Double-Edged Sword: Liquidity Implications of Futures Hedging

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Introduction

Global commodity markets have experienced substantial volatility growth in the recent decade. In this environment, price risk management has become increasingly important. Futures hedging is widely used by market participants to reduce price risk. To achieve this goal, hedgers use futures contracts to offset the price movements in spot markets. The underlying assumption is that if the prices of futures and spot markets move together, the return of the hedged portfolio is relatively stable regardless of substantial price fluctuations in the commodity markets. However, hedging with futures involves costs, such as commission fees and money involved in maintaining the margin account. Among these costs, maintaining an account to meet margin requirements is often said to be the most challenging aspect for many hedgers (FCSA, 2017). While some argue that if the hedge is implemented correctly, the losses in futures positions should be directly offset by the gains in cash markets, large margin calls may lead to significant liquidity problems that often result in premature termination of a hedge or even bankruptcy. Some of the most notorious examples include the Metallgesellschaft debacle (Mello & Parsons, 1995) and bankruptcies of several cotton merchant firms in 2008 (Carter and Janzen, 2009). Margin calls are consistently quoted as the main impediment to using futures markets by agricultural producers (FCSA, 2017).

Despite this evidence, little is known about the costs of maintaining a margin account for a futures hedge. Riley and Anderson (2009) estimated that the average margin requirement for corn was 13 cents/bushel in 2007, which was much higher than 4 cents/bushel in previous years. However, the margin requirement along does not reflect the full costs of futures hedging. Several studies demonstrated theoretically that the costs of hedging would lower optimal hedge ratios (Arias, Brorsen, & Harri, 2000; Chang & Chang, 2003; Dahlgran & Liu, 2011; Deep, 2002; Lien, 2003), but empirical evidence of their conclusions is often limited to numerical illustrations.

The goal of this paper is to examine the costs of maintaining a margin account for a futures hedge and the implications of these costs on hedging behavior. Specifically, we have five objectives: 1) Review factors that affect margin requirements; 2) Measure the cost of maintaining a margin account for a futures hedge (i.e., margin liability and borrowing costs); 3) Estimate how sensitive is the cost to its determinants; 4) Examine changes in the cost of hedging over time and 5) Evaluate the implications of hedging cost on futures market participation. This study will be of interest to the hedgers who concern liquidity risk of using the futures market to manage the price volatility. The findings will help understand changes in futures market participation and the recent expansion of alternative risk management instruments in response to increasing costs of hedging.

Literature Review

Margin requirements are implemented by the exchange to reduce the risk of default on futures contracts and consist of an initial margin, funds required to open a position, and a maintenance margin, a balance required to sustain a position. While the initial margin usually reflects only a small percentage of the position's value (about 2 to 10%), the margin account is updated daily to reflect changes in the value of the entire position. If the position is losing value, the account must be replenished to contain the minimum balance equivalent to the maintenance margin. If the position is gaining value, the account is credited and these additional funds may be withdrawn provided that the minimum balance equivalent to the maintenance margin is sustained.

Although the exchanges usually do not disclose how margin requirements are determined, according to Lam, Yu, and Lee (2010), the margin-setting committee of the clearing house at the exchange calculates some formula-based benchmark margins as the reference level. These benchmark margins are derived as the minimum level to cover a certain probability of loss in the futures market, which is usually set at or above 95% (Lam, Sin, & Leung, 2004). Our study will assess the suitability of the benchmark margin developed by Lam et al. for describing margin requirements in corn and soybean markets.

Several previous studies examined the direct costs of hedging, which include commission fees and borrowing costs to meet margin calls. For example, Riley and Anderson (2009) defined the hedging cost as the amount of initial margin required to take a position. Another study by Alexander, Prokopczuk, and Sumawong (2013) considered transaction cost and margin cost. The transaction cost consists of commission fee and bid-ask spread, and the margin cost is measured as the borrowing cost of financing the initial margin plus interest losses and gains of daily cash flow from margin accounts.

Another group of studies examined the potential liquidity problems associated with hedging as the indirect costs. For instance, Dahlgran and Liu (2011) examined the cash flow risk induced by a margin account and measured it as the variance of uncertain cash flows simulated from a long hedge. Other studies characterized the risk of hedging through financial constraints (Deep, 2002; Lien, 2003). The underlying assumption is that a hedger has to liquidate the futures position when its cumulative loss exceeds a given threshold during the hedging horizon. In this way, risks of hedging can be captured by the probabilities of premature termination of a hedge.

The drawback of direct costs is that these measures are often inadequate to reveal potential liquidity risk caused by hedging, since margin requirements or borrowing costs cannot reflect the actual funds needed to maintain a futures position. On the other hand, evaluating hedging costs indirectly often relies on arbitrary capital constraints. Therefore, we develop a theoretical framework that allows to incorporate costs of hedging in both ways and to examine changes in these costs over time.

To the best of our knowledge, Riley and Anderson (2009) conducted the only empirical study that examined changes in the costs of hedging over time. They compared the amount of initial margin required to take a short position in three time periods: 2001-2005, 2006 and 2007 for different commodities. The main finding was that costs of hedging soybeans, corns and wheat have increased over time. Our study will extend their empirical analysis to include additional measures of the costs of hedging such as margin liability, borrowing costs, as well as probabilities of hedging failure under different borrowing constraint.

Most previous studies that examined the implications of the costs of hedging on hedging behavior came to the conclusion that the costs of hedging lower optimal hedging ratios (OHRs). For example, Arias et al. (2000) suggested that OHR decreases as costs of hedging exceed hedging's benefits of tax reduction. Mello and Parsons (2000) found that for a financially constrained firm, a hedge generates instantaneous cash flow and increases the hedged firm's value. On the other hand, an inappropriate hedge may tighten the liquidity constraints and therefore reduce the firm's value. Chang and Chang (2003) revealed that as the variable cost of hedging increases from 0 to 4.13%, OHR decreases from 1.373 to 0 rapidly. Dahlgran and Liu (2011) derived the optimal hedge ratio by minimizing the combined risk of hedge outcome and cash flows, and found the resulting ratio is substantially below the hedge ratio that only minimizes the variance of hedge outcome. Deep (2002) suggested that the firm faces a tradeoff between hedging more to reduce the spot price risk with the higher risk of liquidating the hedge.

Therefore, the optimal hedge level under a borrowing constraint is well below the unconstrained one.

However, the limitations of using optimal hedging ratio to understand impacts of hedging costs include the following: 1) the implications of hedging costs on OHR may not be comparable between studies using different objective functions; 2) studies found that OHRs poorly represent the actual hedging practice and are often well above the observed ratios (Arias et al., 2000; Goodwin & Schroeder, 1994); 3) observed hedge ratios data are often difficult to collect for empirical analysis. Therefore, instead of OHRs, this study will focus on futures market participation to examine the implications of hedging costs. Hardouvelis and Kim (1995) explored the causal effect of raising margin requirements on the trading volume and open interest of metal futures. They used a control group of metal futures which did not undergo a margin charge over four months and estimated the effects separately. The authors found that an increasing margin requirement significantly reduces the open interest of affected metal futures, and traders seemed to move to the similar metal futures in the control group.

In sum, while several previous studies have looked at various aspects of hedging costs, it is not clear how to measure these costs empirically and assess their effect on hedging behavior. There is no consensus on measurement, as most of these studies ran into data issues that prevented a rigorous empirical analysis of the proposed theoretical conclusions. This study develops a comprehensive framework to measure direct and indirect costs of hedging. Based on historical futures prices and margin requirements, we illustrate changes in hedging costs over time and identify the driving factors behind that. Additionally, we investigate the implications on futures market participation of different trading groups.

Theoretical Framework

The most substantial component of hedging costs is associated with maintaining a margin account for a futures hedge. Margin requirements are set by the exchange to reduce the default risk on futures contracts. If one's margin balance is below the maintenance margin requirement, the margin account will be marked to the market by depositing money back to the initial margin level. Otherwise, the position will be liquidated by the clearinghouse. Lam et al. (2004) provided a formula for calculating a benchmark margin (BMR) at day t, which serves as a reference level for observed margin requirements:

$$BMR_t = p_{f,t-1}|\mu_t + k\sigma_t| \tag{1}$$

$$\mu_t = \frac{1}{Z}\sum_{z=1}^{Z} R_{t-z}, \quad \sigma_t^2 = \frac{1}{Z-1}\sum_{z=1}^{Z}(R_{t-z} - \mu_t)^2, R_t = \ln\left(\frac{p_{f,t}}{p_{f,t-1}}\right) \times 100$$

where $p_{f,t-1}$ is the previous day's futures price, μ_t and σ_t are historical mean and standard deviation of futures returns over past Z days. According to Riley and Anderson (2009), Chicago Mercantile Exchange (CME) commonly sets $Z = 90$ and $k = 1.96$. Thus, the margin requirements are affected by price level as well as mean and standard deviation of futures returns over a relevant historical time period.

The margin requirements and price changes determine the cash flows associated with maintaining a futures hedge. Taking a short hedge[1] as an example, we describe how to measure the direct and indirect costs of maintaining a margin account. For one futures contract with a size of x_f and price p_f, let $MR^0 = \frac{\$\,initial\ margin}{x_f} \cdot 100$ and $MR^m = \frac{\$\,maint.\ margin}{x_f} \cdot 100$ be per-

[1] To simplify the discussion, we focus on a short hedge because many hedgers are agricultural producers. However, this framework can also be illustrated with a long hedge example.

bushel initial and maintenance margin requirements, measured in cents. The per-bushel cash flows (CF) from Mark-to-Market margin at day t is (Dahlgran & Liu, 2011).

$$\mathrm{CF_t}\ (\frac{cents}{bushel}) = \left[MB_{t-1} + \Delta p_{f,t} - MR^0\right]\left[A\left(MB_{t-1} + \Delta p_{f,t} > MR^0\right)\right. \\ \left. + A\left(MB_{t-1} + \Delta p_{f,t} < MR^m\right)\right], \qquad \Delta p_{f,t} = p_{f.t-1} - p_{f.t} \tag{2}$$

where $\mathrm{MB_{t-1}}$ is the per-bushel margin account balance at t-1 and $\mathrm{A}(.)$ is an indicator function. The intuition behind equation (2) is as follows. $\mathrm{CF_t} = MB_{t-1} + \Delta p_{f,t} - MR^0 > 0$ when $MB_{t-1} + \Delta p_{f,t} > MR^0$, meaning the hedger can withdraw at most $\mathrm{CF_t}$ in excess of the initial margin at day t. We assume the excess margin money is withdrawn everyday during a hedge horizon. On the other hand, if $MB_{t-1} + \Delta p_{f,t} < MR^m$, $\mathrm{CF_t} = \left[MB_{t-1} + \Delta p_{f,t} - MR^0\right] < 0$ since $MR^m \leq MR^0$, meaning when the margin account balance is smaller than the maintenance margin requirement at day t, the hedger has to deposit $-\mathrm{CF_t}$ back to initial margin. The extra funds deposited is also called variation margin. This specification demonstrates that the cash flows necessary to maintain the margin account result from price changes exceeding margin levels during the hedging period.

The initial margin and daily settlements of cash flows are financed or reinvested to the margin account, so the cumulative gain (or loss) in the futures position at day t is

$$\pi_t\ \left(\frac{cents}{bushel}\right) = -MR^0 + \sum_{j=1}^{t} CF_j\ \ , for\ t = 1, 2, \dots, T \tag{3}$$

Figure 1 illustrates $\mathrm{CF_t}$ and π_t in two hypothetical three-month hedges for corn. The blue line represents the cumulative margin gain (or loss) associated with the margin account, which is affected by the initial margin requirement and daily cash flows (orange bars). In this example, the initial margin is assumed to be $850 per contract, or 17 cents/bushel. For hedge A, $\pi_1 = -17$ cents/bushel indicates the minimum money needed to open a hedge position. The blue line of margin revenue tends to increase from day 1 to day 7 as most cash flows in those days are positive. From day 11 to day 22, π_t decreases dramatically and reaches the bottom of -48 cents/bushel. After day 22, the cumulative loss becomes quite stable around -40 cents/bushel. Regarding hedge B, the hedger faces growing loss from day 1 to day 5, while she gradually earns positive cash flows and increases the payoff after day 7. Until day 17, π_t turns into positive.

[Figure 1 to be here]

Consistent with Alexander (2013), we assume that the hedger has to borrow when $\pi_t < 0$, and define $\overline{ML}$ as the average margin liability of a hedge held from $t = 1$ to T.

$$\overline{ML}\ \left(\frac{cents}{bushel}\right) = \frac{1}{T_1}\sum_{t=1}^{T} -\pi_t \ \cdot A(\pi_t < 0) \tag{4}$$

where T_1 is the number of days when $\pi_t < 0$ and $A(.)$ is an indicator function. $\overline{ML}$ captures average money shortfall caused by a hedge. In figure 1, the average funds required to maintain hedge A is 35.78 cents/bushel. Although hedge B generates cumulative gains at the most time, the hedger still needs an average of $\overline{ML}$ =13.56 cents/bushel to finance the money shortfalls from day 1 to day 16 and day 26, so $T_1 = 17$. This examples demonstrate that liabilities of maintaining a margin account depend on cumulative losses on a daily basis.

In theory, losses in the futures markets should be offset by the gains in spot markets. However, as Mello and Parsons (1995) pointed out, this requires the maturity of future positions always to match the spot positions remaining to be traded, as well as the convergence of futures and spot prices. If there is mismatched maturity in the hedge or non-convergence problems

(Garcia, Irwin, & Smith, 2015), unfavorable movements of futures prices make hedgers very vulnerable to liquidity crises.

The gains and losses associated with a margin account generate financial returns or costs. If we assume that the margin money earns interest, the margin cost (MC) is defined as the sum of daily borrowing cost of the liability (when $\pi_t < 0$) minus interest gains from positive π_t. Let r be the daily interest rate, the margin cost for one bushel of futures contract from $t = 1$ to T is

$$MC\left(\frac{cents}{bushel}\right) = \sum_{t=1}^{T} -\pi_t * r \tag{5}$$

In this case, MC can be negative if a margin account generates more positive cash flows than the funds required to maintain it. However, if assuming there is no interest gain, the margin cost is

$$MC\left(\frac{cents}{bushel}\right) = \sum_{t=1}^{T} -\pi_t \cdot A(\pi_t < 0) * r = \overline{ML} \cdot T_1 \cdot r \tag{6}$$

Therefore, assuming the funds for maintaining a margin account are borrowed, margin liability and interest rates will directly affect the costs of hedging. Longer hedging horizon raises the costs $\frac{\partial MC}{\partial T_1} > 0$ if the margin money does not general interest gains.

Finally, we discuss the implications of hedging costs on liquidity when a hedger cannot borrow enough funds to sustain the hedge. To isolate this liquidity risk, we focus on the maximum margin liability $\widetilde{ML}$ during a hedge, defined as

$$\widetilde{ML} = -\min(\pi_1, \pi_2, \ldots \pi_T) \tag{7}$$

$\widetilde{ML}$ reflects the largest cumulative loss during a hedging period, and therefore presents a conservative measure of liquidity risk. Similar to previous studies (Deep, 2002; Lien, 2003), we assume that a hedger will abandon the futures position before the expected ending day if $\widetilde{ML} >$

c, where c is the borrowing constraint, measured as a percent of average price over the hedge horizon, $\frac{1}{T}\sum_{t=1}^{T} p_{f,t}$. In other words, the hedger cannot or is not willing to borrow more than c to maintain this hedge program. Otherwise, the futures position is sustained till $t = T$. Figure 1 suggests that one needs to be able to borrow at least 48 cents/bushel to avoid premature termination of hedge A.

Then, the probability of hedging failure can be approximated empirically by averaging over N simulated hedges over a given period as follows

$$Prob\big(\widetilde{ML} > c\big) = \frac{1}{N}\sum_{i=1}^{N} A(\widetilde{ML}_i \ > c) \times 100\%, \ \ i = 1, 2, \ldots, N \quad (8)$$

For hedge i, the indicator function $A(\widetilde{ML}_i > c)$ returns to 1 if total maximum daily liability exceeds the borrowing constraint c, indicating this hedge has to be abandoned. Otherwise, $A(\widetilde{ML}_i > c) = 0.$ Given $\widetilde{ML}$, individual borrowing conditions can be applied to estimate the probability of hedging failure. The model suggests that a more restricted borrowing constraint increases the probability of premature termination of a hedge (Deep, 2002; Lien, 2003). This risk may be a crucial concern for many small producers who have insufficient credit lines.

Additionally, we expect the probability of failure is negatively associated with the market participation of hedgers because hedging with futures becomes less reliable if one is less likely to maintain a position. However, the probability of hedging failure depends on an arbitrary borrowing constraint. In order to avoid the additional assumption of a constraint, we test this association with $\widetilde{ML}$, and hypothesize that an increase in the maximum liability reduces the market participation by increasing the probability of failure, *ceteris paribus*.

Data and Simulation

This study used corn and soybean futures for the empirical analysis. The data consist of futures prices from the Chicago Board of Trade and historical margin requirements from 1/2/2004 to 11/7/2017[2]. We simulate daily short and long hedges for one contract. Each day, a short (long) position is opened with a target ending day in three months later. The target futures contract is specified as the one with the nearest active delivery month to the ending day. Daily settlement prices of the target futures contract are used for these three-month hedge simulations. We assume the hedger switches to the next futures contract at the beginning of a month if its ending day reaches the delivery month of the prior target futures contract.

For each three-month hedge, we calculate $\overline{ML}$ and $\widetilde{ML}$ and the borrowing costs in equations (5) and (6) using daily interest rate[3] $r = 8.5\%/360$. In reality, interest rates on margin accounts vary according to the size of the loan and the brokerage firm being used, and tend to be lower with a higher debit balance. For a given constraint c, a simulated hedge is identified as a failure if its maximum margin liability exceeds c during the hedging period. The probability of hedging failure is calculated as the percent of failed hedges in a year based on equation (8).

We also collect futures market participation data from Disaggregated Commitments of Traders (COT) Report data, which is available from 6/13/2006 to 12/26/2017. The weekly COT reports are published by Commodity Futures Trading Commission on each Friday, and show the positions of disaggregated groups of traders on previous Tuesday. There are five groups:

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[2] Historical margin requirements of corn futures are not available from 9/20/2007 to 1/2/2009.

[3] According to the website https://investorjunkie.com/12389/best-margin-rates/, we select 8.5% as the average annual margin cost rate with a debt balance 0-$9999. Then, we divide it by the number of days in a year to get a daily interest rate. The brokerage industry typically uses 360 days - not 365 (https://www.investopedia.com/ask/answers/07/margin_interest.asp)

producer/merchant/processor/user, swap dealers, managed money manager, other reportable and non-reportable participants. Our primary focus is the first group of commercial traders (producer/merchant/processor/user), who use the futures to hedge risks associated with production, processing or handling physical commodities. However, we also evaluate the market participation of swap dealers and money managers as alternative groups of market participants.

Empirical Analysis

Margin requirements

Following the theoretical framework, we begin with examining margin requirements for corn and soybean futures. Figure 2 compares observed maintenance margins published by the CME to the reference margin calculated using equation (1). The figure suggests that benchmark margins of both corn and soybean futures dramatically exceed actual margin requirements in 2009, 2011 and 2013. This phenomenon suggests that the exchange was careful not to raise margins too much during this period of increased price volatility. After 2013, benchmark margins fall below the actual margin requirements reflecting that the clearinghouse was reluctant to reduce margin levels too fast after the shock.

[Figure 2 to be here]

This observation suggests that the effect of past futures returns on futures margin levels may be asymmetric. In the example above, the clearinghouse appears more likely to adjust margin requirements upwards rather than downwards with changing price volatility. Although benchmark margins are not very close to the actual margins, we can try to predict actual margin requirement (MR^m) based on previous day's futures price $p_{f,t-1}$, historical mean return μ_t and standard deviation σ_t. Additionally, two indicators $D_{\mu<0}$ and $D_{\Delta\sigma>0}$ are added to test the asymmetric effects of mean and standard deviation of futures returns:

$$D_{\mu<0} = \begin{cases} 1 & if\ \mu_t < 0 \\ 0 & otherwise \end{cases} \text{ and } D_{\Delta\sigma>0} = \begin{cases} 1 & if\ \Delta\sigma_t = \sigma_t - \sigma_{t-90} > 0 \\ 0 & otherwise \end{cases}.$$

Margin requirement model is specified as:

$$MR_t^m = \alpha_0 + \alpha_1 p_{f,t-1} + \alpha_2 \mu_t + \alpha_3 \mu_t \cdot D_{\mu<0} + a_4 \sigma_t + a_5 \sigma_t \cdot D_{\Delta\sigma>0} + \varepsilon_t \quad (9)$$

where $\mu_t = \frac{1}{Z}\sum_{z=1}^{Z} R_{t-z}$, $\sigma_t^2 = \frac{1}{Z-1}\sum_{z=1}^{Z}(R_{t-z} - \mu_t)^2$, $R_t = \ln\left(\frac{p_{f,t}}{p_{f,t-1}}\right) \times 100$.

Factors that affect margin liability

In addition to margin requirements, our theoretical framework suggests that price movements also affect margin liability. Focusing on $\overline{ML}$ as the variable of interest, we investigate its sensitivity to maintenance margin requirements (MR^m), as well as volatility of futures returns (S) and price level changes (DP). To estimate volatility S_t associated with a 3-month (66 day) hedge starting at time t, we construct a daily measure as the standard deviation of futures returns in the next three months, $S_t = \sqrt{\frac{1}{65}\sum_{z=1}^{66}(R_{t+z} - \theta_t)^2}$, where $\theta_t = \frac{1}{66}\sum_{z=1}^{66} R_{t+z}$ and $R_t = \ln\left(\frac{p_{f,t}}{p_{f,t-1}}\right) \times 100$. For price level change DP_t, at each day t, we calculate the average futures price over the following three months $avg(p_f)_{[t,t+66]} = \frac{1}{66}\sum_{z=1}^{66} p_{f,t+z}$ and define the daily measure as $DP_t = avg(p_f)_{[t,t+66]} - p_{f,t}$, where $p_{f,t}$ is the price at which the hedge was opened.

Next, we aggregate daily measures into weekly frequencies by taking weekly averages of $\overline{ML}$, S_t, DP_t and MR_t^m. This strategy reduces noise from daily fluctuations of futures prices and overcomes partially the overlapping dependence between observations. Then, we treat weeks

(w: 1~52) as cross-sectional units and years (y: 2004~2017) as the temporal dimension to construct a panel. The margin liability model is specified as follows:

$$\overline{ML}_{wy} = \alpha_1 S_{wy} + \alpha_2 DP_{wy} + \alpha_3 MR_{wy}^{m} + v_{wy} \tag{10}$$

where $x_{wy} = \frac{1}{5}\sum_{t=1}^{5} x_{wyt}$, $x_{wyt} = \overline{ML}_t,\ S_t,\ DP_t \ or\ MR_t^m$ in week w in year y

The intercept is dropped as it is highly collinear with the margin requirement. The return volatility S_{wy} is expected to increase the margin liability by making futures market riskier. The variable DP_{wy} captures the changes of price levels, and is expected to increase the liability of short hedgers, but reduce margin liability for long hedgers. MR_{wy}^{m} is the average maintenance margin requirements in a given week, which determines the frequency and amount of margin calls. Holding other factors fixed, an increase of margin requirement causes a one-time cash outflow, so it is expected to increase average margin liability.

In addition to the level-variable model, we also estimate the elasticities based on percentage changes from the same week in the previous year $y-1$

$$\Delta\overline{ML}_{wy}\% = \beta_0 + \beta_1 \Delta S_{wy}\% + \beta_2 \Delta DP_{wy}\% + \beta_3 \Delta MR_{wy}^{m}\% + \varepsilon_{wy} \tag{11}$$

$where\ \Delta x_{wy}\% = \left(\frac{x_{wy} - x_{wy-1}}{x_{wy-1}}\right),\ x_{wy} = \overline{ML}_{wy},\ S_{wy}, DP_{wy}\ or\ MR_{wy}^{m}.$

The coefficients β_1, β_2 and β_3 are elasticities, which measure the percent change of margin liability with respect to 1% increase of futures returns' volatility, futures prices level changes and margin requirements compared to the previous year.

Impacts on hedging participation

The following analysis focuses on weekly futures market participation from COT data. Following Hardouvelis and Kim (1995), we choose the first measure of market participation as the compounded percentage change in week w's open interest of each trader group: $\Delta lnOI_w = \ln\left(\frac{OI_w}{OI_{w-1}}\right)$, separated by short and long positions. The explanatory variable is weekly maximum $\widetilde{ML}$, denoted as $\widetilde{ML}_w$, because $\widetilde{ML}$ is most relevant to the probability of hedging failure[4], and therefore affects hedgers' participation decisions. Again, we take the compound percentage change $\Delta ln\widetilde{ML}_w = \ln(\widetilde{ML}_{\mathrm{w}}/\widetilde{ML}_{\mathrm{w-1}})$. The first model is

$$\Delta lnOI_w = \eta_0 + \eta_1 \Delta ln\widetilde{ML}_w + \varepsilon_w \tag{12}$$

The error ε_w is assumed to follow a first order autoregressive (AR(1)) process, such that $\varepsilon_w = \rho\varepsilon_{w-1} + v_w$, where v_w is a well-behaved white noise. We expect that an increase of $\Delta ln\widetilde{ML}_w$ reduces the growth of futures positions represented by commercial traders (producer/merchant/processer/user), while this may increase the open interest of other two groups: swap dealer and money managers due to substitute effects.

We also consider the relative size of market participation, so the second measure is percentage change in relative size of open interest held by each group: $\Delta lnOI_w\% = \ln(OI_w\%/OI_{w-1}\%)$, where $OI_w\%$ is the percent of open interest held by each trading group against the total open interest in week w. The corresponding model is

$$\Delta lnOI_w\% = \tau_0 + t_1 \Delta ln\widetilde{ML}_w + u_w \tag{13}$$

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[4] This choice of explanatory variable will be tested in robustness analysis.

Again, u_w is assumed to follow a AR(1) process. A higher maximum margin liability is expected to reduce the growth in market share of producers/merchants/processors/users as it increases the probability of hedging failure.

Results

Margin requirement determinants

The fitted model of equation (9) is[5]

Corn: $\widehat{MA_t} = \underset{(-25.3)}{-423.7} + \underset{(113.2)}{3.4} p_{f,t-1} - \underset{(-22.5)}{981.1}\mu_t + \underset{(2.4)}{177.6}\mu_t \cdot D_{\mu<0} + \underset{(5.1)}{57.5}\sigma_t + \underset{(5.9)}{32}\sigma_t \cdot D_{\Delta\sigma>0}$

Soybean: $\widehat{MA_t} = \underset{(-44.6)}{-1623.4} + \underset{(120.4)}{2.9} p_{f,t-1} - \underset{(-23.2)}{2022.7}\mu_t + \underset{(13.4)}{2216.6}\mu_t \cdot D_{\mu<0} + \underset{(43.1)}{847}\sigma_t - \underset{(-3.0)}{30.1}\sigma_t \cdot$

$D_{\Delta\sigma>0}$

Results suggest that the margin requirements are positively associated with price level and volatility. Higher future returns reduce the margin requirement, but the effect is smaller when the mean return is negative. Figure 2 also plots the fitted margin requirements $\widehat{MA}$. Unlike actual margin requirements, the fitted values change daily, but they follow the movements of actual margin requirements of corn and soybean futures very well. One-sample t-test suggests that the in-sample prediction errors are unbiased, so we use predicted margin requirements in simulation when the actual margin requirements are not available.

Margin Liability Measures

Simulated $\overline{ML}$ and $\widetilde{ML}$ are drawn in figure 3, together with nearby futures prices and margin requirements. The black solid line $\overline{ML}$ measures the average liability to maintain a margin

[5] *t* statistics in parentheses

account. Beginning with corn futures, we observed that its average liability jumps up dramatically after 2007 and exceeds 200 cents/bushel in 2008 for long positions and 2012 for short positions. Meanwhile, a hedger has to borrow \$10000 ($= 200 * 5000/100$) on average to maintain one corn contract. For soybean futures, the average liability of long hedgers was more volatile than that of short hedgers, and was high from 2007 to 2013.

Next, the red dashed line $\widetilde{ML}$ captures the highest liability during a hedge life. It follows the same trend as $\overline{ML}$ but is higher. Figure 3 suggests that mid 2012 is the most risky period for selling corn futures contracts, as it requires a liability above 300 cents/bushel. In other words, a hedger's credit line has to be larger than \$15000 ($= 300 * 5000/100$) to sustain one contract. Mid 2008 is the worst time to buying soybean futures because the maximum margin liabilty exceeded 600 cents/bushel, meaning the hedger's credit line has to be above \$30000 ($= 600 * 5000/100$) to hedge 5000 bushels of soybeans.

[Figure 3 to be here]

According to equations (5) and (6), we simulate borrowing costs for one bushel of corn and soybean futures under different assumptions. The upper left panel of Table 1 reports the means of corn MCs from 2004 to 2017. If hedgers obtain interest from daily surplus, MCs range from -0.12 to 0.91 cents/bushel for long hedges and -0.05 to 0.87 cents/bushel for short hedges. If no interest is earned, the borrowing costs increase to 0.14~1.09 cents/bushel (or 0.05~0.21% of the average price) for long hedgers and 0.13~0.93 cents/bushel (or 0.05~0.13 % of the average price) for short hedgers. The lower panel is about soybean futures. Without interest gain, the borrowing cost range from 0.23 to 2.22 cents/bushel (or 0.02~0.18 % of the average price) for long hedgers and 0.48 to 1.82 (or 0.05~0.12 % of the average price) for short hedgers.

Regardless of different commodities, we find that high-cost years for long hedges are 2008, while for short hedges are 2012.

[Table 1 to be here]

Regarding indirect costs, we report the yearly probabilities of hedging failure at the borrowing constraint c =20%, 25% and 30% of the average prices in Table 1. For example, given the average corn futures price of 247.60 cents/bushel in 2004, the borrowing contranit at c =20% is 49.52 (=247.60*20%). High risks of abandoning corn futures positions are observed when $c = 20\%$. More than a half of simulated long hedges are terminated in 2008 given this borrowing constraint. Risks of failure for short hedgers are relatively high in 2010 and 2012, exceeding 25% if $c = 30\%$ of the average price. The probabilities of hedging failure with soybean futures have the similar pattern as corns except that long hedgers have smaller liquidity risk in the soybean market.

Factors that affect margin liability

Average margin liabilities are used to capture costs of hedging because they are free of assumption of interest rates and borrowing constraints. The research question is how sensitive is the cost to the factors that affect them. We aggregate daily simulated margin liability to weekly frequency and estimate the models in equation (10) and (11). We begin with testing the stationary of weekly margin liability. For each measure, unit root tests consistently reject the null hypothesis that there is a unit root, so we can model these measures in levels. Given there are high cross-sectional dependences between weeks in the same year, we adopt Driscoll and Kraay's method to calculate robust standard errors (Driscoll & Kraay, 1998; Hoechle, 2007).

Pooled OLS models are estimated, and the results of corn futures are provided in the upper panel of table 2. The R-square ranges from 0.243 to 0.910, and it seems that the models for levels (10) fit better than the models for changes (11). Columns (1) and (3) of table 2 show the estimation results of equation (10) for short and long hedges, respectively. We find that the volatility of futures returns has the most substantial impact and it significantly increases weekly average liability for both sides as expected. One standard deviation rise of the futures returns increases the average margin liability of short hedgers by 10.11 cents/bushel and that of long hedgers by 8.43 cents/bushel. Compared to the volatility, effects of price level change and margin requirements are much smaller. The estimated sign of DP_{wy} is significantly positive for short hedges and negative for long hedges, as we expected. With one cent increase in the price level, short $\overline{ML}$ goes up by 0.6 cent per bushel and long $\overline{ML}$ goes down by 0.52 cent. The margin requirement significantly increases average liabilities for all participants, and its coefficients are close to one, meaning a change in per-unit margin requirement results in the similar change in average margin liability.

Columns (2) and (4) show the results of equation (11). Estimated coefficients suggest that, compared to the previous year, one percent increase of volatility increases short hedgers' average margin liability by 3.202%, and 0.761% for long hedgers, *ceteris paribus*. The difference in magnitude may be due to our specific study period. For long hedgers, the elasticity of margin requirement is 1.755, meaning one percent increase of the margin requirement leads to 1.755% increase in $\overline{ML}$. Elasticities of price level change are not statistically significant.

[Table 2 to be here]

The results of soybean futures are reported in the lower panel of table 2. Compared to the corn futures, column (1) and (3) suggest that the effects of volatility on hedging cost with soybean futures are significantly positive and much larger. One standard deviation increase in the volatility results in 23.96 cents increase of short $\overline{ML}$ and 22.55 cents increase for long hedgers. The magnitudes and signs of DP_{wy} and margin requirement are quite similar with the estimated coefficients in corn analysis, and all of them are significant at 1%. Column (2) and (4) show that if the standard deviation of futures returns rises by 1%, the average liability of soybean will go up by 0.953% for short hedgers and 1.067% for long hedgers. The elasticities of margin requirements are also significant. As the margin requirement increases by 1%, short hedgers' average margin liability goes up by 0.21%, while the effect on long hedgers is higher, about 1.14%. Again, percent change in the price level from the previous year only has a minimal impact on the growth of average margin liability.

Implications for hedging participation

Next, we estimate the market participation model, as specified by equation (12) and (13). We test the stationarity of two dependent variables. Unit root tests consistently reject the null hypothesis that there is a unit root. Table 3 reports the estimated coefficient of $\Delta ln\widetilde{ML}_t$. The coefficients in equation (12) and (13) represent elasticities of level and proportion of open interest represented by a trading group with respect to margin liability, respectively. The upper panel reports corn results. For the group of corn producers, merchants and processors, we find 1% increase of margin liability reduces their long positions by 0.058%, and share of open interest by 0.07%. Given an average of 261.386 futures contracts held by this group over our study period, it means 152 positions would be offset. While this increases the long open interest of professional money managers by 0.1% and their share by 0.091%. On the short side, with 1%

increase of margin liability, the first group's positions decrease by 0.049%, and their share of open interest decreases by 0.043%. Predicting this effect at the sample mean of the open interest held by this group, we estimate that an average of 302 short positions would be offset. One additional percent of margin liability increases the open interest of professional money managers by 0.228% and their share by 0.235%.

[Table 3 to be here]

In the lower panel of table 3, we observe the similar patterns in soybean futures. With 1% increase in maximum margin liability, the open interest held by the first group drops 0.083%, and their market share drops 0.091%. For these hedgers with physical commodities, the impact of hedging costs is even more remarkable in soybean markets. Open interest of professional money managers increases with the margin liability, perhaps because their abundant financial resources become a relative advantage over other trader groups, especially when the liquidity risk of hedging is high.

Robustness Analysis

One data limitation of this study is that CME's historical margin requirements of corn futures are not available from 9/20/2007 to 1/2/2009, so we use estimated margin requirements in the simulation. As a robustness checking, we exclude this time period and repeat above analyses. The results are consistent with our main findings. Also, we use average margin liability $\overline{ML}$ to construct the explanatory variable in equation (12) and (13), and check the sensitivity of this specification. The results are quite similar to the main results in table 3. Detailed estimations are not reported in this paper but available upon request.

Conclusion

Hedging with futures is a popular price risk management tool, which may incur substantial liquidity risk when hedgers do not have sufficient funds to meet the margin requirements. Our theoretical framework shows that the liability generated by maintaining a margin account depends on the volatility of futures returns, changes in price levels and margin requirements over the hedge horizon. We then use corn and soybean futures as an example, and simulate margin liabilities, borrowing costs and probabilities of hedging failure over time. Finally, we examine how changes in margin liability affect hedging behavior.

The simulation results suggest that costs of hedging started to increase from 2007 and then declined after 2014. The trend is quite consistent among different commodities: long hedgers faced the highest liquidity risk around financial crisis in 2008, while short hedgers suffered the most around 2012 due to high price volatilities. In these high-risk years, the average margin liability of corn futures exceeded 200 cents/bushel, and a hedger needs about $15000 to sustain a three-month hedge at the worst case. In addition to margin requirements, we find that increasing volatility of futures returns significantly contributes to the hedging costs. For example, one standard deviation increase in the volatility leads to about a 10-cent increase in the per-unit average liability of corn, and 20 cents/bushel in the cost of hedging soybeans. The elasticity of return volatility on soybean margin liability is around 1. Price level changes also affect the cost of hedging, but its effect is relatively small.

Finally, our results suggest that the hedging costs significantly reduce the participation of traders who use futures markets to manage the risk associated with physical commodities, such as producers, merchants, and processors. On average, a 1% increase in margin liability reduces their long open interest of corns by 0.058% (or market share by 0.07%), and short positions by 0.049% (about 302 short positions on average). On the other hand, open interest held by professional money managers increases with margin liability, perhaps because they have sufficient financial resources to face the liquidity risk of hedging.

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Tables

Table 1: Simulated average daily liability and probabilities of hedging failure due to different liability constraints.

Margin cost					Probability of failure				
Year	Long Hedge cents/bu.		Short Hedge cents/bu.		Average price cents/bu.	Long Hedge %		Short Hedge %	
	Eq (5)	Eq (6)	Eq (5)	Eq (6)		20%	30%	20%	30%
Corn Futures									
2004	0.32	0.37	-0.05	0.13	247.60	38.19%	24.02%	6.69%	0.00%
2005	0.18	0.21	0.06	0.13	219.09	15.48%	1.59%	9.13%	0.00%
2006	-0.08	0.14	0.42	0.46	293.27	7.17%	0.00%	38.65%	23.11%
2007	0.20	0.39	0.44	0.55	396.94	38.89%	1.98%	43.65%	19.84%
2008	0.90	1.09	0.12	0.64	522.64	61.51%	45.63%	48.41%	15.87%
2009	0.50	0.59	0.26	0.46	380.17	37.85%	17.93%	32.27%	1.59%
2010	-0.12	0.26	0.83	0.87	474.27	3.23%	0.00%	52.42%	31.45%
2011	0.52	0.66	0.56	0.71	676.23	21.51%	3.98%	16.33%	0.40%
2012	0.32	0.74	0.87	0.93	694.73	8.37%	0.00%	27.89%	25.10%
2013	0.91	0.91	0.26	0.37	521.99	36.90%	3.57%	4.37%	0.00%
2014	0.59	0.65	0.26	0.44	412.50	41.27%	25.79%	19.44%	0.00%
2015	0.49	0.51	0.21	0.27	379.59	7.94%	0.00%	19.44%	0.00%
2016	0.37	0.41	0.28	0.36	363.51	23.81%	9.52%	17.46%	0.00%
2017	0.39	0.39	0.13	0.19	372.21	3.23%	0.00%	0.00%	0.00%
Total	0.39	0.53	0.34	0.47	426.63	24.92%	9.69%	24.20%	8.43%
Soybean futures									
2004	0.74	0.99	0.22	0.59	685.89	44.22%	16.33%	23.11%	4.78%
2005	0.35	0.57	0.41	0.59	620.20	17.86%	5.16%	30.56%	8.33%
2006	0.11	0.34	0.39	0.49	622.21	0.00%	0.00%	13.15%	0.00%
2007	-0.45	0.23	1.56	1.59	954.35	0.00%	0.00%	57.14%	17.06%
2008	1.90	2.22	0.35	1.34	1190.58	49.80%	32.27%	50.60%	8.76%
2009	0.68	1.03	1.21	1.36	1001.39	26.19%	0.00%	29.37%	12.30%
2010	-0.05	0.48	1.67	1.70	1104.01	1.19%	0.00%	40.08%	9.13%
2011	1.28	1.38	0.54	0.87	1303.77	15.08%	3.57%	5.95%	0.00%
2012	0.43	1.09	1.60	1.82	1476.86	10.71%	0.00%	33.73%	9.52%
2013	0.76	0.90	1.28	1.31	1338.21	0.00%	0.00%	4.37%	0.00%
2014	0.99	1.24	0.66	1.00	1160.82	32.14%	2.78%	8.33%	0.00%
2015	0.95	0.98	0.47	0.57	924.45	5.95%	0.00%	0.00%	0.00%
2016	0.43	0.73	1.07	1.18	1007.89	8.33%	0.00%	23.41%	6.75%
2017	0.98	1.02	0.31	0.48	973.82	0.00%	0.00%	0.00%	0.00%
Total	0.64	0.94	0.85	1.08	1027.26	15.11%	4.29%	22.87%	5.48%

Table 2: Estimation results of margin liability for corn futures

Corn model	Short $\overline{ML}$	Short $\Delta\overline{ML}\%$	Long $\overline{ML}$	Long $\Delta\overline{ML}\%$
S_{wy}	10.11***		8.430***	
	(14.16)		(12.47)	
DP_{wy}	0.600***		-0.517***	
	(46.05)		(-41.93)	
MR_{wy}^{m}	0.897***		1.030***	
	(17.82)		(21.61)	
$\Delta S_{wy}\%$		3.202***		0.761***
		(14.23)		(4.24)
$\Delta DP_{wy}\%$		-0.00187		-0.00399
		(-0.55)		(-1.48)
$\Delta MR_{wy}^{m}\%$		-0.204		1.755***
		(-1.58)		(16.98)
Constant		0.624***		0.271***
		(7.58)		(4.13)
N	694	642	694	642
adj. R^2	0.910	0.243	0.924	0.370
Soybean model				
S_{wy}	23.96***		22.55***	
	(17.04)		(18.17)	
DP_{wy}	0.587***		-0.550***	
	(50.15)		(-53.27)	
MR_{wy}^{m}	0.874***		0.894***	
	(20.39)		(23.64)	
$\Delta S_{wy}\%$		0.953***		1.067***
		(6.33)		(5.73)
$\Delta DP_{wy}\%$		-4.03e-09**		1.54e-09
		(-2.52)		(0.78)
$\Delta MR_{wy}^{m}\%$		0.210**		1.140***
		(2.39)		(10.48)
Constant		0.477***		0.405***
		(8.46)		(5.81)
N	713	661	713	661
adj. R^2	0.934	0.101	0.943	0.255

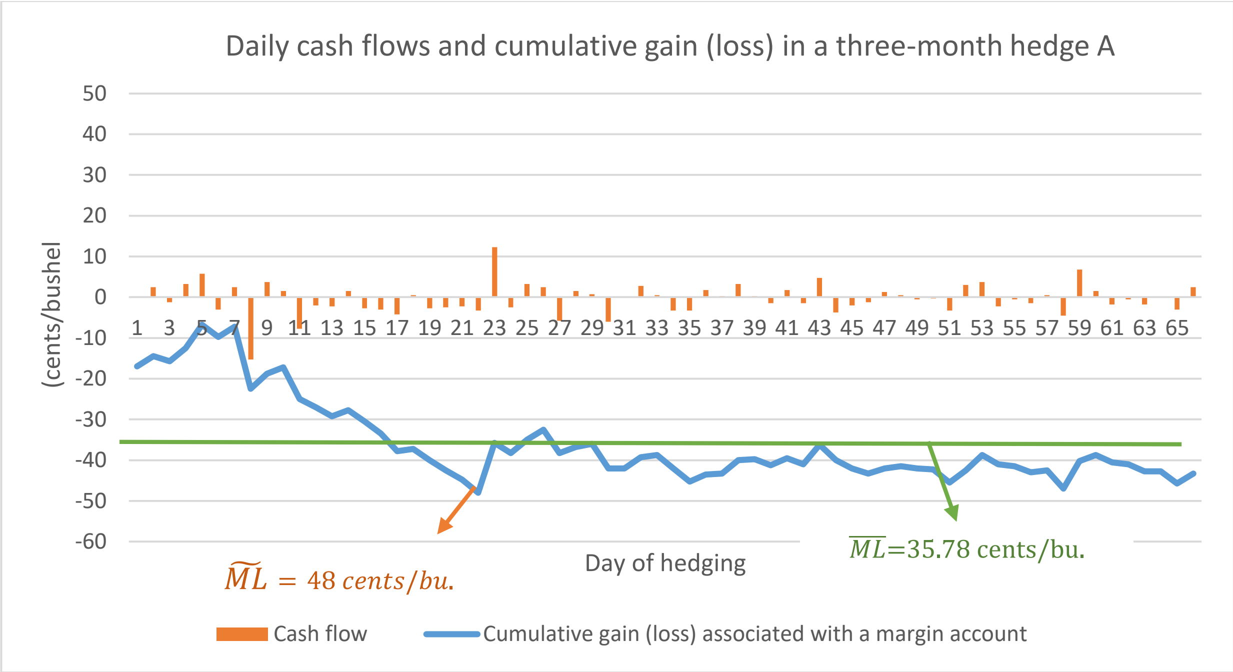
Note: *t* statistics in parentheses: * $p < .1$, ** $p < .05$, *** $p < .01$

Table 3: Estimated coefficient of $\Delta ln\widetilde{ML}_t$ for corn futures market participation

	Long Hedge			Short Hedge		
Dep. Var.	Producer.etc	Swap Dealer	Managed Money	Producer, etc.	Swap Dealer	Managed Money
Corn						
$\Delta lnOI_w$	-0.058***	0.008	0.100***	-0.049***	-0.130	0.228***
	(-7.56)	(1.64)	(11.36)	(-7.01)	(-1.25)	(7.00)
$\Delta lnOI_w\%$	-0.07***	-0.003	0.091***	-0.043***	-0.118	0.235***
	(-11.30)	(-0.40)	(11.49)	(-0.56)	(-1.16)	(7.31)
Soybean						
$\Delta lnOI_w$	-0.083***	0.024***	0.147***	-0.062***	0.009	0.201***
	(-7.02)	(3.93)	(11.33)	(-5.95)	(0.06)	(4.77)
$\Delta lnOI_w\%$	-0.097***	0.008	0.136***	-0.044***	0.032	0.218***
	(-9.44)	(0.94)	(10.95)	(-5.55)	(0.19)	(5.09)

t statistics in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

Figures



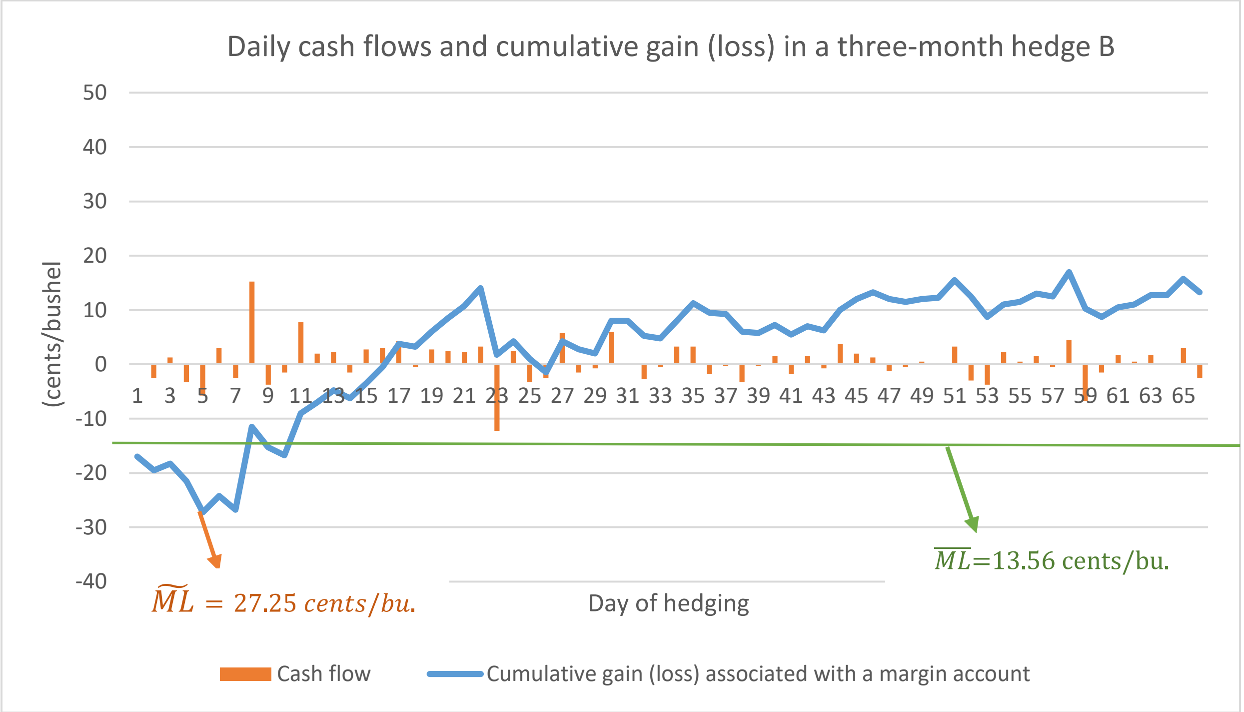
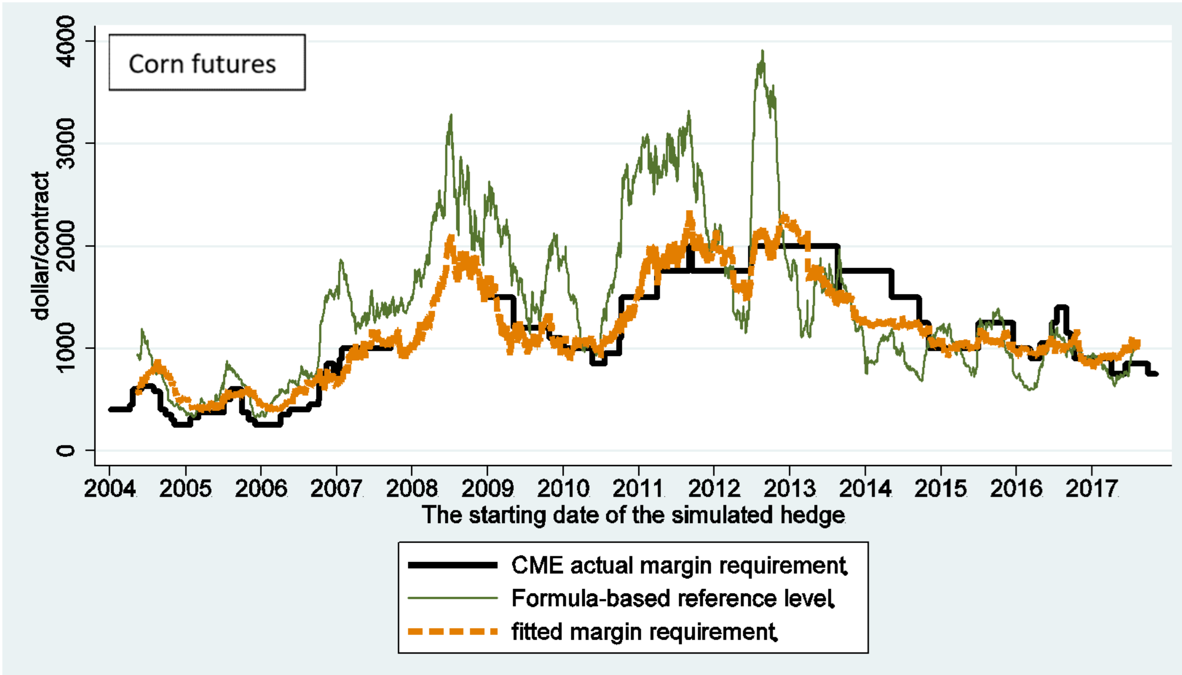


Figure 1: Daily cash flows, cumulative gains (losses) and margin liabilities in two hedges as an illustration.



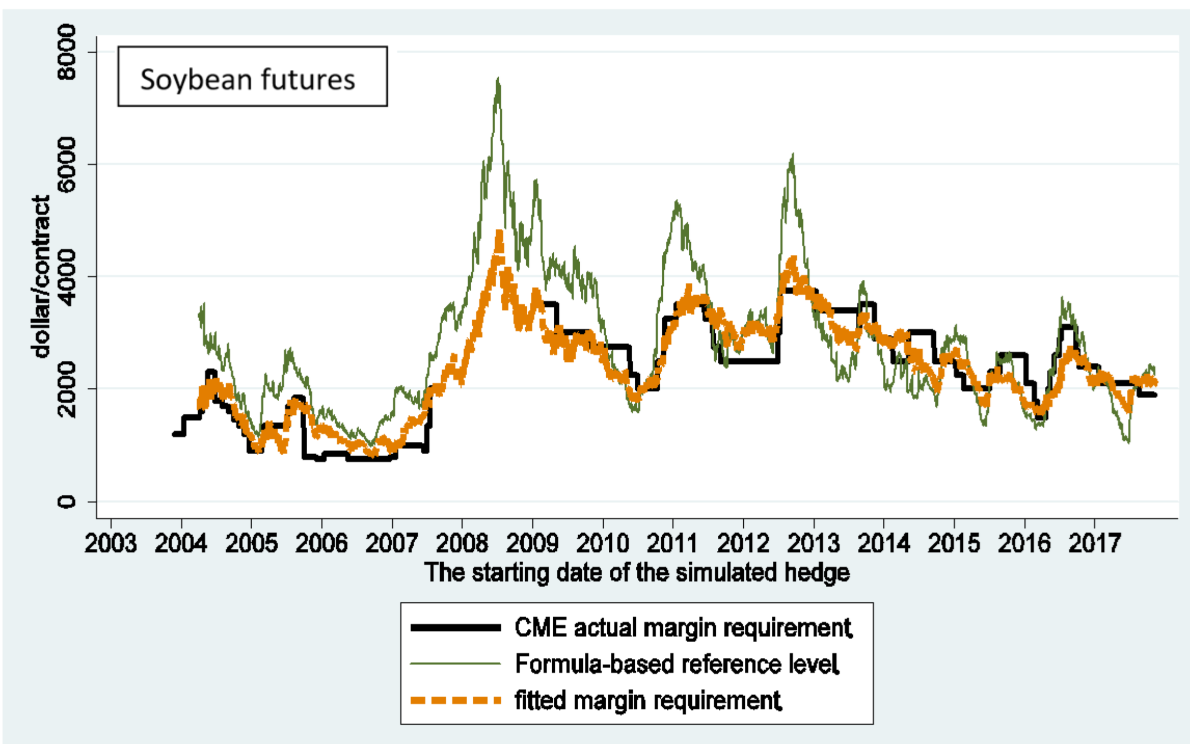


Figure 2: Historical margin requirements from CME, benchmark margins, and fitted margin requirements

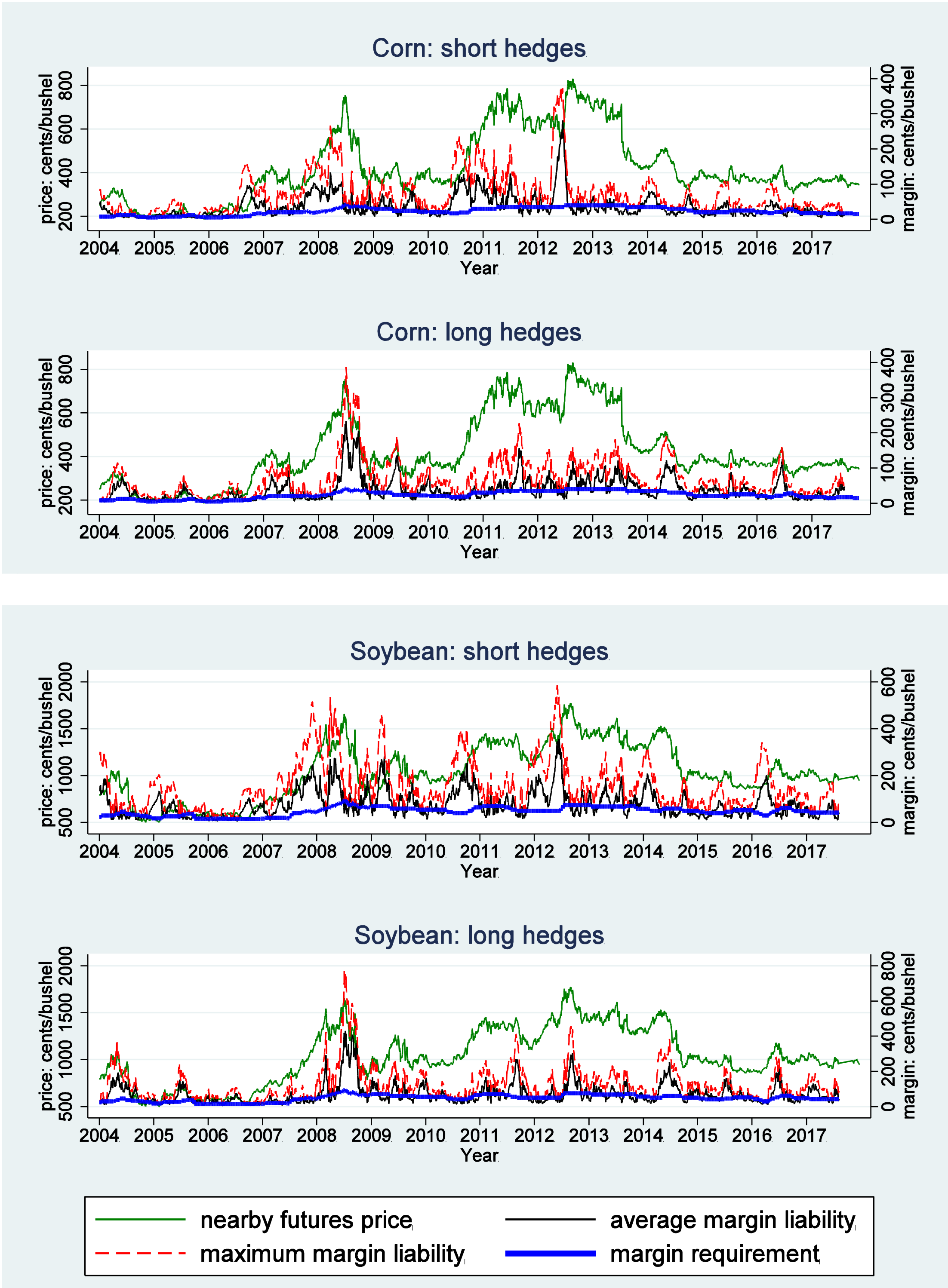


Figure 3: Prices of nearby corn futures, margin requirements, and simulated margin liabilities, 2004-2017