} D(\Delta p_t > 0)}$. The negative price change, DP_w^-, is the average absolute price reduction calculated in a similar manner: DP_w^-, is the average absolute price reduction calculated in a similar manner: $DP_w^- = \frac{\sum_{t=1}^{T} D(\Delta p_t < 0) \cdot |\Delta p_t|}{\sum_{t=1}^{T} D(\Delta p_t < 0)}$. Three seasonal dummy indicators ($Quart_2$, $Quart_3$, $Quart_4$) represent the second, third, and fourth quarters, respectively. $\widehat{L_w}$ indicates the in-sample predicted value at the sample mean reported in the first column, measured in percentage of opening price and $/bu.

(Etienne, Mallory, and Irwin, 2017). A 1 cent/bu increase in positive price changes would increase $\bar{L}_w$ by 3.898%, and a 1 cent/bu increase in negative price changes would decrease it by 3.311%. Our results indicate that short hedges opened during the growing season (second and third quarter) tended to be less expensive to maintain than hedges opened during the storage period (first quarter) since crop prices usually decline during harvest and increase thereafter. The opposite is true for long hedges, as those open during the growing season tended to be more expensive to maintain and these seasonal differences increased in the upper deciles.

Our findings for soybeans (reported in Table 5) were similar to corn results in both magnitudes and directions; the pseudo-R^2s ranged from 0.218 to 0.406 among the quantile regression models for the upper tail of the cost distribution. The estimated $\widehat{\bar{L}_W}$ was about 6.5% ($0.66/bu) at the mean, 5.7% ($0.58/bu) at the median, and 13% ($1.32/bu) at the 90th decile of the cost distribution. Once again, price volatility appeared to be the most influential factor in the upper tail area: a 1-cent increase in the standard deviation leading to a 6.049% increase in $\bar{L}_w$ at $\theta = 0.9$. Price changes and seasonal patterns also have significant effects on the costs of hedging soybeans across quantiles, as shown in Table 5 and Figure S4 in the online supplement.

Estimation results for the maximum margin liability model are provided in Tables S1 and S2 in the online supplement. Overall, the signs and significance of coefficients were similar to the results in Tables 4 and 5 with slightly larger magnitudes.

How to Anticipate Hedging Costs?

Our findings so far have reported unconditional (Table 3) and conditional (Tables 4 and 5) estimates of hedging costs. The use of conditional models for anticipating hedging costs is more involved as it requires expectations of factors shown to affect hedging costs, such as volatility and price changes. In this illustration, we used historical patterns to estimate price changes: The average values of DP_w^+ and DP_w^- for the same hedging period in the past serve as an approximation of $E(DP_w^+)$ and $E(DP_w^-)$. Specifically, to predict the costs when opening a 3-month hedge in 2018, we calculated 4-year averages of the price changes used in the original model from 2014 to 2017 (i.e., $\overline{DP}^+_{w,2014-2017} = \frac{1}{4}\sum_{y=2014}^{2017} DP^+_{w,y}$ and $\overline{DP}^-_{w,2014-2017} = \frac{1}{4}\sum_{y=2014}^{2017} DP^-_{w,y}$). These two variables capture the historical price changes over 3 months starting from week w. Since volatility was the most important driver of hedging costs according to our estimates, we explored several measures that could be used to form expectations and found that implied volatilities derived from corn and soybean options expiring within 3 months performed the best. Implied volatility estimates over 2005 to 2018 were downloaded from Bloomberg.[9] These expectations were used to estimate the following prediction model:

$$\begin{aligned} \hat{Q}(\theta \mid x_w) = {} & \hat{\alpha}_0(\theta) + \widehat{\alpha_1}(\theta) \cdot M_w^0 + \hat{\alpha}_2(\theta) \cdot IV_w + \hat{\alpha}_3(\theta) \cdot \overline{DP}^+_{w,2014-2017} \\ & + \hat{\alpha}_4(\theta) \cdot \overline{DP}^-_{w,2014-2017} + \sum_{k=2}^{4} \hat{\alpha}_{k+3}(\theta) \cdot Quart_k, \end{aligned} \tag{10}$$

where IV_w, $\overline{DP}^+_{w,2014-2017}$, and $\overline{DP}^-_{w,2014-2017}$ are used as expectations of S_w, DP_w^+, and DP_w^- from equation (9). The quantile approach allows us to forecast the range within which $\bar{L}_w$ is expected to fall during a certain proportion of time (e.g., about 80% of the time).

Figure 3 plots the out-of-sample forecasted range of corn average margin liability between 0.1 and 0.9 quantiles (in shadow) for 3-month long and short hedges. Given the actual average margin liability in 2018 (solid line), the figure shows that the forecasted band covered the movement of actual hedging cost most of the time, and the narrowing and widening of the band reflected our

[9] Bloomberg calculates the implied volatility as a weighted average of implied volatilities for 3-month options closest to at-the-money (Yu, Lui, and Wang, 2010).

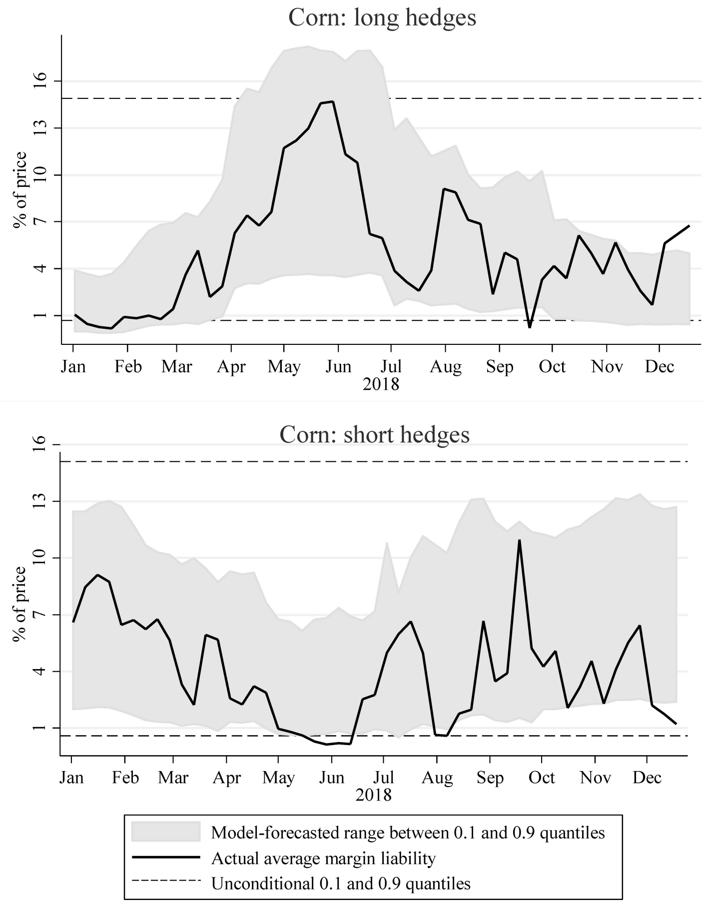

Figure 3. Out-of-Sample Prediction of Average Margin Liability for 3-Month Corn Hedges in 2018

Notes: Figure 3 shows out-of-sample-forecasted range of corn average margin liability between 0.1 and 0.9 quantiles and actual values in 2018. All results are measured in percentage of the opening price..

expectations of the market conditions. Thus, our expected $Q(0.9)$ of long average margin liability was as low as 4% in January and as high as 18% of opening price in May and June for long hedges; 3-month short hedges opened in May had the lowest expected $Q(0.9)$ of hedging costs as 6.8% of opening price and the ones opened in November had the highest expected costs of 13.15%. In contrast, expectations based on an unconditional distribution would result in a flat range of 0.6%–15.1% (between dashed lines) based on the whole sample results.

Figure 4 depicts the anticipated costs of soybean hedges. While our model predicted that the average margin liability for $Q(0.9)$ would top off at 13.4% of price in July, the actual highest average margin liability (17%) was observed in June 2018 and exceeded the forecasted $Q(0.9)$ by 6%. This unexpected spike in hedging cost was likely caused by the start of a trade war between the United States and China. In June 2018, China announced a tit-for-tat tariff on $34 billion in U.S. goods including soybeans, which dropped soybean price by more than 10% to a 10-year low (Swanson, Coppess, and Schnitkey, 2018). Our forecasted range in Figure 4 clearly failed to predict this abnormal event. An alternative model based on forecasted price changes rather than historical patterns might have performed better in this case. Similarly, a flat range of 0.5%–12.9% (between dashed lines) based on the unconditional distribution of 3-month long soybean hedges would have missed some of this hedging cost increase that likely falls in the top 10% of the distribution. Outside

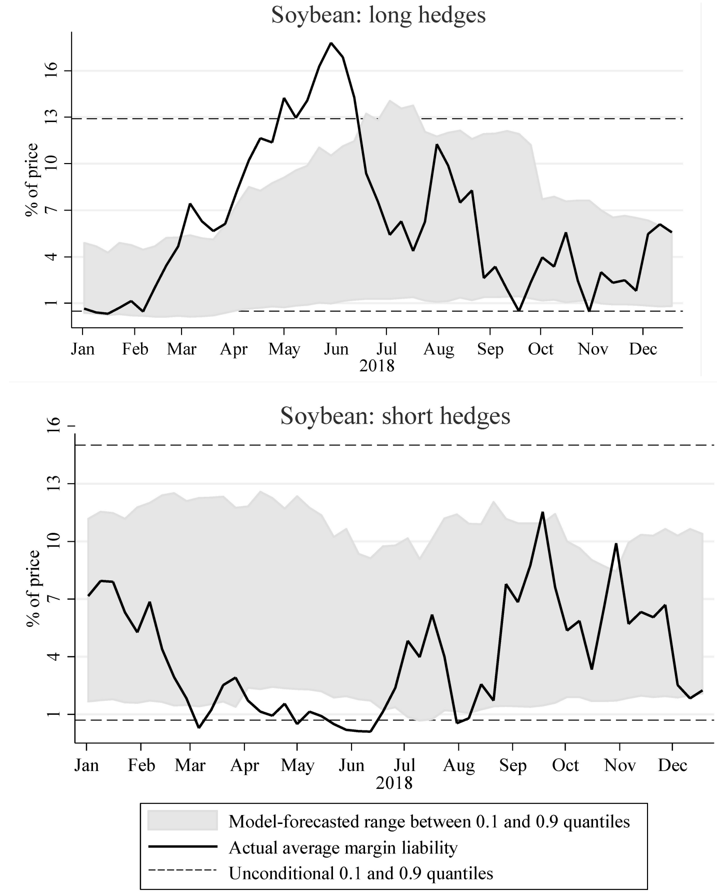

Figure 4. Out-of-Sample Prediction of Average Margin Liability for 3-Month Soybean Hedges in 2018

Notes: Figure 4 shows out-of-sample-forecasted range of soybean average margin liability between 0.1 and 0.9 quantiles and actual values in 2018. All results are measured in percentage of the opening price.

of this event, our predicted ranges for long and short soybean hedges capture most of the movements in actual hedging costs.

Summary and Conclusions

Hedging with futures is a popular price risk management tool but may incur substantial liquidity risk. This study contributes to the risk management literature in three ways. First, it develops a comprehensive set of measures to empirically quantify the costs of futures hedging. Second, it simulates these costs and provides an empirical distribution for 1-, 3-, and 6-month corn and soybean hedges which can be used as unconditional estimates of hedging costs. Third, a quantile regression model is developed to assess the impact of the main determinants (i.e., margin requirement, volatility, and price movements) on various parts of the hedging cost distribution. This model may be used to develop conditional estimates of hedging costs based on market expectations and information available at the opening day of the hedge and has been shown to provide reasonable estimates. These estimates of hedging costs may be used by farmers to compare and assess various risk management tools, such as forward contracting and hedging with futures. Further, since most grain merchants use futures to hedge against the price risks of their issued forward sales, they can use our findings to help anticipate the hedging costs and price forward contracts.

Our primary measures of hedging costs include (i) average margin liability (i.e., the average amount of money that should be deposited in the margin account over the duration of the hedge) and (ii) maximum margin liability (i.e., the maximum amount needed to keep the hedge open). The simulation results suggest that the costs of hedging changed substantially over time, increasing drastically during 2007–2013 and leveling off thereafter. While the costs of hedging far exceeded the margin requirements (used in some studies to represent the costs of hedging), they consistently stayed below the costs of forward contracting (as measured by Etienne, Mallory, and Irwin, 2017). In fact, increases in the costs of hedging during 2007–2013 were not as dramatic as increases in the costs of forward contracting, suggesting that other factors (e.g., such as access to capital and risk of default) may have contributed to the rising costs of forward contracts.

Hedgers can use our empirical distributions of hedging costs to form unconditional expectations of these costs. Their risk tolerance would determine the selection of deciles, and their expectations for market conditions would suggest the use of the most appropriate subperiod results for decision making. If risk-averse short hedgers who are interested in predicting the funds to cover hedges in 90% of the time, expect the next year to be similar to the 2014–2018 subperiod, our findings suggest that they would need about 9% or 11.3% of the opening price to maintain a 6-month corn or soybean hedge, respectively.

The quantile regression approach provides additional insights into the driving factors and their impacts on different parts of the hedging cost distribution. Consistent with previous studies (Garcia, Irwin, and Smith, 2015; Etienne, Mallory, and Irwin, 2017), our estimation results reveal that price volatility was the main driver of hedging costs; at higher quantiles, a 1 cent/bu increase in price volatility would drive the average margin liability up by 6%. The impact of price changes was also significant but about one-half in magnitude. Likewise, although serving as an important driving factor, the margin requirement had a small impact. Compared with unconditional quantiles, the conditional estimates of hedging costs were able to predict seasonal patterns of corn and soybean markets based on the expectations of these drivers available at the time the hedge was open. The out-of-sample prediction intervals were much narrower than unconditional intervals and appeared to include the observed hedging costs most of the time.

In the presence of liquidity risk associated with hedging, it is essential to educate financial institutions on when to loan funds to finance futures positions. Although this study demonstrates that hedging costs may be substantial, they tend to be temporary during the hedge period. If the hedge is placed correctly, the gains in the cash market tend to offset the losses in the futures market. Therefore, hedging loans should be set up separately from other operational loans and consider the size of the cash market position of a business. To reduce the risk of hedging failure, financial institutions may improve access to credit for hedgers and consider using expectations of hedging costs developed in this study.

While this study offers important insights into the costs of hedging, it has several limitations. First, to simulate daily cash flows, we assume simple futures hedges with a margin account balance returning to the initial margin level after daily deposits or withdraws. In practice, diverse hedging strategies may generate different cash flows from the margin account. It would be interesting to investigate how the costs of hedging change under other hedging strategies. Second, we only use corn and soybean hedging to demonstrate the approach, and future research may consider applying this framework to assess the costs of hedging for other commodities. Finally, the out-of-sample forecast models simply use seasonality, historical price patterns, and implied volatility. As a result, the soybean prediction models could not anticipate the exogenous trade war and therefore underestimated costs for long hedgers and overestimated costs for short hedgers in summer 2018. Alternative approaches could be explored to generate more forward-looking estimates of price changes. Addressing these issues will provide interesting areas for future research.

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