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ABSTRACT

Margin regulation raises two policy concerns. First, an alignment of margins to volatility can amplify procyclicality, leading to a build-up of excess leverage in good times and a forced deleverage in bad times. Second, competition among central counterparties (CCPs) can result in lower margin levels in order to attract more trading volume, which is referred to as a "race to the bottom." Motivated by these issues, we empirically analyze the determinants of margin changes by using a data set of various futures margins from Chicago Mercantile Exchange (CME) Group. We first find that CME Group raises margins quickly following volatility spikes but does not immediately lower margins following volatility declines, implying that margin-induced procyclicality is more of a concern in recessions than in expansions. In addition, we find some evidence that the margin difference between CME Group and its competitor, Intercontinental Exchange (ICE), is an important driver of margin changes after changes in other margin determinants are controlled for, implying that competition may be factored into margin setting.

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1 Introduction

The recent collapses of financial conglomerates such as Bear Stearns and Lehman Brothers demonstrated that the opaque, complex interconnections among financial institutions adversely affect market liquidity and induce fire sales during a financial crisis. In response, Title VII of the Dodd-Frank Act requires that standardized over-the-counter (OTC) derivative contracts be cleared through CCPs.[1] The reform is grounded in the conventional wisdom that central clearing can help reduce systemic risk. For example, central clearing can help mitigate counterparty credit risk by removing the direct risk exposure between counterparties, making it easy for regulators to monitor and limit excessive risk taking. In addition, central clearing can reduce the total amount of margin needed to mitigate counterparty risk by allowing for multilateral netting (see Duffie and Zhu (2011)).

However, despite the merits of central clearing, the success of the new regulation hinges on the effectiveness of the risk management tools that CCPs adopt as they bear all the counterparty risk arising from cleared derivative transactions. To help ensure this result, Title VIII of the Dodd-Frank Act reinforces the role of supervisory agencies over the CCPs that are designated as systemically important by the FSOC (Financial Stability Oversight Council). Under this rule, the regulators have the responsibility of examining and approving the margin requirements of CCPs.[2] Against this backdrop, from a regulator's perspective, it is important to understand the determinants of margin changes and their impact on the financial system.

Specifically, the objective of this paper is to analyze the margin setting methods used by CME Group, which is both a CCP and a futures exchange, and evaluate their implications for financial regulation.[3] We will focus on two specific issues related to margin setting. First, we investigate whether CME Group makes immediate margin changes in response to volatility changes for various futures contracts. The margin

[1]This reform was initially decided on by the Group of Twenty (G20) in September 2009, and once it takes effect, about 46 percent of the current notional value of OTC derivatives is expected to be centrally cleared as reported in a quantitative impact study by BCBS and IOSCO (2013).

[2]The scope of supervision goes beyond the margin requirements, covering collateral requirements, default fund management, and the clearing and settlement procedures.

[3]CME Group provides clearing services through the in-house clearing division. Besides, it was formed when CME and CBOT (Chicago Board of Trade) merged in 2007, and it later acquired NYMEX (New York Mercantile Exchange) and COMEX (Commodity Exchange), in March 2008, and KCBOT (Kansas City Board of Trade), in December 2012.

data comprise 15 futures contracts spanning five asset classes including equity index, currency, metal, energy, and agriculture. Second, we examine whether competition among CCPs is factored into margin setting to attract more trading volume. To do this we collect an additional data set of margins for the energy futures from ICE, a rival of CME Group, and then examine whether the margin difference between CME Group and ICE is an important driver of margin changes even after changes in other margin determinants are controlled for.

The first issue is related to the concern that an alignment of margins to volatility can amplify procyclicality in the financial system. It is widely believed that CCPs raise (lower) margins following volatility increases (decreases) in order to keep the probability of margin shortfall that futures price varies more than margin requirements over a close-out period at a certain level over time. If this is the case, investors is allowed to take more leverage in times of low volatility and forced to deleverage their risk exposure in times of high volatility to meet margin calls (see, for example, Committee on the Global Financial System (2010)). This procyclical effect can be further exacerbated through an interacting spiral between funding liquidity and market liquidity as explained by Brunnermeier and Pedersen (2009).

The second issue is motivated by the concern over a "race to the bottom" in which competition among CCPs can result in lower margin levels in order to attract more trading volume.[4] As reported by Hardouvelis and Kim (1995) and Ito and Lin (2001), margin changes affect the volume of trades. In light of this apprehension, the Brady Report published in the wake of the 1987 crisis suggests that margins be harmonized across closely related markets. Therefore, another goal of this paper is to investigate whether competition is factored into margin setting after changes in other determinants are accounted for.

It is important to note that CME Group makes margin changes infrequently. To assess the frequency of margin changes, we compute the average number of days between margin changes for each futures contract. For example, the average number of days between margin changes is on the order of three quarters for the equity futures and on the order of two and a half months for the agriculture futures. The currency,

[4]Santos and Scheinkman (2001) present a model of financial intermediation in which margin requirements can be used as a screening device when clearing members' credit quality is private information, and show that there will be a "race to the bottom" if the exogenous bankruptcy penalty is low.

metal, and energy futures fall in between. These infrequent margin changes imply that CME Group considers increasing or decreasing margin requirements only when margin determinants change beyond certain threshold levels. For this reason, our empirical analysis is based on the assumption that there will be a margin increase only if a latent margin change indicator rises above an upper threshold; a margin decrease only if a latent margin change indicator drops below a lower threshold; and no margin change otherwise.

Our empirical results are twofold. First, the relation between margin changes and volatility changes is asymmetric. CME Group tends to raise margin requirements as volatility increases beyond a certain positive threshold. However, puzzlingly, it does not lower margin requirements even when volatility drops below a certain negative threshold for all of the futures contracts that we consider, except for the corn futures. These results are robust to changes in control variables such as jump risk, market liquidity, and funding liquidity. As a consequence, during economic downturns, clearing members are likely to be forced to deleverage their risky investments, as CME Group raises margins immediately in response to volatility increases. However, during economic expansions, they would not be able to increase their leverage, as CME Group tends to maintain the current margin levels for a while despite volatility decreases.

Second, we find some evidence that the margin difference between CME Group and ICE is an important driver of margin changes even after changes in other risk factors are accounted for. Specifically, CME Group tends to lower its margins when it has higher margin levels than ICE. This is a particularly interesting fact because the margin difference is the only factor that we find to be statistically significant in explaining CME Group's margin cuts at 95 percent or higher confidence levels. On the other hand, ICE tends to raise its margins when it has lower margin levels than CME Group. Overall, these results indicate that competition among CCPs is a significant driver of the current margin levels.

This paper is broadly related to the literature on the margin-volatility relation. Just after the market crash of October 1987, there was heated debate over whether the credit-financed speculation in the stock markets had an adverse effect on the stability of the financial system, driving asset prices out of the fundamental levels. To understand this issue, many researchers examined whether the margin requirements set by the Federal Reserve System affected stock market volatility. The results are mixed. Some authors such as Hardouvelis (1990) and Hardouvelis and Theodossiou (2002) find positive answers, whereas others, such as Schwert (1989), Kupiec (1989), Salinger (1989), and Hsieh and Miller (1990) show inclusive results. Note that this paper is distinct from the existing papers in two main respects. First, we focus on the other side of the margin-volatility relation—whether volatility changes affected margin changes. Second, our application looks at margin requirements in the futures markets rather than the stock markets.

The rest of this paper is organized as follows. Section 2 provides a brief overview of how a margin system works. Section 3 describes the construction of three volatility proxies that are used in our empirical analysis. Section 4 explains the margin data and shows some preliminary analysis of margin changes. The main empirical results are provided in Section 5. Finally, Section 6 provides a summary of the results and policy considerations.

2 Overview of margin requirements

The safeguards used by CCPs include, but are not limited to, collecting margins and guaranty funds, restricting the range of acceptable collateral, and setting forth minimum membership criteria. Of particular interest in this paper are margin requirements, or performance bonds. There are three types of margin requirements: initial, maintenance, and variation margins. Initial or maintenance margins are collected to cover the potential future loss that may arise in the event of a clearing member's default, whereas variation margins are collected to cover realized losses that have already occurred. Specifically, the initial margin is the amount of margin required at the opening of a trading account, whereas the maintenance margin is the least amount of margin that should be maintained throughout the life of a trading account. If the balance of a trading account is lower than the maintenance margin, then a clearing member is required to post a variation margin to bring the balance back to the initial margin. Margins thus play a crucial role in guaranteeing contractual obligations by ensuring that both realized and future losses will be covered.

Margins differ depending on whether the purpose of a trading account is hedging or speculation and according to specifications in some futures contracts. Typically, maintenance margins for speculation, initial margins for hedging, and maintenance margins for hedging are all identical; only initial margins for speculation differ from and are higher than the other three. For illustration, for the Nasdaq 100 futures contract on September 24, 2012, CME Group set the initial and maintenance margins for speculation at $11,000 and $10,000 per contract, respectively, and set both the initial and maintenance margins for hedging at $10,000 per contract. Margins differ by time to maturity for some asset classes such as energy, metal, and agriculture futures. For agriculture futures margins also depend on whether they are old or new crops.

Let us illustrate how a margin system works. Suppose that a speculator buys one Nasdaq 100 futures contract and that the initial and maintenance margins for speculation are currently set at $11,000 and $10,000 per contract. The speculator has to put up an initial margin equivalent to $11,000 at the close of today. Consider a situation where the futures price drops by 5 points the next day. As the contract size of the Nasdaq 100 futures is 100, the 5-point drop corresponds to a loss of $500, and so the remaining balance of the trading account is $10,500. As the remaining balance is still higher than the maintenance margin level, no margin call will be issued in this case. Now consider another situation where the futures price drops by 20 points the next day. The 20-point drop corresponds to a loss of $2,000, and so the remaining balance of the trading account is $9,000. As the remaining balance is lower than the maintenance margin level, a margin call will be issued in this case. That is, the speculator will be called upon to post an additional margin—a variation margin—equivalent to $2,000 in order to bring the balance back to the initial margin level.

3 Volatility measures

Volatility is considered the most important determinant of margin requirements. For example, some authors, such as Figlewski (1984), Gay, Hunter, and Kolb (1986), and Fenn and Kupiec (1993), use a normal distribution model that suggests that margin levels be proportional to the level of volatility, while others, such as Cotter (2001) and Longin (1999), use extreme value theory to capture the tails of return distributions. Yet, little is known about what kind of a volatility proxy has been used in margin setting by CCPs. Hence, we consider three different measures of volatility:

exponentially weighted moving average (EWMA) volatility, range-based EGARCH volatility, and high-frequency-based realized volatility (RV). The frequency of all the volatility measures is daily.

3.1 Exponentially weighted moving average

The first volatility measure applied in our margin analysis is exponentially weighted moving average volatility. We choose to consider this measure because it is easy to compute and widely implemented in practice.[5] Given today's EWMA volatility, the next day's EWMA volatility is recursively computed as

$$\text{EWMA}_t^2 = \lambda \cdot \text{EWMA}_{t-1}^2 + (1-\lambda) \cdot r_t^2, \tag{1}$$

where r_t is the return at time t and λ is a constant between 0 and 1 that represents the weight given to previous volatility estimates relative to a new innovation. In our analysis, we opt to set $\lambda = 0.98$ for higher statistical significance.[6] Additionally, EWMA_0 is initialized by computing the historical standard deviation of returns over the past year:

$$\text{EWMA}_0 = \sqrt{\frac{\sum_{t=1}^{k}(r_t - \widehat{\mu})^2}{(k-2)}}, \tag{2}$$

where $\widehat{\mu}$ is the sample mean of returns over the past year and $k = 252$ for the number of business days in a year.

EWMA volatility is computed using the front-month futures price data that are obtained from Thomson Reuters Datastream. For each futures contract the data comprise open, high, low, and settlement prices, as well as volume and open interest. Some filters are applied to clean the data. Specifically, we exclude the observation if the high price is less than the low price, or if either the high or low price is less than or equal to 0. To get rid of stale prices, we also exclude the observation if the trading volume is less than 10.

[5] For example, it is used in the RiskMetrics solution of J.P. Morgan.

[6] We test $\lambda = 0.97$, $\lambda = 0.98$, and $\lambda = 0.99$ and find that $\lambda = 0.98$ results in the highest statistical significance.

3.2 Range-based EGARCH

For our second volatility proxy, we compute the range-based, one and two-factor EGARCH models of Brandt and Jones (2006) among the variants of the GARCH (generalized autoregressive conditional heteroskedasticity) model. We apply the one-factor model to the currency, metal, energy, and agriculture contracts, and the two-factor model to the equity index contracts.

The range, denoted by d_t, is defined as the difference between the day's high and low prices. The range-based volatility estimator has practical and econometric advantages over daily-return-based or high-frequency-based estimators.[7] The range data are available over a longer history than the high-frequency data.[8] Brandt and Diebold (2006) show that a range-based volatility estimator is robust to market microstructure noises such as bid-ask bounces and nonsynchronous trading, unlike a high-frequency-based estimator. Most importantly, a range-based estimator is five times more efficient than its daily-return-based counterpart, and has the same efficiency as the volatility measures computed using three- or six-hour intraday returns (see Parkinson (1980) and Brandt and Jones (2006)).

The range-based EGARCH models are based on the property that the log range can be approximated by a normal distribution:

$$\log d_t \sim \mathcal{N}(0.43 + \log h_t, 0.29^2), \tag{3}$$

where h_t is the volatility state and $\mathcal{N}$ stands for a normal distribution. The two-factor EGARCH model, which is applied to the equity index contracts, allows for time-variation in the long-run mean of h_t. It takes the following form of volatility dynamics:

$$\begin{aligned} \log h_t - \log h_{t-1} &= \kappa_h(\log q_{t-1} - \log h_{t-1}) + \phi_h X^d_{t-1} + \delta_h r_{t-1}/h_{t-1} \\ \log q_t - \log q_{t-1} &= \kappa_q(\log \overline{q} - \log q_{t-1}) + \phi_q X^d_{t-1} + \delta_q r_{t-1}/h_{t-1} \\ X^d_{t-1} &= \frac{\log d_{t-1} - 0.43 - \log h_{t-1}}{0.29}, \end{aligned} \tag{4}$$

[7] See, for example, Brunetti and Lildholdt (2007).

[8] For example, ranges have been publicized for many decades in the financial press, often in the form of candlestick charts.

where q_t denotes the stochastic long-run mean, κ_h and κ_q are speeds of mean reversion for volatility and long-run volatility, respectively, ϕ_h and ϕ_q are volatility of volatility parameters, $\overline{q}$ is the long-term mean of long-run volatility, and δ_h and δ_q capture the leverage effect, which is the negative correlation between changes in prices and volatility.

The one-factor EGARCH model, which is applied to all of the other contracts, takes a simpler form of volatility dynamics:

$$\log h_t - \log h_{t-1} = \kappa_h(\log \overline{h} - \log h_{t-1}) + \phi_h X_{t-1}^d + \delta_h r_{t-1}/h_{t-1}, \tag{5}$$

where $\overline{h}$ denotes the long-term mean of volatility and we set $\delta_h = 0$ when there is no substantial leverage effect, in cases such as the currency futures.

We estimate the range-based EGARCH models using the maximum likelihood method with the optimizer of Berndt, Hall, Hall, and Hausman (1974). Note that we recalibrate the models on each date only using the information that is available up to that date so that the volatility state is truly observable at the time of CME Group's decision making. We denote by EGARCH_t the one-step-ahead volatility forecast.

3.3 Realized volatility and jump variation

CME Group states that it looks at intraday volatility as well as historical volatility.[9] As our third volatility proxy, we take a monthly measure of realized volatility, following Andersen, Bollerslev, Diebold, and Ebens (2001), Andersen, Bollerslev, Diebold, and Labys (2003), and Barndorff-Nielsen and Shephard (2002). Realized volatility, denoted by RV_t, is obtained by summing the squared five-minute futures returns over the past 21 trading days on each date:

$$\text{RV}_t \equiv \sum_{i=1}^{21} \sum_{j=1}^{1/\Delta} \Big(f_{t-i+j\Delta} - f_{t-i+(j-1)\Delta} \Big)^2, \tag{6}$$

where f_t denotes the log futures price and Δ is the sampling interval for the intraday data.

We also compute the high-frequency-based jump variation because jump risk may

[9]See "Quick Facts on Margins at CME Clearing," CME Group, July 2011.

be accounted for in margin setting. To compute the jump variation we first obtain a daily measure of realized volatility, denoted by $\mathrm{RV}_t^{(d)}$, by summing the squared five-minute futures returns on each date:

$$\mathrm{RV}_t^{(d)} \equiv \sum_{j=1}^{1/\Delta} \Big(f_{t-1+j\Delta} - f_{t-1+(j-1)\Delta} \Big)^2. \tag{7}$$

Next, we compute a daily measure of the bipower variation, denoted by $\mathrm{BV}_t^{(d)}$, using the approach of Barndorff-Nielsen and Shephard (2004):

$$\mathrm{BV}_t^{(d)} \equiv \frac{\pi}{2} \sum_{j=2}^{1/\Delta} \left| f_{t-1+j\Delta} - f_{t-1+(j-1)\Delta} \right| \left| f_{t-1+(j-1)\Delta} - f_{t-1+(j-2)\Delta} \right|. \tag{8}$$

A daily measure of jump variation, denoted by $\mathrm{JV}_t^{(d)}$, is then defined by subtracting a daily measure of bipower variation from a daily measure of realized volatility, with a floor of zero:

$$\mathrm{JV}_t^{(d)} \equiv \max(\mathrm{RV}_t^{(d)} - \mathrm{BV}_t^{(d)}, 0). \tag{9}$$

Finally, a monthly measure of the jump variation, denoted by JV_t, is obtained by summing the daily jump variations over the past 21 trading days:

$$\mathrm{JV}_t = \sum_{i=1}^{21} \mathrm{JV}_{t-i+1}^{(d)}. \tag{10}$$

The five-minute intraday futures price data are obtained from Thomson Reuters Tick History. Because there are two trading sessions, Globex and regular pit trading, we use the composite series, which combines both sessions. For all of the contracts that we consider, except for the metal futures, we use the nearest-month contracts. For the metal contracts, we use the volume-based roll method instead of the nearest-month-based roll method because the former allows for more data than the latter. Even though we use composite prices, we include observations only for pit trading hours for each futures contract because illiquid overnight trading may not represent prices well. Pit trading hours differ by futures contracts, as can be seen in Table 1.

4 Margin data and preliminary analysis

This section describes the margin data collected from CME Group and shows some preliminary results such as summary statistics for the margin changes and the probability of margin shortfall.

4.1 Margin data

For the empirical analysis, we choose CME Group's futures contracts that cover five different asset classes, including stock index, currency, metal, energy, and agriculture. Within each asset class, we choose the three most representative futures contracts. We choose the S&P 500, the Nasdaq 100, and the Dow Jones for stock index futures; the British pound, the euro, and the Japanese yen for currency futures; gold, silver, and copper for metal futures; WTI crude oil, RBOB gasoline, and heating oil for energy futures; and corn, wheat, and soybean for agriculture futures. Specifications of each contract are provided in Table 1.

CME Group publishes historical margin requirements for its futures contracts.[10] Usually CME Group first sets maintenance margins and then sets initial margins by scaling up the maintenance margins; the ratio of the initial to maintenance margins remains constant for a specific contract most of the time. For this reason, the empirical analysis that follows is based on maintenance margins only.

We set a few rules to ensure that we are collecting comparable margins for each contract over time. For both metal and energy asset classes, margins are different depending on the tier or month of the contract; we collect the margin data only for the front month or top tier contract. For the metal contracts, we record the margin data if tier 1 or month 1 is specified or if there is no specification of tier or month, and we also accept the margin data if month 1-4 is specified instead of just month 1. For the energy contracts, we only collect the margin data if month 1 is clearly specified. If the month is not listed, we do not record the margin data for that date. For agriculture contracts, margins are differently set for new- and old-crop contracts, although these margins are rarely different. We choose to use the margin data only for old-crop contracts in our empirical analysis. If neither old nor new is specified,

[10] Historical margin data are available at
`http://www.cmegroup.com/clearing/risk-management/historical-margins.html`.

we assume it is old and still collect the margin data. Note that we collect month 1 contracts here too. For the corn futures, for example, when old or new is not specified, sometimes month 1 will be noted and we record the margin data.

The margin data start on different dates for the various contracts included in our sample but extend through July 2013 for all contracts. Hence, our sample period ends on July 31, 2013 with the longest sample period being approximately $13\frac{1}{2}$ years and the shortest sample period being approximately four and a half years. The first sample date for each contract is listed in Table 2. Note that the margin data have daily frequency as with the volatility measures. Figures 1 through 5 compare margins to volatility (left panels) and to futures prices (right panels) for the stock index, currency, metal, energy, and agriculture futures, respectively.

4.2 Summary statistics of margin changes

Throughout the paper we use M_t to denote the margin level at time t and define it as

$$M_t = \frac{\tilde{M}_t U_t}{C_t}, \tag{11}$$

where $\tilde{M}_t$ denotes the maintenance margin per contract as reported on the CME Group website; U_t denotes the pricing unit, either dollars (1) or cents (0.01); and C_t denotes the contract size. Both contract size and corresponding pricing unit are listed in Table 1. Finally, throughout the paper we define a margin change as the difference in the logarithms of margins:

$$\Delta \log M_t = \log\left(\frac{M_t}{M_{t-1}}\right). \tag{12}$$

While the margin changes are obtained on a daily basis, they are zero for most of the days because CME Group infrequently changes margins. In other words, there are only a few days when the margin changes are nonzero. In Table 2, we present summary statistics only on the nonzero margin changes for each futures contract. The third column reports the total number of the nonzero margin changes that have been made throughout the sample period for each futures contract, while the fourth and fifth columns break down the number into the number of increases and the number of decreases, respectively. These numbers clearly show that very few margin changes have been made, whether decreases or increases. For example, there have been just six margin increases and eight margin decreases for the S&P 500 index futures over the past $13\frac{1}{2}$ years.

In the sixth column, we present the average number of days between margin changes for each futures contract, which indicates the frequency with which CME Group makes margin changes. Interestingly, these numbers vary across asset classes but are very similar within each asset class. For example, for stock index contracts the average number of days between margin changes is on the order of three quarters, while for agriculture contracts, margin changes are made around every two and a half months. The currency, metal, and energy futures fall in between.

Another interesting feature revealed by the table is that once CME Group has decided to change the current margin, it makes a large adjustment. The seventh and eighth columns in Table 2 report average margin increases and decreases, respectively, for each futures contract. The average margin increases across different futures contracts range from 10 to 25 percent except for the heating oil futures, and the all-contract average is around 18.9 percent. The average margin decreases across different futures contracts range from -10 to -25 percent, and the all-contract average is -16.7 percent. This feature can be confirmed by the histogram of the margin changes for all futures contracts shown in Figure 6. The histogram shows that most of the margin changes are concentrated in the ranges of plus and minus 10 to 25 percent and that there are very few observations of small margin changes.

All in all, margins are sticky. This can be explained by the fact that margin changes can incur operational costs to CME Group and have material financial impacts on its clearing members. In an effort to minimize the side effects of margin changes, CME Group makes margin changes only when margin determinants change beyond certain threshold levels, which takes place infrequently. This feature is very important in analyzing the determinants of margin changes, which will be clarified in Subsection 5.2.

4.3 Probability of margin shortfall

As stated earlier, CCPs usually set margins to ensure that futures price swings can be covered over a specific close-out horizon at a certain confidence level. CME Group documents that margins are set to cover 99 percent of potential price swings (the close-out horizon is not specified).[11] The confidence level is a key variable in margin calculations and is ultimately associated with the extent of risk that the CCP bears.

To understand CME Group's degree of risk tolerance, we look at the probability of margin shortfall, or the probability that future prices vary more than what its margin requirements cover over a one- or three-day close-out horizon. This is equal to one minus the associated confidence level. Computing the probability of margin shortfall requires full knowledge of return distributions. For simplicity, we assume that futures returns follow a normal distribution with mean zero and standard deviation measured by EWMA volatility. This assumption allows us to compute the probability of margin shortfall over the horizon τ, denoted by $\alpha_{t,\tau}$:

$$\alpha_{t,\tau} = \Phi\left(\log\left(\frac{F_t - M_{t+2}}{F_t}\right); 0, \sqrt{\tau}\mathrm{EWMA}_t\right), \tag{13}$$

where F_t is the futures price and Φ stands for the standard normal cumulative distribution function. Notice that we use the two-day-ahead margin level, M_{t+2}, because we assume that M_{t+2} is already determined at time t. This will be explained in Subsection 5.1. Also note that we compute the probability of margin shortfall only when margin changes are actually made.

Table 3 reports the mean, minimum, and maximum of the probability of margin shortfalls for each futures contract. The left panel of the table corresponds to a one-day close-out horizon, and the right panel corresponds to a three-day close-out horizon. The table shows that the probability of margin shortfall varies across asset classes, implying that CME Group takes different levels of risk tolerance for different asset classes. For the stock index contracts, the mean of the one-day probability of margin shortfall is much lower than 1 percent, implying that CME Group sets margins very conservatively for these contracts. The mean of the one-day probability of margin shortfall is 0.03 percent for the S&P 500, 0.12 percent for the Nasdaq 100, and 0.05 percent for the Dow Jones. The metal futures are another case in which CME Group sets margins conservatively. The conservative margin setting for the equity and metal futures can be in part attributed to the fact that those contracts usually have higher levels of jump risk relative to the others. In contrast, for the agriculture contracts, the mean of the one-day probability of margin shortfall is higher than 1

[11] See `http://archive.opnmkts.com/clearing/understanding-margin-changes`.

percent, implying that CME Group sets margins much less conservatively for these contracts. The mean of the one-day probability of margin shortfall is 1.75 percent for corn, 1.79 percent for wheat, and 1.19 percent for soybean. For currency and energy contracts, CME Group sets the probability of margin shortfall close to 1 percent, on average.

Figure 7 presents a scatter plot of the mean of the probability of margin shortfall against the average number of days between margin changes across different futures contracts. This plot indicates that there is a negative relation between these variables. That is, the higher the probability of margin shortfall the smaller the average number of days between margin changes. The negative relation indicates that there are some futures contracts for which CME Group sets the probability of margin shortfall more conservatively and makes margin changes less frequently, and other futures contracts for which CME Group sets the probability of margin shortfall less conservatively and makes margin changes more frequently.

5 Empirical analysis of margin changes

This section aims to understand the determinants of futures margin changes and draw policy implications for financial stability policy. Specifically, we examine the asymmetric relation of margins to volatility and the effects of competition between CME Group and ICE on margin setting.

5.1 Determinants of margin levels

Although our main interest is to understand the determinants of margin changes, we start by examining the determinants of margin levels. To do this, we run the following linear regression for each futures contract:

$$\begin{aligned} M_t = {} & \beta_0 + \beta_1 \mathrm{EWMA}_{t-2} + \beta_2 \mathrm{EGARCH}_{t-2} + \beta_3 \mathrm{RV}_{t-2} + \beta_4 \mathrm{PRC}_{t-2} \\ & + \beta_5 \mathrm{JV}_{t-2} + \beta_6 \mathrm{VLM}_{t-2} + \beta_7 \mathrm{OI}_{t-2} + \beta_8 \mathrm{TED}_{t-2} + \varepsilon_t, \end{aligned} \tag{14}$$

where EWMA_t is the EWMA volatility, EGARCH_t is the range-based EGARCH volatility, RV_t is the realized volatility, PRC_t is the futures price, JV_t is the jump variation, VLM_t is the trading volume, OI_t is the open interest, and TED_t is the TED spread.

While we suspect volatility is the most important determinant of margin requirements, it is not known what kind of a volatility proxy has been used in setting margins by CCPs. Thus, we consider three choices of a volatility proxy—EWMA, EGARCH, and RV—in the regressions. Table 4 shows correlations across the three volatility proxies for each contract. The table shows that the correlations range from 0.65 to 0.97 depending on contracts. Although the correlations are sometimes as high as 0.95, we do not experience a singularity issue in the regression of the margin levels.

We also add to the regression other variables that CME Group may consider in setting margins, including futures price, jump variation, trading volume, open interest, and TED spread. In particular, futures prices should be an important factor in setting margins because futures margins are specified in dollar amounts but not in percentage terms. For example, if futures returns are assumed to follow a normal distribution, margins should be linearly proportional to futures prices. Jump variation is included to see if CME Group takes into account jump or tail risk. Lastly, trading volume and open interest are included as measures of market liquidity, and TED spreads are included as a measure of funding liquidity.

It is very important to note that explanatory variables are lagged by two business days. We do this because CME Group is obligated to announce a margin change at least 24 trading hours in advance to give clearing members sufficient time to assess its financial impact and prepare for it. On top of that, CME Group needs time to decide upon a margin change and make an announcement for it. For this reason, we assume that CME Group uses information that it currently has at the close of today to set margins that will be effective in two business days.[12]

Table 5 presents the linear regression results with Newey and West (1987) robust t statistics (10 lags). EWMA is the only volatility proxy that is statistically significant at a 99 percent confidence level for every contract and that consistently has a positive coefficient for every contract. This is not always the case with the EGARCH and RV volatility proxies. For EGARCH, 7 out of 15 contracts lack statistical significance, 6 out of 15 are statistically significant at 95 percent confidence levels, and only 2 out of 15 are statistically significant at 99 percent confidence levels. For RV, 8 out

[12]In practice, CME group sometimes sends out an advisory notice in more than two business days in advance.

of 15 contracts lack statistical significance, 3 out of 15 are statistically significant at 95 percent confidence levels, and only 4 contracts are statistically significant at 99 percent confidence levels. In addition, EGARCH and RV have negative coefficients for some futures contracts. Based on these results we conclude that, among the choices considered, EWMA volatility best represents the volatility proxy that is used in margin setting. Hence, in the empirical analysis that follows, we use the EWMA volatility as our primary proxy for volatility.

As is expected, futures price has a statistically significant coefficient at 99 percent confidence levels for all of the futures contracts except for the pound contract. One thing we should note is that the coefficients on futures price have negative signs for two equity index futures contracts: S&P 500 and Dow Jones. The negative signs can be explained by the leverage effect, which is the negative correlation between stock returns and volatility changes. That is, even though futures prices increase in boom periods, margins are likely to be lowered as volatility decreases, and conversely in bust periods. So, while volatility and futures prices tend to have opposing effects on margin levels for the equity index futures, the former appears to have a first-order impact on margins, whereas the latter seem to have a second-order impact.

5.2 Determinants of censored margin changes

The preceding subsection looks at the determinants of margin levels and find that EWMA volatility best represents the volatility proxy that is used in margin setting by CME Group. We now turn to investigating whether CME Group makes immediate margin changes in response to volatility changes. In analyzing this issue, it is important to remember that margin changes are made infrequently, as explained in Subsection 4.2. Because of this empirical fact, we assume that there will be a margin increase only if a latent margin change variable rises above an upper threshold, a margin decrease only if a latent margin change variable drops below a lower threshold, and no margin change otherwise. To account for this assumption, we run a Tobit regression in which margin changes are censored around zero for each futures contract:

$$
\begin{aligned}
\Delta \log M_t &= \begin{cases} 0 & \text{if } L < y_t^* < U \\ y_t^* & \text{otherwise} \end{cases} \\
y_t^* &= \beta_0 + \beta_1 \Delta_h \text{EWMA}_{t-2} + \beta_2 \Delta_h \text{PRC}_{t-2} + \beta_3 \Delta_h \text{JV}_{t-2} + \beta_4 \Delta_h \text{VLM}_{t-2} \\
&\quad + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t,
\end{aligned} \tag{15}
$$

where $L < 0$ and $U > 0$ are the lower threshold for margin decreases and the upper threshold for margin increases, respectively; y_t^* is the latent margin change variable that is driven by changes in EWMA volatility and other margin determinants; and $\Delta_h(\cdot)$ denotes a difference operator over the lookback period h, that is, $\Delta_h(\cdot)_t \equiv (\cdot)_t - (\cdot)_{t-h}$. As in Subsection 5.1, the Tobit regression is based on the assumption that CME Group uses information that it currently has at the close of today to set margins that will be effective in two business days.

There are two kinds of parameters that need to be determined for the Tobit regression. First, threshold levels, which can vary across futures contracts, are not observable. To resolve this issue, we set L equal to the smallest of the historical margin decreases and U equal to the smallest of the historical margin increases for each futures contract. These numbers are provided in the last two columns of Table 2. For example, for the gold futures, L and U are set at -7.3 percent and 5.7 percent, respectively.

Second, the lookback period h is unknown. It may be the case that CME Group considers a change in volatility over the last week, the last month, or the cumulative change since the most recent margin change date. Hence, the lookback period reflects how quickly CME Group responds to changes in market conditions. We compare Tobit regressions across different choices of a lookback period—one day, one week, two weeks, one month, and the period since the most recent margin change—and find that weekly changes in the explanatory variables can best explain CME Group's margin changes (the results are available upon request).

Table 6 presents the results for Tobit regressions of margin changes against weekly changes in volatility and other margin determinants, with t statistics provided in parentheses and explanatory power computed by McFadden's adjusted R^2. From these regression results, we conclude that volatility changes are the only important driver of margin changes that is consistently significant for all of the futures contracts.

Changes in EWMA volatility have positive coefficients for every contract, implying that CME Group immediately changes margins when the volatility changes over the past week are larger than the certain threshold level. These results are statistically significant for 14 out of the 15 futures contracts at 99 percent confidence levels and for the RBOB gasoline futures at a 95 percent confidence level.

In Subsection 5.1, we find a statistically significant relation between margin levels and futures prices for most of the futures contracts. However, in this subsection, we find that changes in futures prices have no statistically significant relation to margin changes for many of the futures contracts; there are only five cases—silver, RBOB gasoline, corn, wheat, and soybean—where the coefficients on price changes are statistically significant at 95 or 99 confidence levels with the expected sign. In fact, this result is consistent with the statement made by CME Group that "[m]argins are set based on volatility, not prices."[13] Therefore, we argue that a change in volatility is the only important factor in determining whether to make a margin change, but once a margin change has been decided upon, futures price is also considered in determining the magnitude of the change.

5.3 Determinants of trichotomous margin changes

We now turn to examining the determinants of trichotomous margin changes, meaning that we consider only three possible outcomes of margin changes. The trichotomous margin change variable, denoted by T_t, is equal to $+1$ if there is a margin increase, -1 if there is a margin decrease, and 0 otherwise. As in the Tobit regression, we assume that there will be a margin increase only if a latent margin change variable rises above an upper threshold; a margin decrease only if a latent margin change variable drops below a lower threshold; and no margin change otherwise. To account for this assumption, we run an ordered trinomial Probit regression for each futures

[13]See "Quick Facts on Margins at CME Clearing," CME Group, July 2011.

contract:

$$T_t = \begin{cases} -1 & \text{if } y_t^* \leq L \\ 0 & \text{if } L < y_t^* < U \\ 1 & \text{if } y_t^* \geq U \end{cases} \tag{16}$$
$$y_t^* = \beta_0 + \beta_1 \Delta_h \text{EWMA}_{t-2} + \beta_2 \Delta_h \text{PRC}_{t-2} + \beta_3 \Delta_h \text{JV}_{t-2} + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t,$$

where $\varepsilon_t \sim N(0,1)$; $L < 0$ and $U > 0$ are the lower threshold for margin decreases and the upper threshold for margin increases, respectively; and y_t^* is the latent margin change variable. As in the Tobit regression, we assume that the lookback period, h, is the past week. However, unlike the Tobit regression, the lower and upper thresholds here will be determined by estimation. Because of an identification issue, we assume that $L = -U$.[14] Notice that while the Probit regression does not account for the magnitude of margin changes, as opposed to the Tobit regression.

Table 7 presents the Probit regression results for trichotomous margin changes, with t statistics reported in parentheses and explanatory power computed by McFadden's adjusted R^2. From these regression results, we reach virtually the same conclusion as we did from the Tobit regression results. That is, volatility changes are the sole important factor in determining whether to make margin changes. Specifically, the coefficients on changes in volatility have positive signs for all of the contracts, implying that CME Group changes margins when volatility changes beyond a certain threshold. The results are statistically significant for 12 out of the 15 futures contracts at 99 percent confidence levels and for the gold futures at a 95 percent confidence level. The results for RBOB gasoline and heating oil contracts lack statistical significance.

5.4 Asymmetric margin changes

In Subsection 5.2 we find that CME Group makes timely margin changes following volatility changes. Of particular interest in this subsection is whether CME Group reacts differently to volatility increases and decreases. To investigate this asymmetric response, we first introduce volatility increases, $\Delta_h \text{EWMA}_t^+ = \max(\Delta_h \text{EWMA}_t, 0)$,

[14] Alternatively, one can assume that $\beta_0 = 0$, letting L and U both be free parameters.

and volatility decreases, $\Delta_h \text{EWMA}_t^- = \min(\Delta_h \text{EWMA}_t, 0)$. We then run the following Tobit regression of margin changes against volatility increases and decreases for each futures contract:

$$\begin{aligned} \Delta \log M_t &= \begin{cases} 0 & \text{if } L < y_t^* < U \\ y_t^* & \text{otherwise} \end{cases} \\ y_t^* &= \beta_0 + \beta_1^+ \Delta_h \text{EWMA}_{t-2}^+ + \beta_1^- \Delta_h \text{EWMA}_{t-2}^- + \beta_2 \Delta_h \text{PRC}_{t-2} + \beta_3 \Delta_h \text{JV}_{t-2} \\ &\quad + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t. \end{aligned} \tag{17}$$

The coefficients on $\Delta_h \text{EWMA}_t^+$ and $\Delta_h \text{EWMA}_t^-$ indicate CME Group's responsiveness to volatility increases and decreases, respectively. If margins are raised because of volatility increases, $\Delta_h \text{EWMA}_t^+$ must have a positive coefficient; if margins are lowered because of volatility decreases, $\Delta_h \text{EWMA}_t^-$ must have a positive coefficient; and if CME Group is indifferent to volatility increases and decreases, $\Delta_h \text{EWMA}_t^+$ and $\Delta_h \text{EWMA}_t^-$ must have the same positive coefficient.

Table 8 presents the Tobit regression results for margin changes against volatility increases and decreases, with t statistics in parentheses and explanatory power computed by McFadden's adjusted R^2. Expectedly, the volatility increases have statistically significant and positive coefficients at 95 or 99 percent confidence levels for all of the futures contracts except for the corn futures. The positive signs indicate that CME Group immediately increases margins when volatility rises above a certain threshold level. However, we do not find evidence that CME Group immediately decreases margins even when volatility drops below a certain negative threshold. Only the corn futures have a statistically significant and positive coefficient on volatility decreases.

To sum up, the relation between margin changes and volatility changes is asymmetric. CME Group quickly reacts to volatility increases by increasing margins, but it takes a conservative stance in improving environments by maintaining current margin levels for a while despite volatility decreases. As a consequence, during economic downturns, clearing members are required to post additional margins immediately after volatility increases and forced to deleverage their risk exposure to meet the margin call. During economic expansions, however, they are not able to expand their leverage as quickly as volatility decreases. Overall, margin-induced procyclicality is more of a concern in recessions than in expansions.

5.5 The impact of competition on margin changes

When setting margins, CCPs face two conflicting objectives: achieving financial health by maintaining margins at a certain confidence level, and attracting more trading volume by setting margins lower than they would otherwise set. This subsection looks at whether or not competition among CCPs distorts margin levels in order to attract more trading volume, which is commonly referred to as a race to the bottom.

We consider the two largest futures exchanges in the world: CME Group and ICE. The analysis in this subsection is limited to the energy futures contracts: WTI crude oil, RBOB gasoline, and heating oil, each of which is competitively traded in both CME Group and ICE. Unfortunately, we are unable to include the other asset classes for various reasons; the equity and metal futures that we consider in this paper are not traded in ICE; the currency futures we consider in this paper are thinly traded in ICE; and the agriculture futures were launched recently, in May 2012, so the sample period is too short.

Figure 8 presents a comparison of margin levels between CME Group and ICE for the energy futures contracts. Not surprisingly, the two exchanges tend to make margin changes in tandem most of the time, although there are some notable differences in early 2009.

To examine the effect of competition on margin setting, we introduce the margin difference between the two CCPs, denoted by MRGN_DIFF_t:

$$\text{MRGN\_DIFF}_t \equiv \log M_t^{\text{own}} - \log M_t^{\text{comp}} - \delta, \tag{18}$$

where M_t^{own} and M_t^{comp} denote a CCP's own margin and its competitor's margin, respectively, and δ refers to the fundamental, or long-term, difference in margins between two CCPs. A fundamental margin difference may exist because the two CCPs may have different levels of risk tolerance or because there are some contractual differences between the two CCPs; for example, CME Group's energy futures contracts are physically settled, whereas ICE's contracts are cash-settled. Because the fundamental margin difference is not observable, we take the sample mean of the historical log margin differences as a proxy for it:

$$\delta = \overline{\log M_t^{\text{own}} - \log M_t^{\text{comp}}}. \tag{19}$$

where the upper bar indicates the sample mean.

From a macroprudential perspective, we are particularly interested in whether a CCP is likely to lower its margins when it has higher margins than its competitor, after controlling for changes in other margin determinants. To this end, we divide the margin difference into positive and negative components:

$$\begin{aligned} \text{MRGN\_DIFF}_t^+ &\equiv \max(\text{MRGN\_DIFF}_t, 0) \\ \text{MRGN\_DIFF}_t^- &\equiv \min(\text{MRGN\_DIFF}_t, 0), \end{aligned} \tag{20}$$

where MRGN_DIFF_t^+ and MRGN_DIFF_t^- denote positive and negative margin differences, respectively, from a CCP's perspective. We then run the following Tobit regression of the margin changes against the positive and negative margin differences for each CCP-futures pair:

$$\begin{aligned} \Delta \log M_t &= \begin{cases} 0 & \text{if } L < y_t^* < U \\ y_t^* & \text{otherwise} \end{cases} \\ y_t^* &= \beta_0 + \beta_1^+ \text{MRGN\_DIFF}_{t-2}^+ + \beta_1^- \text{MRGN\_DIFF}_{t-2}^- + \beta_2 \Delta_h \text{EWMA}_{t-2} \\ &\quad + \beta_3 \Delta_h \text{PRC}_{t-2} + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t. \end{aligned} \tag{21}$$

Note that MRGN_DIFF_t^+ is associated with a race to the bottom, whereas MRGN_DIFF_t^- is associated with a race to the top. That is, if a CCP tends to lower its margins when it has higher margins than its competitor, MRGN_DIFF_t^+ is expected to have a negative coefficient. On the other hand, if a CCP tends to raise its margins when it has lower margins than its competitor, MRGN_DIFF_t^- is expected to have a negative coefficient.

Panel A of Table 9 shows whether CME Group takes ICE's margin levels into consideration. As can be seen by this panel, the result for CME Group has negative coefficients on positive margin differences for each futures contract, implying that CME Group tends to lower its own margins when it has higher margins than ICE. This empirical result is statistically significant at 95 percent confidence levels for every energy futures contract, despite the fact the sample period is relatively short. This is particularly interesting because competition is the only factor that we find to be statistically significant in explaining CME Group's margin cuts. The result for CME Group also has negative coefficients on negative margin differences for each futures contract, even though statistical significance is obtained only for the WTI crude oil at a 95 confidence level. These negative coefficients imply that CME Group has a tendency to increase its margins when it has lower margins than ICE.

Now let us look at whether ICE takes CME Group's margin levels into account. Panel B of Table 9 shows that ICE have negative coefficients on negative margin differences for each futures contract, implying that ICE tends to raise its own margins when it has lower margins than CME Group. This empirical result is statistically significant at 99 percent confidence levels for the RBOB gasoline and the heating oil futures. However, we do not find evidence that ICE tends to lower its own margins when it has higher margins than CME Group.

In sum, the empirical results above indicate that margin changes can be partly explained by competition even after changes in other margin determinants are controlled for. This finding is important from the financial stability perspective because competition among CCPs can make overall margin requirements inappropriately lax.

6 Summary and policy considerations

Title VII of the Dodd-Frank Act requires that standard OTC derivative contracts be cleared through CCPs, and Title VIII of the Dodd-Frank Act grants supervisory organizations the authority to examine and approve the margin requirements of CCPs. Against this backdrop, this paper empirically analyzes the current margin setting methods used by CCPs and evaluates their implications for the financial regulations.

First, we provide evidence that the current margin rule as set by CME Group is indeed sensitive to volatility. To be specific, CME Group promptly increases margins as volatility increases beyond a certain positive threshold, although it does not immediately decrease margins even when volatility drops below a certain negative threshold. Although the risk-based margin rule helps better protect the CCP per se, it can further deteriorate the funding conditions of clearing members especially when they are already financially constrained during economic downturns. Thus, regulators should consider introducing some tools to measure and dampen procyclical behavior of margins, such as through-the-cycle margin or countercyclical buffer, which are typical of other financial regulations.

Second, we provide some evidence that the margin difference between CME Group and Intercontinental Exchange is a statistically significant driver of margin changes in the energy futures markets after other factor changes are controlled for, implying that competition may be factored into margin setting. In fact, competition can arise in other ways beyond margin levels. For example, CCPs can compete in terms of acceptable collateral, haircut rates, or guaranty fund contributions. As competition can make overall margin requirements inappropriately lax, regulators should monitor market-wide margin decreases that cannot be justified by variations in risk factors.

At last, given that a substantial fraction of the margin variation is still unexplained by the risk factors that we consider in this paper, it is likely that CCPs may account for qualitative or subjective factors such as market sentiment. The opaque nature of margin changes may make it difficult for market participants to expect and prepare for a future margin change. As unexpected margin changes can further escalate procyclicality, it might be beneficial to increase the transparency of margin determination to some degree.

References

Andersen, T., T. Bollerslev, F. Diebold, and H. Ebens (2001): "The distribution of realized stock return volatility," *Journal of Financial Economics*, 61, 43–76.

Andersen, T., T. Bollerslev, F. Diebold, and P. Labys (2003): "Modeling and forecasting realized volatility," *Econometrica*, 71, 579–625.

Barndorff-Nielsen, O. E., and N. Shephard (2002): "Econometric analysis of realized volatility and its use in estimating stochastic volatility models," *Journal of Royal Statistical Society B*, 64, 253–280.

——— (2004): "Power and bipower variation with stochastic volatility and jumps," *Journal of Financial Econometrics*, 2, 1–37.

BCBS and IOSCO (2013): "Margin requirements for non-centrally cleared derivatives," Working paper, Bank for International Settlements.

Berndt, E., B. Hall, R. Hall, and J. Hausman (1974): "Estimation and inference in nonlinear structural models," *Annals of Economic and Social Measurement*, 3, 653–665.

Brandt, M., and F. Diebold (2006): "A no-arbitrage approach to range-based estimation of return covariances and correlations," *Journal of Business*, 79, 461–74.

Brandt, M., and C. Jones (2006): "Volatility forecasting with range-based EGARCH models," *Journal of Business and Economic Statistics*, 24, 470–486.

Brunetti, C., and P. Lildholdt (2007): "Time series modeling of daily log-price ranges for CHF/USD and USD/GBP," *Journal of Derivatives*, 15, 39–59.

Brunnermeier, M. K., and L. H. Pedersen (2009): "Market liquidity and funding liquidity," *Review of Financial studies*, 22(6), 2201–2238.

Committee on the Global Financial System (2010): "The role of margin requirements and haircuts in procyclicality," Working paper, Bank for International Settlements.

Cotter, J. (2001): "Margin exceedances for European stock index futures using extreme value theory," *Journal of Futures Markets*, 25, 1475–1502.

Duffie, D., and H. Zhu (2011): "Does a central clearing counterparty reduce counterparty risk?," *Review of Asset Pricing Studies*, 1(1), 74–95.

Fenn, G. W., and P. Kupiec (1993): "Prudential margin policy in a futures-style settlement system," *Journal of Futures Markets*, 13, 389–408.

Figlewski, S. (1984): "Margins and market integrity: Margin setting for stock index futures and options," *Journal of Futures Markets*, 4, 385–416.

Gay, G. D., W. C. Hunter, and R. W. Kolb (1986): "A comparative analysis of futures contract margins," *Journal of Futures Markets*, 6, 307–324.

Hardouvelis, G., and D. Kim (1995): "Margin requirements, price fluctuations, and market participation in metal futures," *Journal of Money, Credit, and Banking*, 27, 659–671.

Hardouvelis, G. A. (1990): "Margin requirements, volatility, and the transitory component of stock prices," *American Economic Review*, pp. 736–762.

Hardouvelis, G. A., and P. Theodossiou (2002): "The asymmetric relation between initial margin requirements and stock market volatility across bull and bear markets," *Review of Financial Studies*, 15(5), 1525–1559.

Hsieh, D. A., and M. H. Miller (1990): "Margin regulation and stock market volatility," *Journal of Finance*, 45(1), 3–29.

Ito, T., and W.-L. Lin (2001): "Race to the center: Competition for the Nikkei 225 futures trade," *Journal of Empirical Finance*, 8(3), 219–242.

Kupiec, P. H. (1989): "Initial margin requirements and stock returns volatility: Another look," *Journal of Financial Services Research*, 3, 287–301.

Longin, F. (1999): "Optimal margin level in futures markets: Extreme price movements," *Journal of Futures Markets*, 19, 127–152.

Newey, W. K., and K. D. West (1987): "A simple positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix," *Econometrica*, 55, 703–708.

Parkinson, M. (1980): "The extreme value method for estimating the variance of the rate of return," *Journal of Business*, 53, 61–65.

Salinger, M. A. (1989): "Stock market margin requirements and volatility: Implications for regulation of stock index futures," *Journal of Financial Services Research*, 3(2), 121–138.

Santos, T., and J. A. Scheinkman (2001): "Competition among exchanges," *Quarterly Journal of Economics*, 116(3), 1027–1061.

Schwert, G. W. (1989): "Margin requirements and stock volatility," *Journal of Financial Services Research*, 3, 153–164.

Table 1: **Contract specifications**

This table presents specifications for each futures contract. Columns correspond to contract name organized in panels by asset class, the exchange that the contract is traded on, the contract size which is the unit the contract is traded in, the pricing unit (cents or dollars), and the pit trading hours. We choose the three most representative contracts across various asset classes traded on multiple exchanges, including CME (Chicago Mechantile Exchange), CBOT (Chicago Board of Trade), NYMEX (New York Mercantile Exchange), and COMEX (Commodity Exchange).

Contract name	Exchange	Contract size	Pricing unit	Pit trading hours
Panel A: Stock Index				
S&P 500	CME	250 S&P 500	dollars	8:30-15:15
Nasdaq 100	CME	100 Nasdaq 100	dollars	8:30-15:15
Dow Jones	CBOT	10 Dow Jones	dollars	8:30-15:15
Panel B: Currency				
pound	CME	62,500 British pounds	dollars	7:20-14:00
euro	CME	125,000 euros	dollars	7:20-14:00
yen	CME	12,500,000 Japanese yens	dollars	7:20-14:00
Panel C: Metal				
gold	COMEX	100 troy ounces	dollars	8:20-13:30
silver	COMEX	5,000 troy ounces	cents	8:25-13:25
copper	COMEX	25,000 pounds	cents	8:10-13:00
Panel D: Energy				
WTI	NYMEX	1,000 barrels	dollars	9:00-14:30
RBOB	NYMEX	42,000 gallons	dollars	9:00-14:30
heat. oil	NYMEX	42,000 gallons	dollars	9:00-14:30
Panel E: Agriculture				
corn	CBOT	5,000 bushels	cents	9:30-14:00
wheat	CBOT	5,000 bushels	cents	9:30-14:00
soybean	CBOT	5,000 bushels	cents	9:30-14:00

Table 2: **Summary statistics for margin changes**

This table presents summary statistics on margin changes for various futures contracts. Margin changes are defined as $\Delta \log M_t = \log(\frac{M_t}{M_{t-1}})$, where M_t denotes the maintenance margin at time t. Note that while the margin changes are observed on a daily basis, they are nonzero only for a few days when margins are actually changed. These summary statistics are computed only using the nonzero margin changes. The margin data start at different dates for the various contracts included in our sample, but extend through July 2013 for all contracts. Columns correspond to contract name, the first date in the sample, the number of margin changes, the number of margin increases, the number of margin decreases, the average number of days between margin changes, the average margin increase, the average margin decrease, the smallest of the historical margin increases, and the smallest of the historical margin decreases, respectively.

Contract name	First date	No. of changes	No. of increases	No. of decreases	Avg. days between changes	Avg. margin increase (%)	Avg. margin decrease (%)	Smallest increase (%)	Smallest decrease (%)
Panel A: Stock Index									
S&P 500	01/03/2000	14	6	8	311.0	11.4	-9.4	9.5	-1.6
Nasdaq 100	01/03/2000	22	11	11	232.3	17.1	-22.1	4.7	-9.1
Dow Jones	11/24/2003	15	9	6	211.0	15.1	-18.9	10.5	-5.6
Panel B: Currency									
pound	01/03/2000	53	23	30	93.2	22.2	-15.9	6.9	-6.9
euro	01/02/2002	47	23	24	91.0	14.2	-11.4	2.7	-4.3
yen	01/03/2000	68	27	41	72.9	23.7	-14.5	9.5	-4.9
Panel C: Metal									
gold	01/08/2009	17	9	8	100.7	17.7	-12.2	5.7	-7.3
silver	01/08/2009	25	16	9	64.3	12.6	-16.1	5.3	-6.5
copper	01/08/2009	15	7	8	98.8	15.5	-18.1	7.8	-11.1
Panel D: Energy									
WTI	01/12/2009	16	5	11	101.3	14.1	-10.9	9.1	-4.1
RBOB	01/12/2009	16	7	9	96.5	24.3	-22.6	5.4	-8.7
heat. oil	01/12/2009	16	5	11	98.8	29.4	-19.3	7.7	-6.5
Panel E: Agriculture									
corn	11/24/2003	43	26	17	71.5	19.5	-20.4	5.1	-8.3
wheat	11/24/2003	43	26	17	78.6	22.0	-25.9	6.9	-8.3
soybean	11/24/2003	44	25	19	76.5	17.6	-17.6	6.5	-4.4

Table 3: **Probability of margin shortfall**

This table presents the probability of margin shortfall, or the probability that futures prices will vary more than what is covered by the margin requirements over a one- or three-day close-out period. Our computation of this probability is based on the assumption that futures returns follow a normal distribution with mean zero and standard deviation measured by the exponentially weighted moving average method. Also note that we compute the probability of margin shortfall only when margin changes are actually made.

	1-day close-out horizon			3-day close-out horizon		
Contract name	Mean(%)	Min.(%)	Max.(%)	Mean(%)	Min.(%)	Max.(%)
Panel A: Stock Index						
S&P 500	0.03	0.00	0.20	1.37	0.00	4.85
Nasdaq 100	0.12	0.00	0.56	2.62	0.00	7.17
Dow Jones	0.05	0.00	0.31	1.58	0.00	5.73
Panel B: Currency						
pound	1.05	0.02	3.05	8.57	1.96	13.96
euro	1.00	0.01	3.22	8.23	1.66	14.27
yen	0.39	0.00	2.65	5.04	0.14	13.19
Panel C: Metal						
gold	0.13	0.00	1.61	2.67	0.57	10.80
silver	0.43	0.00	1.56	5.12	0.05	10.67
copper	0.27	0.03	0.92	4.77	2.27	8.67
Panel D: Energy						
WTI	0.66	0.02	2.25	6.44	1.99	12.35
RBOB	1.14	0.13	7.68	7.97	4.07	20.50
heat. oil	0.68	0.04	5.18	6.32	2.66	17.36
Panel E: Agriculture						
corn	1.75	0.13	8.65	10.31	4.10	21.57
wheat	1.79	0.01	10.49	9.86	1.26	23.45
soybean	1.19	0.00	5.13	8.09	1.09	17.29

Table 4: **Correlations among the volatility proxies**

This table shows correlations among the volatility proxies for various futures contracts. EW is volatility estimated by the exponentially weighted moving average method, EGARCH is volatility estimated by the range-based EGARCH model, RV is realized volatility. The starting date of the sample varies across the contracts as shown in the Table 2, while the sample ends on July 31, 2013 for every contract. The data are obtained on a daily basis.

Contract	corr(EW, EGARCH)	corr(EW, RV)	corr(EGARCH, RV)
Panel A: Stock Index			
S&P 500	0.84	0.89	0.92
Nasdaq 100	0.91	0.94	0.94
Dow Jones	0.83	0.90	0.91
Panel B: Currency			
pound	0.91	0.90	0.94
euro	0.92	0.87	0.95
yen	0.75	0.85	0.80
Panel C: Metal			
gold	0.72	0.83	0.86
silver	0.54	0.81	0.65
copper	0.75	0.93	0.81
Panel D: Energy			
WTI	0.90	0.93	0.96
RBOB	0.89	0.94	0.94
heat. oil	0.94	0.97	0.97
Panel E: Agriculture			
corn	0.72	0.75	0.88
wheat	0.65	0.78	0.85
soybean	0.79	0.84	0.90

Table 5: **Determinants of margin levels**

This table presents the results of the following linear regression of margin levels against volatility and other control variables:

$$M_t = \beta_0 + \beta_1 \text{EWMA}_{t-2} + \beta_2 \text{EGARCH}_{t-2} + \beta_3 \text{RV}_{t-2} + \beta_4 \text{PRC}_{t-2} + \beta_5 \text{JV}_{t-2} + \beta_6 \text{VLM}_{t-2} + \beta_7 \text{OI}_{t-2} + \beta_8 \text{TED}_{t-2} + \varepsilon_t,$$

where M_t is margin level, EWMA_t is volatility estimated by the exponentially weighted moving average method, EGARCH_t is volatility estimated by the range-based EGARCH model, RV_t is realized volatility, PRC_t is futures price, JV_t is high-frequency-based jump variation, VLM_t is trading volume, OI_t is open interest, and TED_t is the TED spread. Newey and West (1987) robust t statistics with 10 lags are reported in parentheses, and * and ** stand for statistical significance at 95 and 99 percent confidence levels, respectively.

Contract name	Constant	EWMA	EGARCH	RV	PRC	JV	VLM	OI	TED	R^2
Panel A: Stock Index										
S&P 500	319.38**	6.75**	-2.00*	-1.21	-3.44**	-1.49	-0.19	-6.76**	3.02**	0.54
	(12.0)	(6.7)	(-2.3)	(-0.9)	(-4.5)	(-1.5)	(-0.4)	(-9.6)	(4.8)	
Nasdaq 100	-239.78**	38.11**	11.54**	-17.65**	34.66**	-1.34	8.47**	12.65**	-1.62	0.71
	(-7.7)	(7.1)	(3.1)	(-2.8)	(13.6)	(-0.3)	(4.0)	(5.4)	(-1.1)	
Dow Jones	3285.92**	79.30**	-29.36	15.34	-97.51**	-1.91	-5.41	-142.98**	-13.45	0.71
	(16.6)	(4.1)	(-1.4)	(0.5)	(-8.5)	(-0.1)	(-0.5)	(-10.9)	(-1.2)	
Panel B: Currency										
pound	-2.29**	0.50**	-0.07	0.17*	0.03	-0.06**	0.16**	0.06*	0.09**	0.84
	(-6.7)	(10.0)	(-1.1)	(2.4)	(1.4)	(-2.7)	(5.7)	(2.3)	(4.4)	
euro	-10.77**	0.66**	-0.17*	0.05	0.07**	0.01	0.10**	0.25**	-0.01	0.85
	(-16.6)	(15.4)	(-2.4)	(0.8)	(2.7)	(0.3)	(4.0)	(11.1)	(-0.2)	
yen	-1.94**	0.28**	-0.12**	0.05	0.49**	-0.02	0.13**	-0.06*	-0.01	0.78
	(-3.5)	(7.1)	(-4.9)	(0.9)	(22.1)	(-0.8)	(5.3)	(-2.4)	(-0.5)	
Panel C: Metal										
gold	-38.68	17.17**	-1.88*	-3.83**	14.64**	0.14	-0.01	-0.07	-5.95**	0.89
	(-0.7)	(9.4)	(-2.0)	(-3.0)	(30.6)	(0.2)	(-0.0)	(-0.1)	(-5.8)	
silver	-4.24	0.73**	-0.07	-0.25**	0.76**	-0.02	-0.05	0.04	-0.08	0.78
	(-0.6)	(6.1)	(-1.3)	(-2.7)	(14.5)	(-0.2)	(-1.2)	(0.5)	(-1.3)	
copper	-0.17	0.04**	0.00	-0.00	0.02**	-0.00	0.00*	0.00	0.00	0.74
	(-0.9)	(6.2)	(0.3)	(-0.3)	(8.2)	(-0.6)	(1.8)	(0.5)	(1.3)	
Panel D: Energy										
WTI	-11.41	1.08**	0.43*	-0.48*	0.79**	0.33**	-0.07*	0.11*	-0.14*	0.66
	(-1.6)	(8.7)	(2.3)	(-2.4)	(7.3)	(3.8)	(-2.4)	(1.7)	(-1.7)	
RBOB	0.94**	0.02**	0.01*	-0.00	0.03**	-0.01*	0.00	-0.01**	-0.01	0.48
	(4.2)	(3.2)	(2.5)	(-0.5)	(9.0)	(-1.9)	(0.6)	(-4.6)	(-1.5)	
heat. oil	-0.38	0.05**	0.00	-0.02	0.03**	0.00	0.00*	0.00	-0.00	0.49
	(-1.0)	(6.2)	(0.1)	(-1.2)	(10.0)	(1.2)	(2.3)	(0.4)	(-0.9)	
Panel E: Agriculture										
corn	38.47**	3.93**	-0.63	-0.83	10.34**	0.34	1.20**	-1.64**	0.09	0.90
	(3.4)	(9.9)	(-1.0)	(-1.2)	(28.0)	(0.7)	(5.2)	(-6.4)	(0.3)	
wheat	-62.62**	10.89**	-2.33*	-3.02*	9.79**	2.18**	3.41**	-0.55	0.77	0.87
	(-4.3)	(9.9)	(-2.5)	(-2.4)	(10.2)	(2.6)	(5.6)	(-1.2)	(1.2)	
soybean	-69.64*	12.05**	1.13	-6.19**	15.01**	1.36	2.40**	-0.07	0.40	0.89
	(-2.2)	(14.0)	(1.0)	(-4.0)	(18.6)	(1.6)	(5.1)	(-0.1)	(0.9)	

Table 6: **Determinants of censored margin changes**

This table presents the results of the following Tobit regression of margin changes against volatility changes:

$$\Delta \log M_t = \begin{cases} 0 & \text{if } L < y_t^* < U \\ y_t^* & \text{otherwise} \end{cases}$$
$$y_t^* = \beta_0 + \beta_1 \Delta_h \text{EWMA}_{t-2} + \beta_2 \Delta_h \text{PRC}_{t-2} + \beta_3 \Delta_h \text{JV}_{t-2} + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t,$$

where $L < 0$ and $U > 0$ are the lower threshold for margin decreases and the upper threshold for margin increases, respectively; y_t^* is the latent margin change variable that is driven by changes in EWMA volatility and other control variables; $\Delta_h(\cdot)$ denotes a difference operator over the lookback period h, that is, $\Delta_h(\cdot)_t \equiv (\cdot)_t - (\cdot)_{t-h}$; M_t is margin level; EWMA_t is volatility estimated by the exponentially weighted moving average method; PRC_t is futures price; JV_t is high-frequency-based jump variation; VLM_t is trading volume; OI_t is open interest; and TED_t is the TED spread. The frequency of the data is daily. The t statistics are reported in parentheses, explanatory power is computed by McFadden's adjusted R^2, and * and ** stand for statistical significance at 95 and 99 percent confidence levels, respectively.

Contract name	Constant	Δ_hEWMA	Δ_hPRC	Δ_hJV	Δ_hVLM	Δ_hOI	Δ_hTED	R^2
Panel A: Stock Index								
S&P 500	3.77**	0.22**	-0.01*	-0.51*	-0.00	2.47	0.23	0.51
	(31.0)	(3.1)	(-1.8)	(-2.0)	(-0.0)	(1.4)	(0.3)	
Nasdaq 100	-2.30**	0.41**	-0.00	0.21	0.04	0.12	1.39*	0.23
	(-15.8)	(6.3)	(-1.5)	(1.2)	(0.2)	(0.2)	(1.8)	
Dow Jones	2.46**	0.50**	-0.00	0.10	-0.12	1.00	-1.24	0.41
	(10.9)	(4.6)	(-1.6)	(0.3)	(-0.5)	(1.2)	(-1.3)	
Panel B: Currency								
pound	-0.17	1.07**	1.99	-0.88	-0.07	0.10	-0.20	0.09
	(-1.4)	(3.2)	(0.4)	(-1.4)	(-0.3)	(0.1)	(-0.2)	
euro	-0.91**	0.72**	2.75	0.09	-0.12	-0.53	0.00	0.08
	(-13.7)	(3.9)	(0.8)	(0.3)	(-0.7)	(-1.0)	(0.0)	
yen	2.23**	0.82**	5.09	0.80	0.52*	-0.36	0.81	0.18
	(18.6)	(4.0)	(0.6)	(1.6)	(2.6)	(-0.8)	(1.0)	
Panel C: Metal								
gold	-0.57**	0.39**	0.01	0.20	0.42	-4.62	6.72	0.34
	(-3.0)	(2.6)	(1.0)	(0.5)	(1.1)	(-0.9)	(1.1)	
silver	-0.27	0.39**	0.32**	0.17	0.31	-3.66	2.97	0.22
	(-1.6)	(4.9)	(2.6)	(0.9)	(0.9)	(-0.8)	(0.6)	
copper	-1.66**	0.78**	-1.81	0.50	-0.38	14.76*	5.30	0.57
	(-5.6)	(3.7)	(-0.8)	(1.2)	(-0.5)	(2.0)	(0.6)	
Panel D: Energy								
WTI	2.31**	0.46**	0.03	0.21	1.32*	-8.91	-2.70	0.42
	(11.1)	(3.7)	(0.5)	(0.9)	(2.2)	(-1.2)	(-0.4)	
RBOB	-1.64**	0.25*	4.45*	0.11	0.48	1.92	1.82	0.09
	(-7.6)	(2.3)	(2.3)	(0.4)	(0.7)	(0.4)	(0.3)	
heat. oil	0.48*	0.57**	0.45	0.65*	0.46	0.47	-11.55*	0.04
	(2.2)	(3.0)	(0.2)	(2.1)	(0.6)	(0.1)	(-1.7)	
Panel E: Agriculture								
corn	-1.40**	0.15**	0.01*	0.02	0.44	0.17	-0.47	0.10
	(-10.3)	(2.6)	(1.7)	(0.2)	(1.4)	(0.0)	(-0.5)	
wheat	-0.58**	0.41**	0.02**	0.28*	0.21	3.65	0.64	0.04
	(-3.8)	(4.5)	(4.1)	(2.1)	(0.7)	(0.9)	(0.6)	
soybean	1.14**	0.61**	0.01*	-0.00	-0.04	-2.27	-0.35	0.09
	(10.6)	(7.9)	(1.9)	(-0.0)	(-0.2)	(-0.8)	(-0.5)	

Table 7: **Determinants of trichotomous margin changes**

This table presents the results of the following ordered trinomial Probit regression of trichotomous margin changes against volatility changes:

$$T_t = \begin{cases} -1 & \text{if } y_t^* < L \\ 0 & \text{if } L < y_t^* < U \\ 1 & \text{if } y_t^* > U \end{cases}$$

$$y_t^* = \beta_0 + \beta_1 \Delta_h \text{EWMA}_{t-2} + \beta_2 \Delta_h \text{PRC}_{t-2} + \beta_3 \Delta_h \text{JV}_{t-2} + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t,$$

where T_t denotes the trichotomous margin change variable; $\varepsilon_t \sim N(0,1)$; $L < 0$ and $U > 0$ are the lower threshold for margin decreases and the upper threshold for margin increases, respectively; y_t^* is the latent margin change variable that is driven by changes in EWMA volatility and other control variables; $\Delta_h(\cdot)$ denotes a difference operator over the lookback period h, that is, $\Delta_h(\cdot)_t \equiv (\cdot)_t - (\cdot)_{t-h}$; EWMA_t is volatility estimated by the exponentially weighted moving average method; PRC_t is futures price; JV_t is high-frequency-based jump variation; VLM_t is trading volume; OI_t is open interest; and TED_t is the TED spread. The frequency of the data is daily. The t statistics are reported in parentheses, explanatory power is computed by McFadden's adjusted R^2, and * and ** stand for statistical significance at 95 and 99 percent confidence levels, respectively.

Contract name	Constant	Δ_hEWMA	Δ_hPRC	Δ_hJV	Δ_hVLM	Δ_hOI	Δ_hTED	R^2
Panel A: Stock Index								
S&P 500	-0.12	0.15**	-0.00	-0.22	0.04	0.90	0.10	0.05
	(-1.2)	(4.0)	(-1.6)	(-1.2)	(0.2)	(0.7)	(0.2)	
Nasdaq 100	-0.07	0.12**	-0.00	0.13	0.02	0.26	0.51	0.04
	(-0.9)	(4.0)	(-0.4)	(1.5)	(0.2)	(0.9)	(1.4)	
Dow Jones	-0.01	0.17**	-0.00*	-0.07	-0.05	0.32	-0.31	0.05
	(-0.1)	(4.2)	(-2.0)	(-0.4)	(-0.5)	(0.9)	(-0.8)	
Panel B: Currency								
pound	-0.06	0.49**	1.85	-0.34	0.04	-0.17	0.02	-0.00
	(-1.2)	(4.0)	(0.8)	(-1.2)	(0.5)	(-0.6)	(0.1)	
euro	-0.04	0.81**	-0.90	0.11	-0.15	-0.20	0.29	0.04
	(-0.8)	(6.4)	(-0.3)	(0.4)	(-1.1)	(-0.4)	(0.9)	
yen	-0.10*	0.24**	4.59	0.40*	0.08	-0.07	-0.07	0.01
	(-2.2)	(3.6)	(1.4)	(2.1)	(1.1)	(-0.4)	(-0.2)	
Panel C: Metal								
gold	0.02	0.12*	0.00	0.13	0.16	-1.47	2.74	-0.04
	(0.2)	(2.0)	(0.4)	(0.7)	(0.9)	(-0.6)	(1.0)	
silver	0.11	0.13**	0.12*	0.04	0.02	-1.19	3.29	0.02
	(1.3)	(4.0)	(2.4)	(0.6)	(0.1)	(-0.5)	(1.5)	
copper	-0.04	0.19**	-0.67	0.17	-0.19	4.27*	2.23	0.01
	(-0.4)	(3.1)	(-0.9)	(1.4)	(-0.9)	(1.8)	(0.7)	
Panel D: Energy								
WTI	-0.18*	0.20**	0.02	0.01	0.40	-2.25	-4.11	0.01
	(-1.8)	(3.8)	(0.7)	(0.1)	(1.4)	(-0.6)	(-1.3)	
RBOB	-0.05	0.06	1.35*	0.13	-0.05	-0.06	-2.61	-0.05
	(-0.5)	(1.5)	(1.7)	(1.3)	(-0.2)	(-0.0)	(-0.9)	
heat. oil	-0.15	0.10	0.15	0.20	0.13	0.14	-5.22*	-0.04
	(-1.5)	(1.1)	(0.1)	(1.6)	(0.4)	(0.1)	(-2.0)	
Panel E: Agriculture								
corn	0.06	0.06**	0.00	0.04	0.17	0.10	-0.27	-0.01
	(1.0)	(3.3)	(1.4)	(0.6)	(1.3)	(0.1)	(-0.7)	
wheat	0.04	0.12**	0.00**	0.11*	0.04	0.44	0.21	0.05
	(0.6)	(3.9)	(2.7)	(2.2)	(0.3)	(0.3)	(0.6)	
soybean	0.01	0.23**	0.00*	0.00	-0.06	-1.06	-0.14	0.04
	(0.2)	(6.8)	(1.7)	(0.0)	(-0.4)	(-0.7)	(-0.4)	

Table 8: **Asymmetric margin changes**

This table presents the results of the following Tobit regression of margin changes against the volatility increases, $\Delta_h \text{EWMA}_t^+ = \max(\Delta_h \text{EWMA}_t, 0)$, and volatility decreases, $\Delta_h \text{EWMA}_t^- = \min(\Delta_h \text{EWMA}_t, 0)$:

$$\Delta \log M_t = \begin{cases} 0 & \text{if } L < y_t^* < U \\ y_t^* & \text{otherwise} \end{cases}$$

$$\begin{aligned} y_t^* &= \beta_0 + \beta_1^+ \Delta_h \text{EWMA}_{t-2}^+ + \beta_1^- \Delta_h \text{EWMA}_{t-2}^- + \beta_2 \Delta_h \text{PRC}_{t-2} + \beta_3 \Delta_h \text{JV}_{t-2} \\ &\quad + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t, \end{aligned}$$

where $L < 0$ and $U > 0$ are the lower threshold for margin decreases and the upper threshold for margin increases, respectively; y_t^* is the latent margin change variable that is driven by volatility increases and decreases and changes in other control variables; M_t is margin level; EWMA_t is volatility estimated by the exponentially weighted moving average method; PRC_t is futures price; JV_t is high-frequency-based jump variation; VLM_t is trading volume; OI_t is open interest; and TED_t is the TED spread. The frequency of the data is daily. The t statistics are reported in parentheses, explanatory power is computed by McFadden's adjusted R^2, and * and ** stand for statistical significance at 95 and 99 percent confidence levels, respectively.

Contract name	Constant	Δ_hEWMA$^+$	Δ_hEWMA$^-$	Δ_hPRC	Δ_hJV	Δ_hVLM	Δ_hOI	Δ_hTED	R^2
Panel A: Stock Index									
S&P 500	3.74**	0.23**	0.13	-0.01*	-0.49*	0.00	2.46	0.23	0.51
	(21.8)	(3.0)	(0.4)	(-1.8)	(-1.8)	(0.0)	(1.4)	(0.3)	
Nasdaq 100	-2.32**	0.41**	0.38	-0.00	0.21	0.05	0.12	1.39*	0.23
	(-11.6)	(5.8)	(1.4)	(-1.5)	(1.2)	(0.2)	(0.2)	(1.8)	
Dow Jones	2.59**	0.48**	0.89	-0.00	0.07	-0.14	0.98	-1.32	0.40
	(8.9)	(4.3)	(1.6)	(-1.6)	(0.2)	(-0.6)	(1.1)	(-1.3)	
Panel B: Currency									
pound	-0.48**	1.70**	-0.83	3.20	-0.81	-0.02	0.02	-0.18	0.09
	(-2.6)	(4.0)	(-0.9)	(0.6)	(-1.3)	(-0.1)	(0.0)	(-0.2)	
euro	-0.94**	0.79**	0.54	2.76	0.09	-0.11	-0.53	0.00	0.08
	(-9.0)	(3.1)	(1.1)	(0.8)	(0.3)	(-0.7)	(-1.0)	(0.0)	
yen	2.02**	1.01**	-0.29	4.07	0.82	0.55**	-0.37	0.81	0.18
	(10.8)	(4.2)	(-0.4)	(0.5)	(1.6)	(2.7)	(-0.8)	(1.0)	
Panel C: Metal									
gold	-0.44	0.36*	0.72	0.01	0.19	0.40	-4.53	5.95	0.34
	(-1.5)	(2.1)	(1.1)	(1.0)	(0.5)	(1.0)	(-0.8)	(1.0)	
silver	-0.26	0.39**	0.41	0.32*	0.16	0.30	-3.63	2.92	0.22
	(-0.9)	(4.2)	(1.4)	(2.5)	(0.9)	(0.8)	(-0.8)	(0.6)	
copper	-1.93**	0.88**	0.30	-1.48	0.54	-0.33	14.33*	6.09	0.57
	(-4.1)	(3.6)	(0.4)	(-0.6)	(1.3)	(-0.4)	(2.0)	(0.6)	
Panel D: Energy									
WTI	1.51**	0.75**	-0.48	0.01	0.19	1.12*	-9.05	2.74	0.43
	(4.7)	(5.2)	(-1.5)	(0.2)	(0.8)	(1.8)	(-1.2)	(0.4)	
RBOB	-1.81**	0.30*	0.03	4.40*	0.12	0.49	1.68	2.21	0.09
	(-5.3)	(2.3)	(0.1)	(2.2)	(0.5)	(0.7)	(0.3)	(0.3)	
heat. oil	-0.05	0.88**	-0.28	1.14	0.62*	0.39	-0.84	-8.75	0.04
	(-0.1)	(3.7)	(-0.6)	(0.5)	(2.0)	(0.5)	(-0.1)	(-1.3)	
Panel E: Agriculture									
corn	-1.20**	0.11	0.48*	0.01	0.01	0.39	0.54	-0.46	0.10
	(-5.7)	(1.5)	(1.8)	(1.6)	(0.1)	(1.2)	(0.1)	(-0.5)	
wheat	-0.67**	0.44**	0.27	0.02**	0.29*	0.22	3.74	0.64	0.04
	(-2.8)	(3.9)	(0.9)	(4.1)	(2.1)	(0.7)	(0.9)	(0.6)	
soybean	1.01**	0.66**	0.38	0.01*	0.00	-0.02	-2.27	-0.33	0.09
	(5.8)	(6.8)	(1.4)	(2.0)	(0.0)	(-0.1)	(-0.8)	(-0.5)	

Table 9: **Impact of competition on margin changes**

We define a margin difference between two competing CCPs as $\text{MRGN\_DIFF}_t \equiv \log M_t^{\text{own}} - \log M_t^{\text{comp}} - \delta$, where M_t^{own} and M_t^{comp} denote a CCP's own margin and its competitor's margin, respectively, and δ is subtracted to account for the fundamental difference in margins between the two CCPs. This table presents the results of the following Tobit regression of margin changes against a positive margin difference, $\text{MRGN\_DIFF}_t^+ \equiv \max(\text{MRGN\_DIFF}_t, 0)$; a negative margin difference, $\text{MRGN\_DIFF}_t^- \equiv \min(\text{MRGN\_DIFF}_t, 0)$; and changes in other risk factors such as volatility:

$$\Delta \log M_t = \begin{cases} 0 & \text{if } L < y_t^* < U \\ y_t^* & \text{otherwise} \end{cases}$$

$$y_t^* = \beta_0 + \beta_1^+ \text{MRGN\_DIFF}_{t-2}^+ + \beta_1^- \text{MRGN\_DIFF}_{t-2}^- + \beta_2 \Delta_h \text{EWMA}_{t-2} + \beta_3 \Delta_h \text{PRC}_{t-2} + \beta_4 \Delta_h \text{VLM}_{t-2} + \beta_5 \Delta_h \text{OI}_{t-2} + \beta_6 \Delta_h \text{TED}_{t-2} + \varepsilon_t.$$

where $L < 0$ and $U > 0$ are the lower threshold for margin decreases and the upper threshold for margin increases, respectively; y_t^* is the latent margin change variable that is driven by the positive and negative margin differences and changes in EWMA volatility and other control variables; $\Delta_h(\cdot)$ denotes a difference operator over the lookback period h, that is, $\Delta_h(\cdot)_t \equiv (\cdot)_t - (\cdot)_{t-h}$; M_t is margin level; EWMA_t is volatility estimated by the exponentially weighted moving average method; PRC_t is futures price; VLM_t is trading volume; OI_t is open interest; and TED_t is the TED spread. The frequency of the data is daily. The t statistics are reported in parentheses, explanatory power is computed by McFadden's adjusted R^2, and * and ** stand for statistical significance at 95 and 99 percent confidence levels, respectively.

Name	Constant	MRGN_DIFF$^+$	MRGN_DIFF$^-$	Δ_hEWMA	Δ_hPRC	Δ_hVLM	Δ_hOI	Δ_hTED	R^2
Panel A: CME Group									
WTI	2.41**	-6.44*	-4.80*	0.55**	0.01	1.26*	-8.88	0.83	0.43
	(7.9)	(-2.1)	(-1.8)	(4.8)	(0.2)	(2.1)	(-1.2)	(0.1)	
RBOB	-1.29**	-5.61*	-0.10	0.28*	4.13*	0.47	1.82	1.89	0.09
	(-3.9)	(-1.7)	(-0.1)	(2.6)	(2.1)	(0.7)	(0.4)	(0.3)	
heat. oil	0.81**	-6.77*	-0.32	0.65**	0.03	0.58	0.14	-11.06*	0.04
	(2.8)	(-2.4)	(-0.2)	(3.6)	(0.0)	(0.7)	(0.0)	(-1.7)	
Panel B: ICE									
WTI	-0.60**	0.13	-0.74	0.03	0.00	-0.02	-0.01	0.52	0.27
	(-7.7)	(0.2)	(-0.9)	(0.8)	(0.1)	(-0.3)	(-0.1)	(0.3)	
RBOB	1.17**	1.58	-10.94**	-0.20*	3.76**	0.14	0.29	8.26*	0.26
	(4.8)	(1.3)	(-4.0)	(-2.4)	(2.8)	(1.0)	(1.2)	(2.2)	
heat. oil	0.43**	0.03	-3.24**	0.14*	-0.63	0.02	0.04	1.37	0.08
	(3.6)	(0.0)	(-2.8)	(2.1)	(-0.7)	(0.2)	(0.2)	(0.6)	

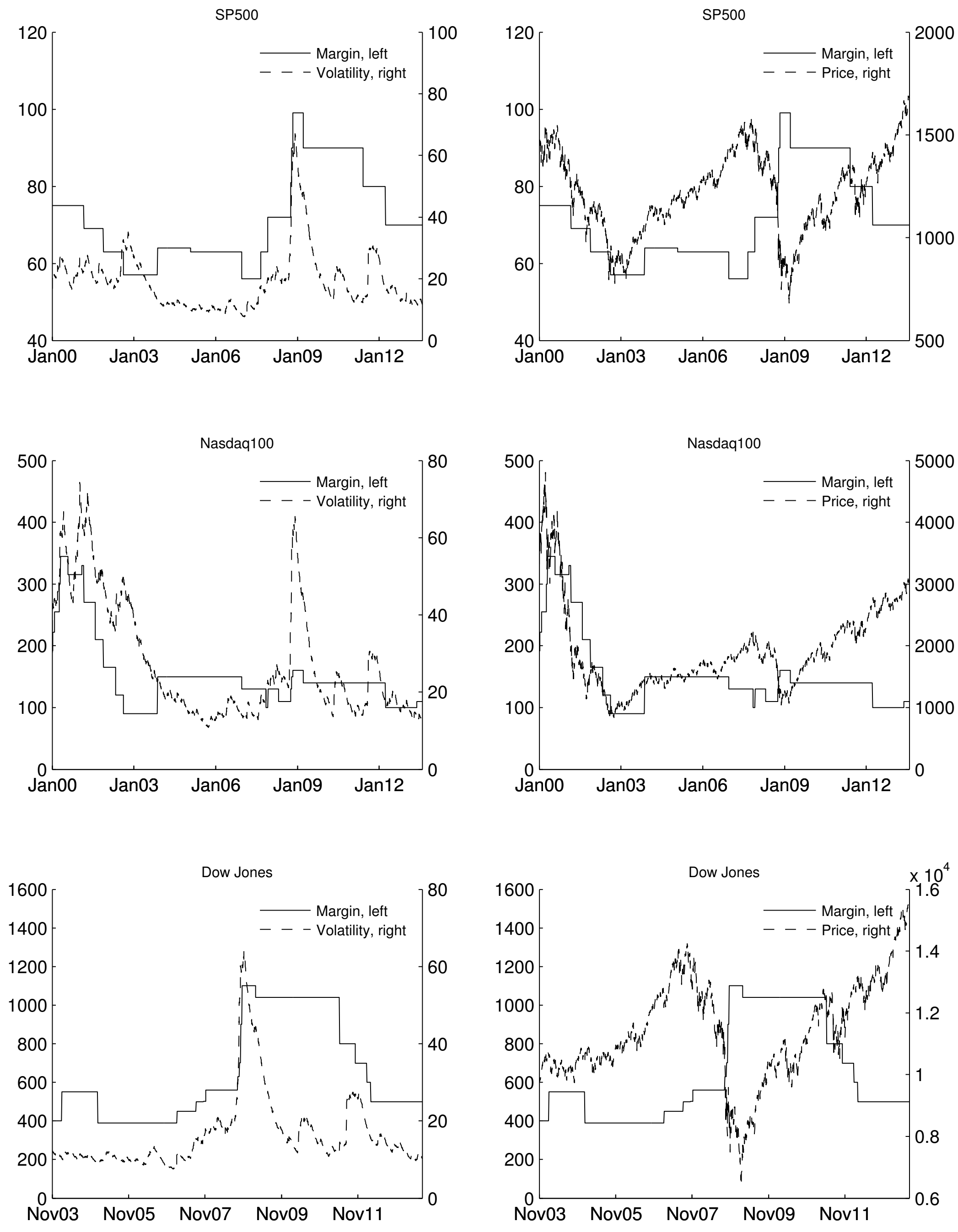

Figure 1: **Relations of margin to volatility (left panel) and to futures price (right panel) for stock index futures**

The left panels compare maintenance margin level (solid line) to EWMA volatility (dashed line), and the right panels compare maintenance margin level (solid line) to the futures price (dashed line) for CME Group's stock index futures. The top, middle, and bottom panels correspond to the S&P 500 index, the Nasdaq 100, and the Dow Jones futures, respectively.

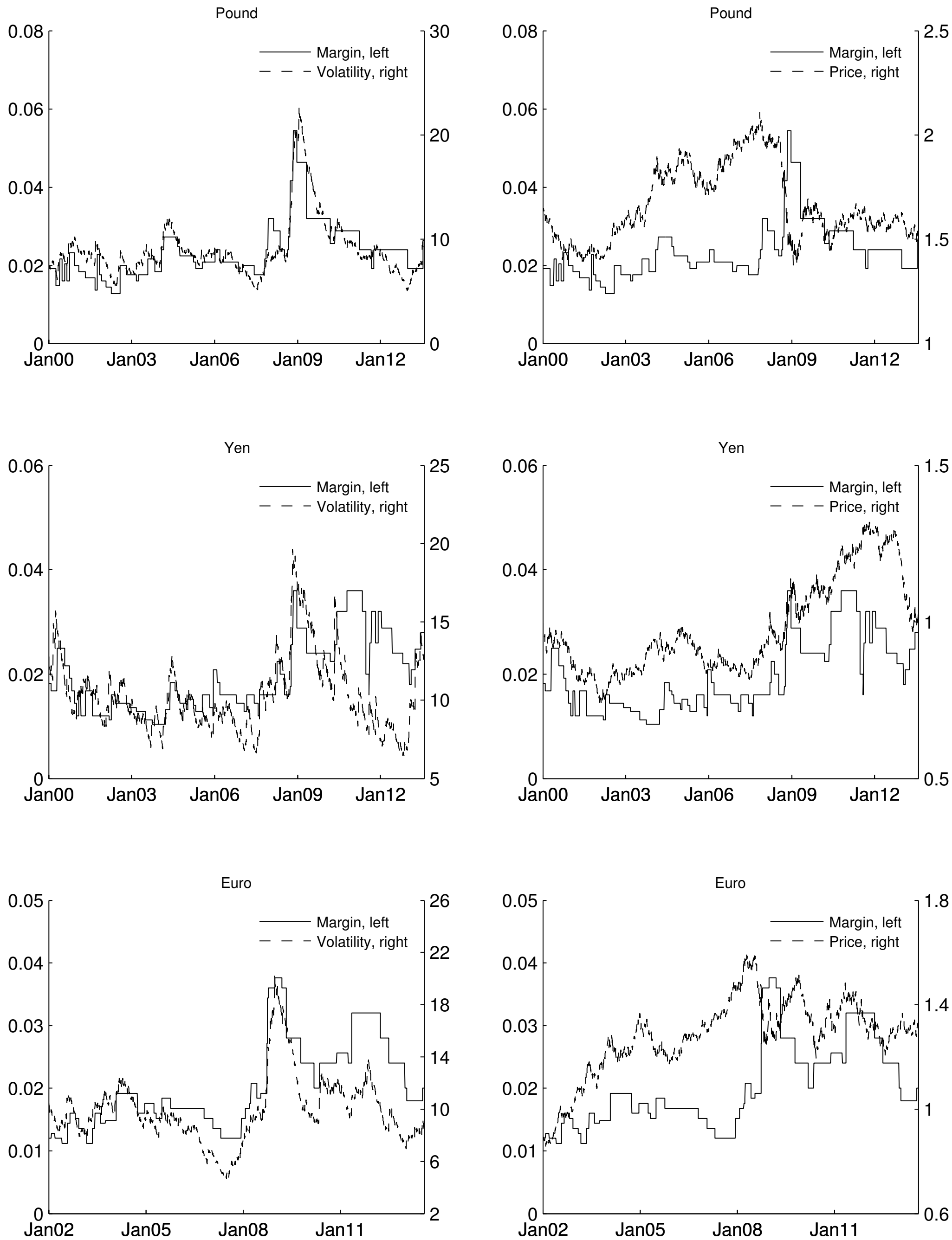

Figure 2: **Relations of margin to volatility (left panel) and to futures price (right panel) for currency futures**

The left panels compare maintenance margin level (solid line) to EWMA volatility (dashed line), and the right panels compare maintenance margin level (solid line) to the futures price (dashed line) for CME Group's currency futures. The top, middle, and bottom panels correspond to the British pound, the Japanese yen, and the euro futures, respectively.

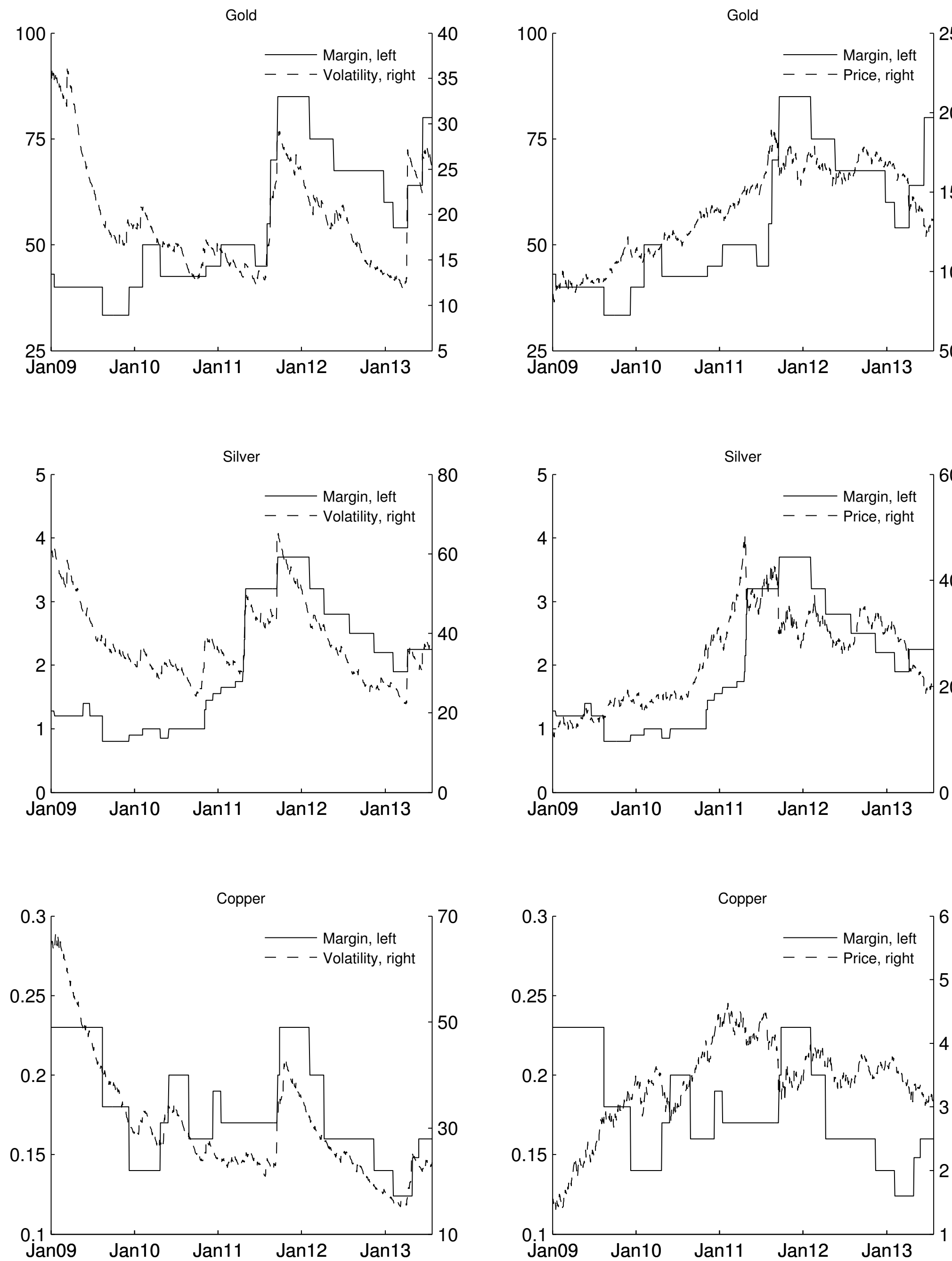

Figure 3: **Relations of margin to volatility (left panel) and to futures price (right panel) for metal futures**
The left panels compare maintenance margin level (solid line) to EWMA volatility (dashed line), and the right panels compare maintenance margin level (solid line) to the futures price (dashed line) for CME Group's metal futures. The top, middle, and bottom panels correspond to gold, silver, and copper futures, respectively.

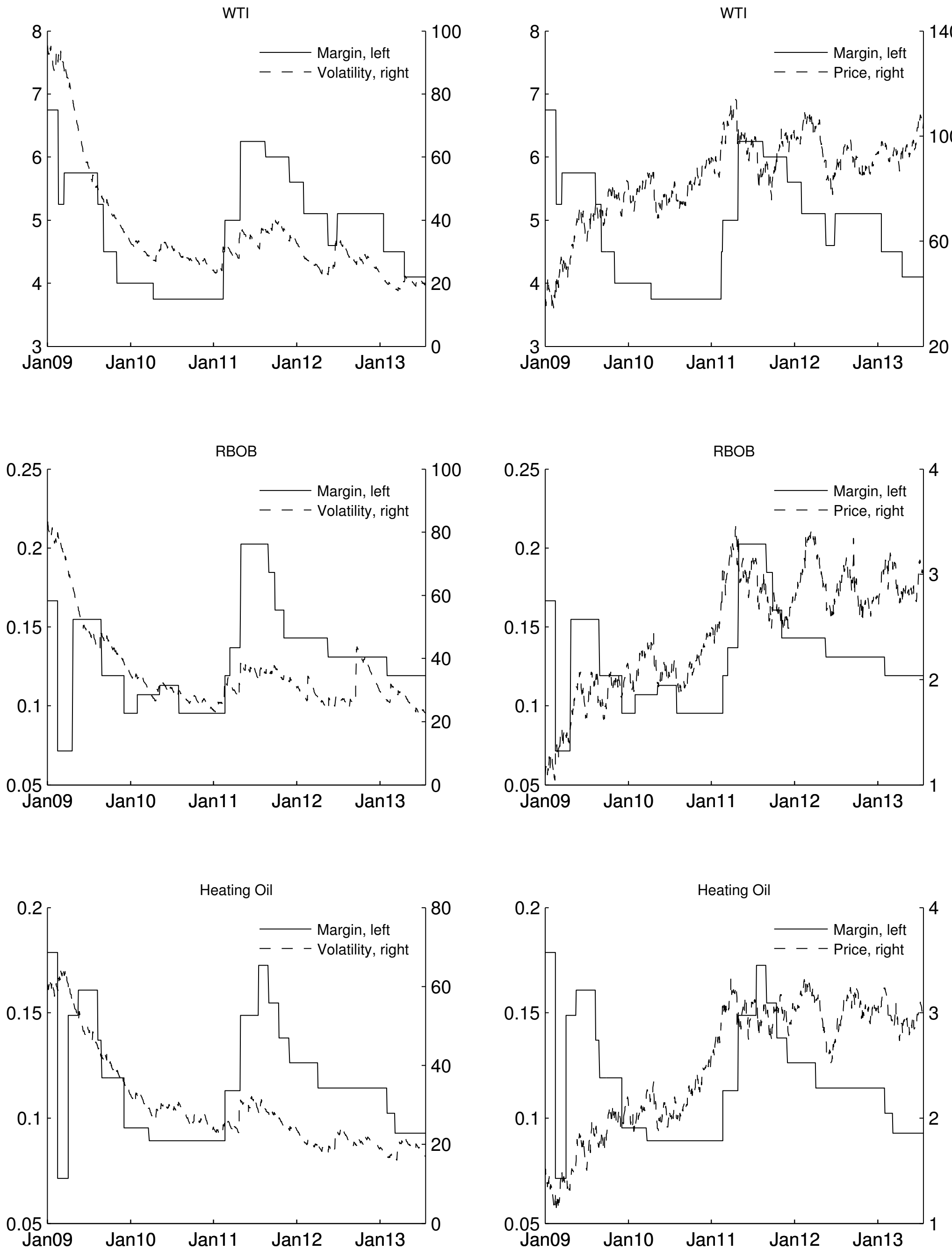

Figure 4: **Relations of margin to volatility (left panel) and to futures price (right panel) for energy futures**

The left panels compare maintenance margin level (solid line) to EWMA volatility (dashed line), and the right panels compare maintenance margin level (solid line) to the futures price (dashed line) for CME Group's energy futures. The top, middle, and bottom panels correspond to WTI crude oil, RBOB gasoline, and heating oil futures, respectively.

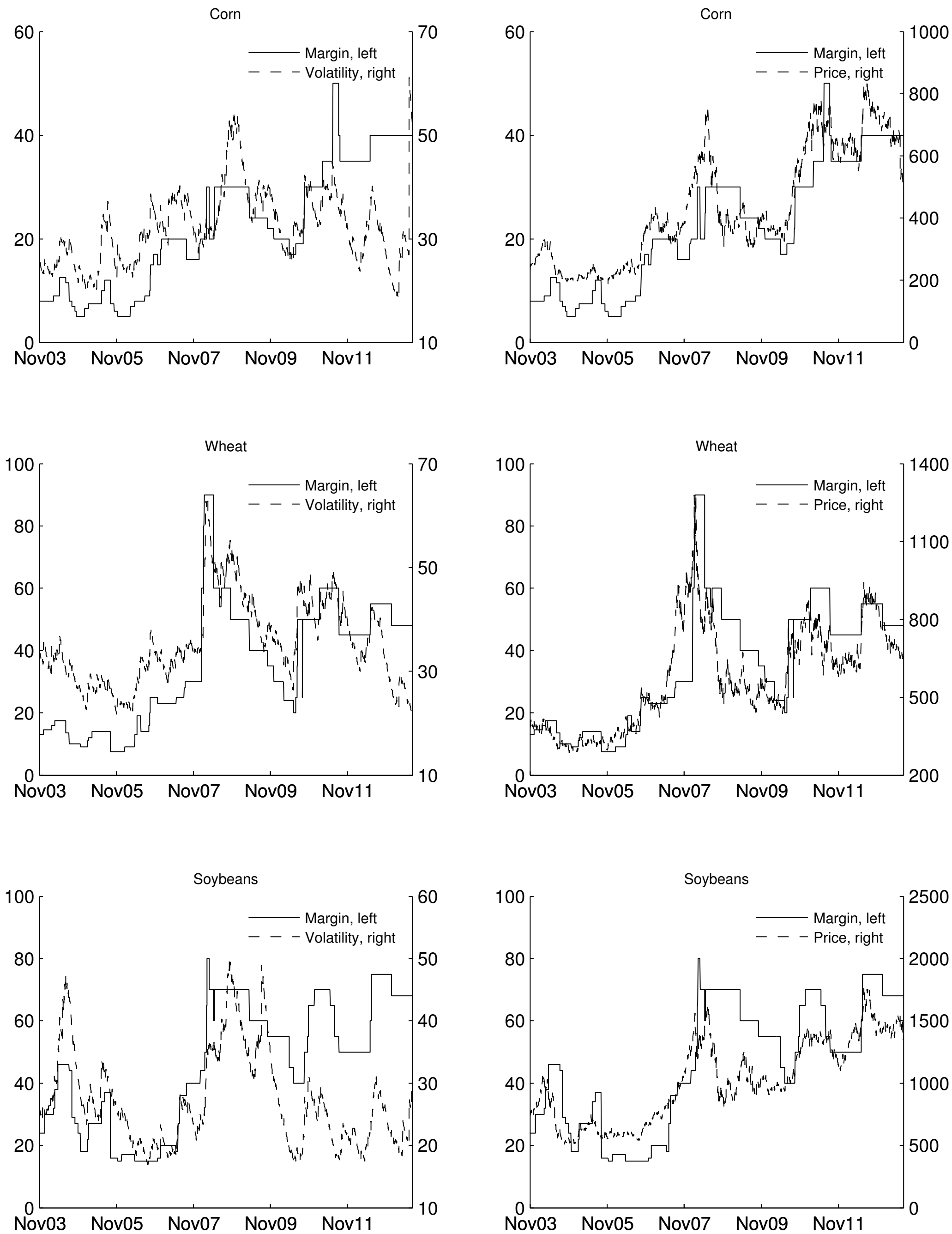

Figure 5: **Relations of margin to volatility (left panel) and to futures price (right panel) for agriculture futures**

The left panels compare maintenance margin level (solid line) to EWMA volatility (dashed line), and the right panels compare maintenance margin level (solid line) to the futures price (dashed line) for CME Group's agriculture futures. The top, middle, and bottom panels correspond to corn, wheat and soybean futures, respectively.

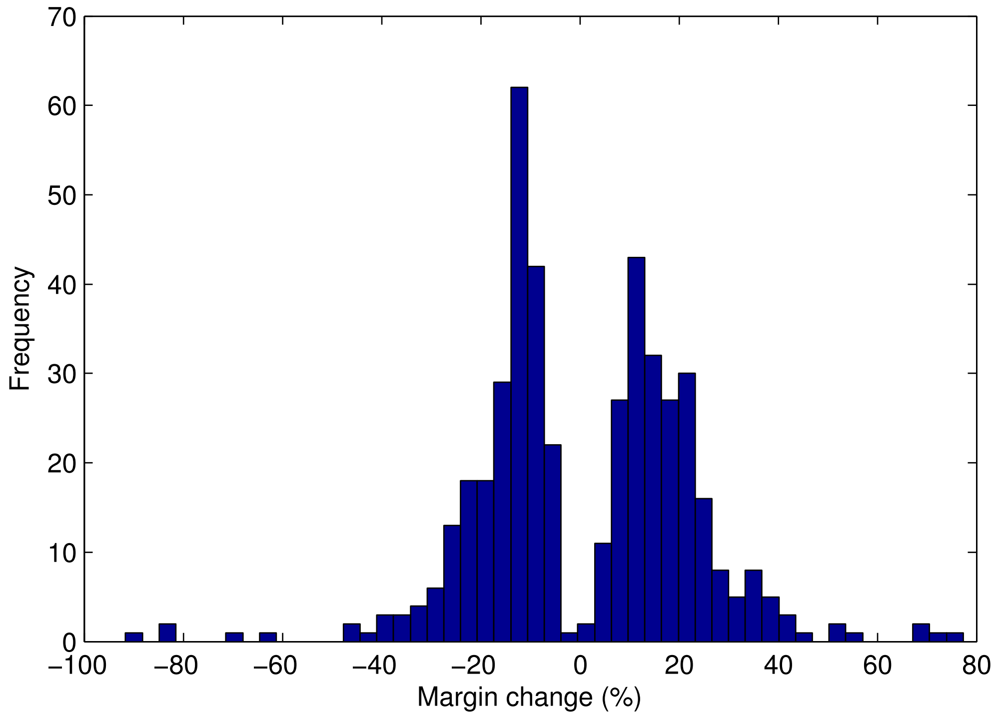

Figure 6: **Histogram of margin changes for all futures contracts**
This figure plots the frequency of margin changes for all futures contracts. It can be seen that most of the margin changes are concentrated in the ranges of plus and minus 10 to 25 percent and that there are very few observations of small margin changes.

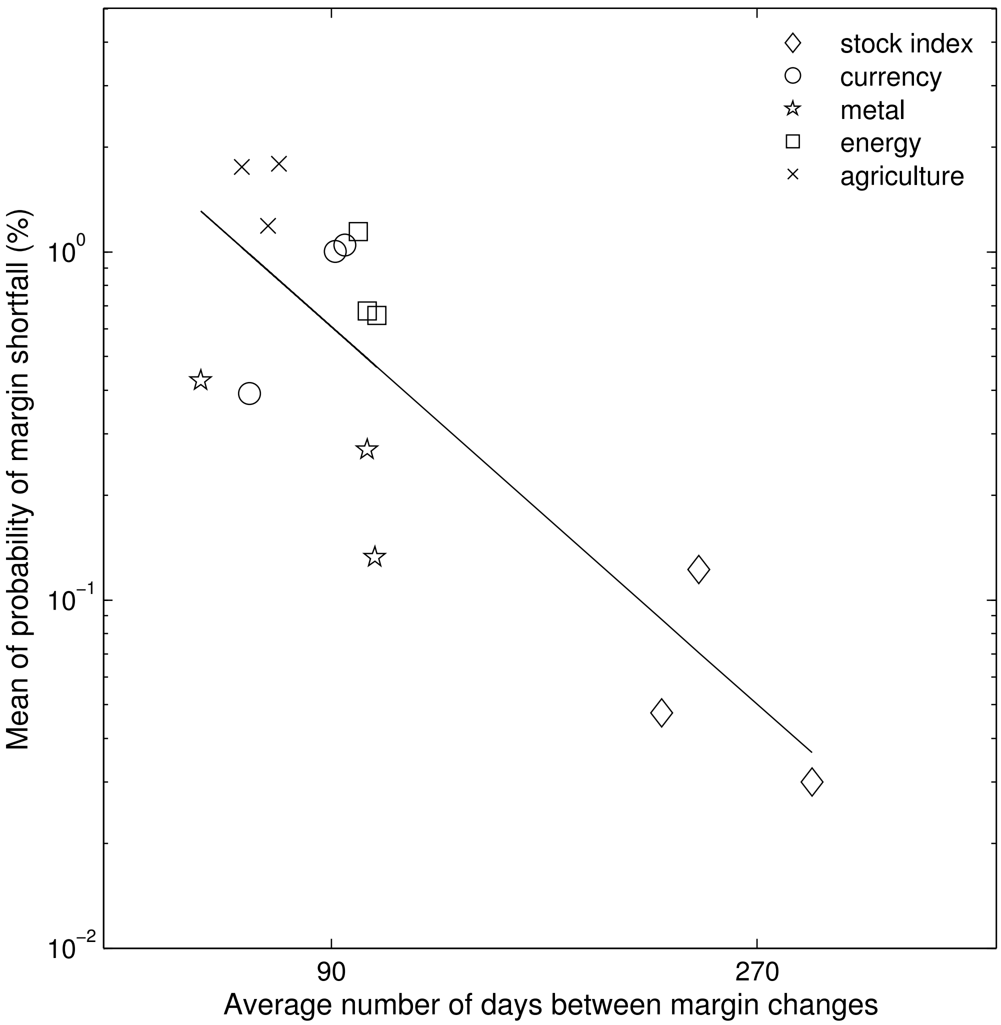

Figure 7: **Average probability of margin shortfall versus the average number of days between margin changes across different futures contracts**
The figure shows a scatter plot of the average number of days between margin changes against the mean of 1-day probability of margin shortfall. This scatter plot indicates that there is a negative relation between these variables. That is, the higher the probability of margin shortfall the smaller the average number of days between margin changes.

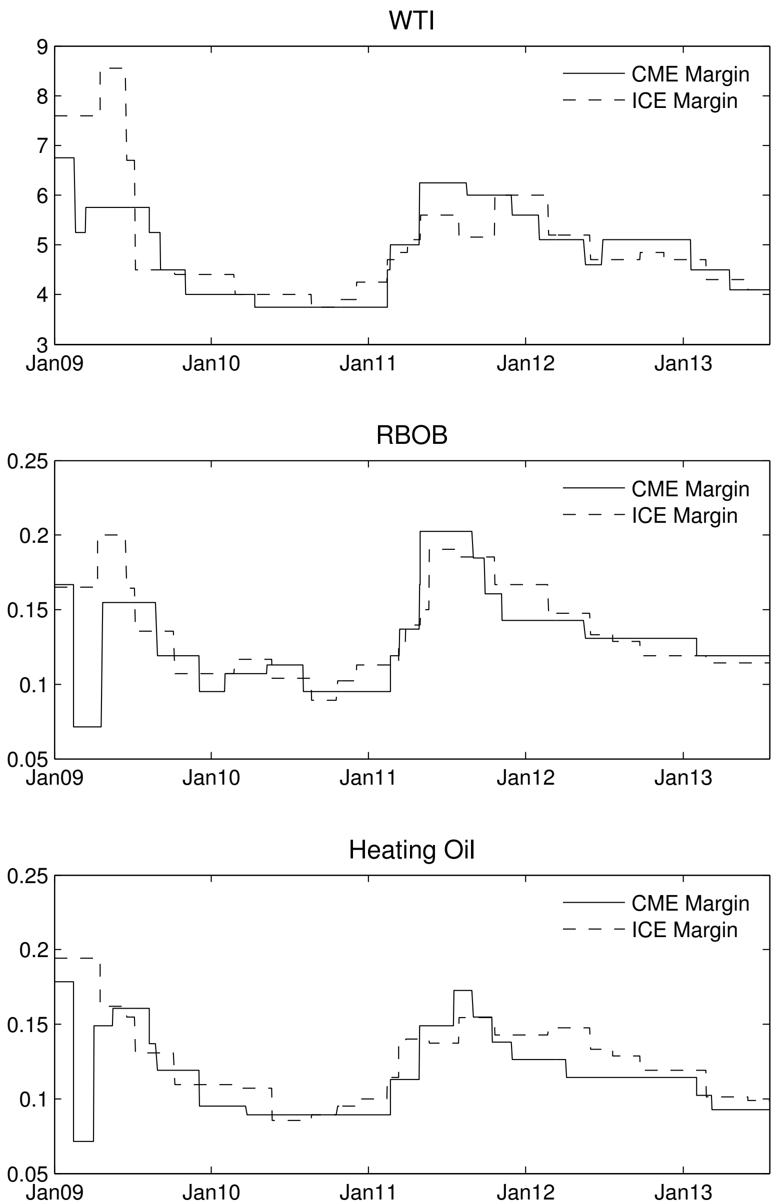

Figure 8: **Comparison of energy futures margins between CME Group and ICE**

This figure compares maintenance margin levels between CME Group and ICE for the energy futures contracts. The top, middle, and bottom panels correspond to WTI crude oil, RBOB gasoline, and heating oil futures. The solid and dashed lines of each panel correspond to CME Group and ICE, respectively.