Does Funding Liquidity Cause Market Liquidity? Evidence from a Quasi-Experiment

Petri Jylhä*

February 18, 2019

Abstract

Using an exogenous reduction in margin requirements, this paper shows that funding liquidity causally affects market liquidity. On July 14, 2005, the Securities and Exchange Commission approved a pilot program that permitted portfolio margining of index options. The resulting significant improvement of funding liquidity led to an increase in trading volume and a decrease bid-ask spread compared to the unaffected equity options. The liquidity improvements are larger for options that experience a larger reduction in margin requirements. These results provide strong causal evidence in support of the theories presented by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009).

JEL Classification: G12, G28.

Keywords: Funding liquidity, market liquidity, portfolio margin.

---

*Aalto University School of Business; P.O. Box 21220, FI-00076 Aalto, Finland; petri.jylha@aalto.fi. I thank Bruno Biais, Nick Bollen, Ralph Koijen, Pietro Veronesi, and the participants at European Finance Association 2016, European Summer Symposium in Financial Markets 2016, Financial Engineering and Banking Society 2015, Financial Management Association European Meeting 2016, Luxembourg Asset Management Summit 2015, SUERF conference "Liquidity and Market Efficiency - Alive and Well?", and Aalto University for helpful comments. Declarations of interest: none.

1 Introduction

What causes market liquidity? This question has received a lot of attention in recent years. One prominent line of answers posits that funding liquidity (the liquidity pertaining to a trader's liabilities) causes market liquidity (the liquidity of the assets traded). This literature builds on Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) who provide theoretical models where funding constraints result in traders not fully providing liquidity to the market, resulting in a causal effect from funding liquidity on market liquidity. These papers are both highly cited and the idea of relation between funding and market liquidities is widely applied. However, the empirical testing of these theories is not a trivial task. A mere correlation between measures of funding liquidity and market liquidity is not enough to establish a causal relation from the former to the latter and may as well arise from a confounding factor affecting both variables simultaneously or from market liquidity having an effect on funding liquidity.[1] Nonetheless, for the validity of the theories, a causal link from funding liquidity to market liquidity should be established.

In this paper, I use an exogenous shock to the margin requirements of a limited set of securities to show the causal effect of funding liquidity on market liquidity. On July 14, 2005, after a lengthy process, SEC approved a new method for calculating margin requirements for index options. This new portfolio margining method greatly reduced the required margins of index option while, importantly, having no impact at all on the margins of equity options. The reduction in the margin requirements acts a significant positive shock to index options' funding liquidity: in some cases, the capital required to set up a portfolio of options is reduced by as much as 90%. The same margining method was later extended to single-name equity options and other securities but in the first stage

[1] In the model of Brunnermeier and Pedersen (2009) there is a feedback effect from market liquidity to funding liquidity.

only applied to index options. Being exogenous to the prevailing market conditions and affecting only a part of the options market, this implementation of a new margining method provides a quasi-experiment and allows for identification of the causal link from funding liquidity to market liquidity.[2]

The results of this paper are clear: an improvement in funding liquidity causes an improvement in market liquidity. Using the unaffected equity options as a control group, I show, in a difference-in-difference framework, that following the margin requirement reduction the market liquidity of index options improves significantly. First, the trading volume of index options increases by 16% over and above the simultaneous growth in the trading volume of equity options. This result is perfectly in line with the predictions of both Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) that margin constraints prevent traders from taking socially optimal positions and fully providing liquidity. Further, as a result of the margin reduction, option trading moves towards out-of-the-money options for which the reduction in margin requirements is the largest.

Second, the improvement in funding liquidity of index options leads to a reduction in their bid-ask spreads. On average, the index options' spreads narrow by about 9% compared to the pre-treatment spread. This reduction in direct trading costs signifies a very sizable improvement in market liquidity resulting from the reduction in margin

[2] A quasi-experiment differs from a natural experiment in the way the treatment is assigned. In a natural experiment, the treatment is assigned randomly to subjects. In a quasi-experiment, the treatment is assigned non-randomly. The liquidity shock used in this paper applies to index options but not to equity options. Hence the assignment is not random as it is defined by the type of the underlying asset. Importantly, however, the decision to only apply the new margining method to index options was made well in advance. Hence, there should be no concerns of reverse causality, i.e. improvement in the index option market liquidity after the the approval of portfolio margining affecting the decision to apply the new margining practice to index options rather than equity options.

requirements. Moreover, in line with the theories, in the cross-section of index options the reduction in spreads is greater for those options that experience a larger reduction in margin requirements.

From the theory point of view, this paper is motivated by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009), both of which establish the connection between funding liquidity and market liquidity. In the model of Gromb and Vayanos (2002), some traders have the ability to trade identical securities in segmented markets. However, they cannot fully exploit the the price discrepancies between the two markets due to each market requiring its own separate margin. Hence, the constraints in the arbitrageurs' funding liquidity result in a suboptimal level of liquidity being provided to the markets. Actually, in the framework of Gromb and Vayanos (2002), implementation of the type of a margin calculation method used in this study would result in the arbitrageurs fully arbitraging away any price difference between the markets and hence fully supplying the liquidity demanded by other traders.

Brunnermeier and Pedersen (2009) provide a model to study liquidity spirals, i.e. self-reinforcing cycles of tightening funding constraints decreasing traders' positions resulting in worsening market liquidity, which in turn increases margin requirements and further tightens the funding constraints and so forth. A key ingredient in this spiral is the feedback effect from market liquidity to margin requirements. This feedback effect also highlights the problem facing any attempts to empirically verify the causal effect of funding liquidity on market liquidity. A mere correlation between the two does not establish causality as both dimensions of liquidity affect each other and are both likely also affected by other variables. Hence, to establish causality, a strictly exogenous shock to funding liquidity is required, such as a regulatory change in margin requirements, as used in this study.

Some existing empirical research studies the causal effect of margin requirements on market liquidity. Kahraman and Tookes (2017) analyze the relation between funding liquidity and market liquidity using data on margin trading of stocks in India and find results similar to mine. Heimer and Simsek (2017) study the effects of a margin requirement increase in a sample of retail foreign exchange traders. While they mainly focus is on the improved portfolio returns, they also document a decrease in trading volume but no change in bid-ask spread resulting from increased the margin requirement. Using the implementation of portfolio margining in the US options markets has a number of advantages over the Indian stock market and retail foreign exchange trader data. First, the US options market is large and liquid to begin with making it difficult to identify further liquidity improvements. Finding market liquidity improvements in such a difficult laboratory is strong evidence in favor of the theories. Second, the traders in the market are likely to be sophisticated and any results are unlikely to be driven by the margin requirement changes affecting the behavioral biases of the market participants. Third, there are large cross-sectional differences in option liquidity; for example out-of-the-money options are less liquid than at-the-money options. This allows the study of what kinds of assets benefit most from funding liquidity improvements.

Also the work of Hedegaard (2011) is related. Using data on time-varying margins on futures contracts traded on the Chicago Mercantile Exchange (CME) he shows that higher margins imply lower liquidity. The problem with the futures margins is that, by definition, they are set and changed according to volatility. Volatility, of course, may affect traders' decisions to provide liquidity directly, not just through the margin requirements. As such, margins that are set as a function of past market conditions are not exogenous to future market conditions and do not allow for identification of causality. These issues in the existing literature highlight the need for truly exogenous variation in funding liquidity, such as the approval of portfolio margining, to establish its causal effect on market liquidity.

This paper is also related to the literature on the effects of margin regulation on asset markets. Matsypura and Pauwels (2014) provide evidence that the implementation of portfolio margining fueled the growth of margin debt prior to the financial crisis of 2008. Earlier, between the years 1934 and 1974, the Federal Reserve used its Regulation T to actively manage the initial margin requirement on levered stock purchases. These regulatory changes of funding constraints have been used to study the effect of margin requirements on volatility and asset pricing. Starting from Officer (1973), the nearly unanimous conclusion of these studies is that margin regulation has no impact on market volatility. Kupiec (1997) provides an extensive review of this literature. Jylhä (2018) uses the federally mandated initial margin requirements to show that tighter funding constraints result in a flatter security market line, as predicted by Frazzini and Pedersen (2014).

The rest of the paper is organized as follows. Section 2 describes the margining practices in the US securities markets and especially the portfolio margining pilot program used as the exogenous funding liquidity shock in this paper. Section 3 describes options data and the construction of market liquidity proxies. Section 4 presents the empirical results and Section 5 concludes.

2 Funding liquidity shock

This section describes the exogenous shock to funding liquidity used in this paper: the gradual implementation of portfolio margining in the US markets. Margin requirements dictate the equity proportion investors must hold in their margin accounts when borrowing to purchase securities, borrowing securities for short-selling, or entering a position in derivative securities. This equity serves to provide a cushion against future liabilities resulting from adverse market moves. The two main components of margin requirements are the initial margin which represents the required equity at the initiation of the position, and the maintenance margin which is the minimum equity to be maintained throughout the life of the position. Generally, margin requirements serve four purposes: 1) protecting the counterparty against default of the investor, 2) protecting the investors against taking excessive leverage, 3) protecting the functioning of the market by reducing the likelihood of fire sales, and 4) preventing credit being allocated excessively to speculation at the cost of productive businesses (Fortune, 2003).

In the United States, federal regulation of margin requirements dates back to the Securities Exchange Act of 1934 that mandates the Board of Governors of the Federal Reserve to set the margin requirements for the US securities markets. The Fed exercises this power mainly via its Regulation T which sets the minimum initial margin levels for borrowing from broker-dealers.[3] The setting of minimum levels for maintenance margin is delegated to the the exchanges. Currently, the maintenance margin requirements are set in, for example, the New York Stock Exchange's (NYSE) Rule 431, the Financial Industry Regulatory Authority's (FINRA) Rule 4210, and the Chicago Board Options Exchange's (CBOE) Rule 12.3.

Originally, margin requirements were set on a position-by-position basis where positions in different securities have to be collateralized separately. The development of derivatives markets made it possible to set up portfolios of related securities whose overall risk level is far lower than that of the individual components. In such cases, the security level margining would result in very high margin requirements compared to the total risk of the portfolio. To remedy this, SEC (which is granted the power the set the margin requirements for option markets under section 12 of Regulation T) allowed for strategy-based margining of some predefined options strategies. Such strategy-based margining takes into account

[3]Regulations U and X, and formerly G, applied similar margin requirements to borrowing from banks and other non-broker-dealer lenders.

the overall riskiness of the strategy as a whole rather than the riskiness of the individual securities making up the strategy and results lower margin requirements than security level margining.

With the development of more complex option strategies, the strategy level margin calculation rules seem outdated. Also, developments in tools to analyze the risks of option portfolios, especially the Theoretical Intermarket Margining System ("TIMS") by the Options Clearing Corporation, made it efficient to calculate margins on the portfolio level regardless of what strategies are followed by the investors. In 2002, NYSE and CBOE sought SEC approval to amend margin rules to allow for portfolio level margining of positions in related securities, i.e. options on the same underlying and the underlying itself. After three years of comments and amendments, the SEC approved the use of such portfolio margining on a pilot basis. The first phase of the pilot program came into effect on July 14, 2005, and allowed for portfolio margining of listed derivatives on broad-based market indexes (SEC, 2005). After the successful first phase, the pilot program was extended to include listed derivatives on individual stocks on July 11, 2006, and stocks and unlisted derivatives on April 2, 2007. The pilot program was ended, and portfolio margining made a permanent practice effective on August 1, 2008 (SEC, 2008).

To understand how the different margining systems work, let us examine a simple example of a short option strangle which consists of a written (sold) put option and a written call option. Let us assume that the underlying of these options is a broad-based market index with current index value of 1451.19, and that the strike prices are 1425 and 1500 and the premiums are 11.66 and 5.96, for the put and the call respectively. In the standard security-level margining, the put and the call must be collateralized separately. The CBOE Rule 12.3 states that for written options the writer must deposit the full proceeds of the sale plus 15% of the underlying index value minus out-of-money amount, if any. This results in margin requirement of $19,149 for the put and $16,887 for the call.[4] Hence, under security level margining, the investor would have to deposit $36,036 in a margin account to set up the short strangle. The strangle, however, is one of the predetermined strategies listed in CBOE Rule 12.3 for which the strategy-based margining can be applied. In the case of the short strangle, the strategy-based margin requirement is equal to the margin requirement of the put or the call, whichever is greater plus the proceeds of writing the other option. This results in the strategy-based margin requirement for the short strangle to be identical to that of written put option above, i.e. $19,149, which is 47% less than under security-level margining.

The portfolio-based margining works quite differently from the security or strategy-based methods. Rather than defining margin requirement as a percentage of the portfolio value, the portfolio margin requirements are based on a scenario analysis of theoretical portfolio profits and losses. The total portfolio is valued for a range of possible values of the underlying asset and the margin requirement is set to equal largest loss in this range.[5] The more the positions within the portfolio offset each other the lower the margin requirement will naturally be. In the case of the short strangle, losses occur when the underlying either appreciates or depreciates a lot. In our example, the largest theoretical loss in the potential range of underlying index values is $6,704, which is also then the portfolio-based margin requirement for the short strangle.[6] This is 65% less than the margin requirement under strategy-based margining representing a significant reduction

[4] Note that index options have a multiplier of 100, i.e. one contract is on 100 units of the index. Writing options results in proceeds which, in this example, are deposited to the margin account.

[5] For example, for an index underlying the range is from -8% to +6% of current index value, and for an equity underlying the range is from -15% to +15% of current stock price.

[6] This number is based on valuation of the options using the TIMS and is provided as an example by CBOE (2007).

in the investor's capital requirement and a major improvement in funding liquidity. This reduction in margin requirements when moving to portfolio margining is not an atypical example. CBOE (2007) provides other similar examples of margin requirements for various common option positions using the strategy-based margining method and the portfolio margining method. These example calculation show that for positions fully made out of S&P 500 index options the portfolio margin requirement is, on average, only 28% of the strategy-based margin requirement.

In this paper, I use the first phase of the portfolio margining pilot program as a quasi-experiment to study the causal effect funding liquidity has on market liquidity. The first phase, implemented on July 14, 2005, allowed portfolio margining of index options but not of single-name equity options and is ideal for this study for five main reasons reasons. First, the margin requirements are a very important aspect of option markets. In the stock market the margin requirements are only relevant when short-selling or buying on the margin but in the options markets every trade is affected by the requirements as the option writer always has to provide a collateral. Hence, changes in margin requirements directly affects traders' ability to write options. Portfolio margining also lowers the margin required when borrowing money to buy options. Before the implementation of portfolio margining, options with less than nine months to maturity could not be purchased on the margin at all and for longer maturity options the margin requirements were relatively high. Portfolio margining significantly lowers these requirements and makes the shorter maturity options marginable as well, improving also the funding liquidity of the option buyers.

Second, this design is free of any reverse causality concerns, i.e. the changes in option market liquidity following the approval of portfolio margining affecting the way in which the portfolio margining pilot program was implemented. It is highly unlikely that CBOE applied for the approval of portfolio margining in 2002 because it knew that in the liquidity of index options is going to significantly improve compared to the liquidity of equity options in the latter half of 2005. This exogeneity of the funding liquidity shock is key to identifying a causal relation, rather than just establishing a correlation.

Third, and importantly from the econometric point of view, the first phase of the portfolio margining pilot only affects a part of the equity-based options market. The fact that the new margining treatment only applies to index options but not equity options allows for a difference-in-difference estimation of the effects of improved funding liquidity using the index options as a treatment group and the equity options as a control group. This setup controls for any concurrent market-wide trends in liquidity measures and identifies the causal effect of improvement in funding liquidity on market liquidity.

Fourth, the reduction in the margin resulting from the implementation of portfolio margining is not uniform across the affected index options. Under portfolio margining, the margin requirement depends on the total portfolio of the trader making it impossible to determine a single margin requirement for an individual option. Regardless, the margins required for naked writing of an option yield useful insight into the cross-sectional variation in the effect of portfolio margin implementation. The top left panel of Figure 1 presents the required margins for writing a call option with price of underlying 100, volatility 30%, time to maturity 0.5 years, risk-free rate 2%, and strike price varying from 40 to 180. The strategy-based margin is calculated according to CBOE Rule 12.3. The portfolio-based margin is calculated using a second order approximation of the Black and Scholes (1973) option value. The top right panel gives the relative difference between the strategy-based and portfolio-based margin requirements, and the bottom part of the graph provides the same for put options. These graphs show that while the margin reduction resulting from the portfolio margining implementation is sizable for all options, out-of-the-money options are affected much more than in-the-money options.[7] Also, the reduction in the margin is not linear in moneyness. Hence, in some of the empirical analyses below, I use the reduction in margin to measure the magnitude of the effect portfolio margining has on the options.

[Figure 1 here]

Fifth, and finally, the start of the pilot program happens during very calm market conditions. Figure 2 plots the development of the S&P 500 index, the VIX volatility index, and the TED spread (i.e. the difference between the three-month Eurodollar rate and the three-month Treasury yield) around the portfolio margining implementation date of July 14, 2005. As is evident in the graph, the market environment is relatively tranquil during the 200-day time window used for estimation below. The S&P 500 index trades within an 11% range (1,138 to 1,268), the VIX stays at very low levels between 10.2 and 17.7, and the TED spread remains relatively low. This market calmness is good for identification as it rules out the possibility of any market turmoil explaining the results. If the portfolio margining pilot was approved, say, during the financial crisis of late 2008, simultaneous improvement or worsening of market liquidity could be explained by other crisis events. However, as the funding liquidity shock happens during an uneventful period, concurrent market turmoil cannot explain the results below.

[Figure 2 here]

Measuring funding liquidity–especially its variation, in the cross section or in the time series–is a difficult task. A commonly used proxy for funding liquidity is an interest rate

[7] Curiously, the reduction in put option margin reaches a minimum at the point where the strike exceeds the price of underlying by 50%. However, there are very few so deep-in-the-money puts in the data.

spread–such as the TED spread.[8] However finding a positive correlation between an interest rate spread and a market liquidity measure would not establish a causal effect of funding liquidity market liquidity. Such correlation can as well be driven by market liquidity affecting the interest rate spread or a third factor, such as changes in investors' expectation or risk aversion, affecting both without any further connection between the two liquidity measures. Drehmann and Nikolaou (2013) measure funding liquidity by banks' bidding aggressiveness in the European Central Bank's auctions for short-term refinancing. Whereas this potentially provides a more accurate measure of funding liquidity, it would still suffer from the same problems of establishing causality if correlated with market liquidity measures. The bidding aggressiveness can also be affected by confounding variables that affect also liquidity provision directly. As mentioned above, Hedegaard (2011) uses variation in margin requirements on futures traded on the CME as a measure of funding liquidity. However, since the variation in margin requirement is driven by past volatility, this measure cannot be used to establish a causal link. All these examples highlight the need for an exogenous funding liquidity shock, like one driven by a regulatory change as used in this paper or the monthly reassignment of marginable stocks in India used by Kahraman and Tookes (2017).

3 Data

In the first pilot phase, portfolio margining was available for positions in derivatives whose underlying asset is a broad-based market index, but not for derivatives whose underlying

[8]For examples of papers that use the TED spread as a funding liquidity proxy, see Asness, Moskowitz, and Pedersen (2013), Moskowitz, Ooi, and Pedersen (2012), Cornett, McNutt, Strahan, and Tehranian (2011), Ranaldo and Söderlind (2010), Gârleanu and Pedersen (2011), Brunnermeier and Pedersen (2009), and Brunnermeier, Nagel, and Pedersen (2009).

asset is a stock (SEC, 2005). To reflect this, the treatment group used in the empirical tests contains the broad-based index options whereas the control group contains the most actively traded equity options. The treatment group includes options on the Dow Jones Industrial Average, Nasdaq 100, Russell 2000, S&P 100, and S&P 500. These are the broad market indexes whose options have sufficient amount of trading volume throughout the sample period to reliably estimate the market liquidity measures.[9] The control group consists of options on those 30 U.S. common stocks that had the highest option trading volume in 2004. As the effects of the portfolio margining pilot program are likely to take some time to materialize, I use a 200-day sample window starting 100 trading days before the approval of the first pilot stage, i.e. on February 18, 2005, and ending on December 2, 2005.

I use daily option price and volume data from OptionMetrics to construct measures of option market liquidity. Before construction of the liquidity measures, I filter the data in a number of ways–closely following Cao and Wei (2010)–to ensure that the results are not driven by anomalous outliers. First, all option-day observations with zero trading volume are removed. I also remove observations with very short (less than 9 days) or long (over a year) time to maturity. To mitigate any microstructure issues, I remove those option-day observations where the best quoted bid is less than $0.125. To filter out potentially erroneous data, I also remove all observations where the best quoted bid is higher than the best quoted ask and observations where the difference between the best bid and ask quotes is more than half of the mid quote. Finally, I only keep observations for which OptionMetrics provides implied volatility, delta, and gamma.

I measure market liquidity by trading volume and bid-ask spread. I measure trading

[9]Options on the Russell 1000 index are excluded from the sample as they were very thinly traded in 2005.

volume in two ways: contract volume and dollar volume. Contract volume is the number of option contracts traded during a trading day. Dollar trading volume is the dollar value of the contracts traded, calculated as the contract volume times closing mid quote. These trading volume measures are summed over all options for each underlying asset each day to get an underlying-day level measure of trading volume. The bid-ask spread is simply the difference between the best bid and the best ask quote at market closing time divided by the mid quote. Table 1 provides the means and standard deviations of the market liquidity measures separately for the treatment group of index options and the control group of equity options before and after the approval of the portfolio margining pilot program.

[Table 1 here]

Some interesting observations and implications arise from the table. First, the index options have higher trading volumes than the equity options, both in terms of numbers of contracts traded and the dollar value of trading. For this reason, in the regressions presented below, the trading volume variables will always be in logarithms and the analysis akin to studying the relative change in volumes as a result of the funding liquidity shock. Second, and more interestingly, the effect of funding liquidity improvement on market liquidity is evident when comparing the changes of the liquidity measures for the index options as opposed to the equity options. The contract trading volumes increase for both types but more for the index options. The average bid-ask spread tightens for index options whereas it actually widens slightly for the equity options. These results point to the conclusion that improved funding liquidity causes an improvement in market liquidity, as predicted by Brunnermeier and Pedersen (2009).

As noted above, the reduction in margin resulting from the implementation of portfolio margining is not uniform across the affected index options. To measure the magnitude of the effect at the option-level, I calculate for each option each day the relative difference between the strategy-based margin and portfolio based-margin required when writing the option. According to the CBOE Rule 12.3, the additional margin, over the proceeds from writing the option, is

$$m_S = \begin{cases} \max\left(a\,S - \max\left(K - S, 0\right), b\,S\right) & \text{for calls} \\ \max\left(a\,S - \max\left(S - K, 0\right), b\,K\right) & \text{for puts} \end{cases} \tag{1}$$

where S is the current price of the underlying and K is the strike price of the option. For index options $a = 15\%$ and $b = 10\%$, while for equity options $a = 20\%$ and $b = 10\%$.

The portfolio-based margin depends on the portfolio of the trader and the model used to value the options. As explained above, the portfolio margin equals the maximum loss of the trader's total portfolio in a predetermined set of scenarios. I simplify the calculation and estimate the portfolio margin for a naked writer of the option who does not hold a position in the underlying asset or other derivatives on it. I also assume that the portfolio margin is calculated based on a second-order Taylor series of the Black and Scholes (1973) value with a constant volatility. The portfolio margin then becomes

$$m_P = \delta\,\Delta S + \frac{1}{2}\gamma\left(\Delta S\right)^2, \tag{2}$$

where ΔS is the most adverse change in the underlying asset, and δ and γ are the first and second partial derivatives of the option value with respect to the price of the underlying asset. The portfolio margining rules define that the scenarios for index options run from an 8% decrease to a 6% increase in the price of the underlying asset. I use $\frac{\Delta S}{S} = 6\%$ for call options and $\frac{\Delta S}{S} = -8\%$ for put options as these represent the worst scenarios for the option writers. Finally, I calculate the reduction in margin as the difference between m_S and m_P divided by m_S. This number represents the percentage decrease in the margin required for writing the option resulting from the portfolio margining implementation.

4 Results

4.1 Pre-existing trends

An assumption of the difference-in-difference framework employed below is that the trends in the outcome variables before the treatment are similar for the treatment and control groups. Hence, before the formal analyses of the causal impact of the effects, Figure 3 presents the trends in the market liquidity measures for the two years before and after the portfolio margining implementation date.

[Figure 3 here]

The left panel of the figure plots the monthly averages of the logarithm of trading volume for the index options and equity options separately. The average trading volumes of both index options and equity option display an increasing trend before the implementation of portfolio margining in July 2005. While the averages are rather noisy, it is clear from the figure that trends before the treatment are rather similar. After the implementation, the index option volumes are clearly larger before the implementation, whereas the increase in the equity option volume is more modest. This effect of the implementation on the volumes is studied in detail in Section 4.2 below.

The right panel of Figure 3 plots the monthly averages of the logarithm of the bid-ask spread. Also here, the pre-implementation trends are close to parallel albeit the monthly averages are quite volatile. The sharp drop in the bid-ask spread following the implementation is analyzed in Section 4.3 below.

Overall, the evidence in Figure 3 shows that before the implementation of portfolio margining the market liquidity measures of the index options and equity options developed in a relatively parallel manner. This allows for the use of the difference-in-difference framework to identify the causal effect of the portfolio margining on market liquidity. Furthermore, below I use a relatively short estimation window around the implementation date to isolate the impact of the change in margins.

4.2 Trading volume

The way the portfolio margining was gradually introduced allows for the identification of the causal effect of the funding liquidity shock on the market liquidity of the affected index options while using the unaffected equity options as a control group to capture any concurrent market-wide changes in liquidity. I start by studying the effect of the margin requirement reduction on option trading volume, and estimate the following regression:

$$Volume_{i,t} = \alpha + \beta_1\, Treated_i \times After_t + \beta_2\, Treated_i + \beta_3\, After_t + \theta'\, Controls_{i,t} + \varepsilon_{i,t}, \quad (3)$$

where $Volume_{i,t}$ is the logarithm of the total contract or dollar volume of options on underlying i on day t. $Treated$ equals one for the index options and zero for the equity options, and $After$ equals zero prior to the launch of the pilot program, on July 14, 2005, and one after the launch. In this framework, the β_2 coefficient gives the difference in the volume between index options and equity option before the treatment and β_3 gives the change in the volume for the equity options between the periods before and after the pilot program launch. The parameter of most interest in this setup is the difference-in-difference coefficient β_1 which gives the difference in volume changes between the index options and equity options. A significantly positive (negative) β_1 coefficient implies that the improvement in funding liquidity causes an increase (decrease) in the trading volume. It is important to note that due to the exogenous nature of the funding liquidity shock, β_1 measures the causal effect of funding liquidity on trading volume, rather than just statistical correlation between the two measures.

[Table 2 here]

Table 2 presents the results of estimating Equation (3) using the logarithm of the number of contracts traded as the dependent variable. The coefficient of the $Treated$ dummy in column (1) is highly significant and equal to 0.38 implying that the index options have, on average, 46.3% higher trading volume than the equity options in the period prior to the approval of the portfolio margining pilot program. The coefficient of the $After$ dummy is positive but lacks statistical significance. This implies that the trading volume of the equity options is not significantly affected by the reforms in the margin practices of index options. Finally, and most interestingly, the coefficient of the interaction term is positive and highly significant (t-statistic 3.30). As the dependent variable is logarithmic, the difference-in-difference coefficient of 0.146 implies that the improvement of funding liquidity causes the trading volume of index options to increase by 15.7% over and above the simultaneous change in equity option trading volume.

This causal effect from funding liquidity to market liquidity is robust to different regression specifications. Adding the lagged implied volatility, the lagged return of the underlying, and the squared lagged return of the underlying as controls has a minimal impact on the estimates of interest in column (2). The difference-in-difference coefficient is equal to 0.147 (t-statistic 3.32) which identical to the one without controls. To control for any remaining unobservable underlying and time characteristics, column (3) adds underlying and date fixed effects to the list of controls. Again, the impact of additional controls on the estimate of interest is limited. The interaction coefficient is equal to 0.165 (t-statistic 3.64) which is marginally higher than without the fixed effects. This estimate implies an increase of 18.0% in trading volume of the index option resulting from margin requirement reduction.[10] Overall, the funding liquidity improvement causes a sizable and robust increase in the trading volume. This is direct evidence in support of the theories of Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009) that funding constraints lead investors to take less-than-optimal positions.

The remaining columns present the results estimated using different sub-samples of data. Columns (4) and (5) show that the effect is somewhat larger for puts than calls. The increase in trading volume resulting from the portfolio margining introduction is 17.9% for call options and 25.2% for puts. There is a more notable difference in the impacts on in-the-money and out-of-the-money options. The introduction of portfolio margining does not have a significant impact on the trading volume of in-the-money options whereas the effect on out-of-the-money options is large and highly significant. The out-of-the-money index option trading volume increases by 27.7% (t-statistic 5.15) while the increase in the in-the-money volume is only 5.8% and not statistically significant. This result is consistent with the observation that the decrease in margin requirements, i.e. the size of the funding liquidity shock, is significantly larger for out-of-the-money options. Also, the out-of-the-money options are originally much less liquid than the in-the-money options. The results hence indicate that the funding liquidity improvement affects the less liquid assets more than the more liquid ones. These results highlight the importance of funding liquidity as a driver of market liquidity.

[Table 3 here]

Table 3 presents the estimation results of Equation (3) using the logarithm of the dollar trading volume as the dependent variable. The increase in dollar trading volume of the index options resulting from the funding liquidity improvement is only 2.9% in the

[10] Note that the $Treated$ and $After$ variables are subsumed by the fixed effects.

specification without controls or fixed effects, 3.7% with controls, and 6.5% with controls and fixed effects. None of the estimated difference-in-difference coefficients using the full sample is statistically significant at conventional levels. For the different sub-samples of the data, the effect of the funding liquidity shock on dollar volume is non-significant for calls and in-the-money options. Consistent with the contract volume results above, however, the difference-in-difference coefficient is significant positive for puts and out-of-the-money options. The improvement in the funding liquidity of the index options increases the dollar trading volume of index puts by 24.0% and out-of-the-money options by 15.3%.

If the average price of the options does not change with the implementation of the portfolio margining, the results in Tables 2 and 3 would be identical, i.e. growth in dollar volume would match the growth in contract volume. However, empirically, the funding liquidity improvement results in sizeable growth in in contract volume but a smaller, and often non-significant, increase dollar volume. This must be a result of the average price of the traded option decreasing with the treatment. This would be consistent with the result above that the contract volume growth happens especially in the out-of-money options. To investigate this issue further, the first three columns of Table 4 presents the results of difference-in-difference regressions where the dependent variable is the dollar volume-weighted average moneyness of options traded. The moneyness variable is defined as the logarithm of the price of the undrelying divided by the strike price for call options and as the logarithm of the strike price divided by the underlying for put options. Hence, a positive value means that the option is in-the-money and a negative value implies that the option is out-of-the-money.

[Table 4 here]

Consistent with the results above, the three first columns of Table 4 show that there is a significant change in the moneyness of the traded index options as a result of the funding liquidity shock. The average moneyness decreases meaning that more out-of-the-money options are traded as a result of the lower margin requirements.

The last three columns of Table 4 report the regression results using the dollar volume-weighted reduction in margin requirement as the dependent variable. As explained above, the reduction equals the relative difference between the strategy-based and portfolio-based margins required for naked writing of the option. The average value of this difference increases for the index options as a result of the portfolio margin implementation. This means that following the implementation, traders trade more of the options that were more affected by the new margining method. This result is consistent with trading moving towards more out-of-the-money options as Figure 1 shows that the margin reduction is higher for out-of-the-money options.

As a summary of the results presented in so far, it can be concluded that that the improvement in funding liquidity causes the number of traded contracts to increase significantly, the trading to shift more to out-of-the-money options for which the decrease in margin requirements is the largest, and the dollar volume of trading to increase for the less liquid out-of-the-money options.

4.3 Bid-ask spread

Next, I estimate the different versions of Equation (3) using the logarithm of the dollar volume-weighted bid-ask spread as the dependent variable. Conceptually this corresponds to studying the relative, rather than absolute, changes in the spreads. The results are presented in Table 5.

[Table 5 here]

The first column of the table presents the results without controls or fixed effects. The difference-in-difference coefficient is equal to -0.097 (t-statistic -4.84) which implies that the spread of the index option decreases by 9.3% compared to the pre-treatment average level. This result again is consistent with the theoretical models predicting that margin requirements result in traders providing non-optimal amount of liquidity. This causal effect of funding liquidity improvement decreasing the bid-ask spread is very strong across the different specifications and sub-samples of data. Including the control variables and fixed effects only changes the difference-in-difference coefficient marginally. The effect is also of very similar magnitude for both the call options and put options. For in-the-money options the reduction in the index options' bid-ask spread is 12.1%, whereas it is 15.6%, for the out-of-the-money option. Hence, again, the improvement in market liquidity resulting from the improvement in funding liquidity is larger for the less liquid assets, i.e. the out-of-the-money options.

Studying the bid-ask spreads on a trade volume-weighted basis may be problematic as the results above clearly show that the average type of option traded changes as a result of the margin requirement reduction. It could be that the negative interaction coefficients in Table 5 are just a result of trading moving to options that inherently have a lower bid-ask spread. This, however, is unlikely as the results in Table 4 show that trading moves towards out-of-the-money options which typically have higher, rather than lower, spreads. To control for the changes in the types of options traded, in Table 6 I report the results of an option-day level difference-in-difference regression:

$$Spread_{i,j,t} = \alpha + \beta_1 \, Treated_i \times After_t + \beta_2' \, I_i + \beta_3' \, I_t + \theta' \, Controls_{i,j,t} + \varepsilon_{i,j,t}, \qquad (4)$$

where the unit of observation is option j on underlying i on day t. As above, $Treated$ equals 1 for index options and 0 for equity options, and $After$ is one after July 14, 2005, and 0 otherwise. The regression specification includes underlying and day fixed effects which subsume $Treated$ and $After$ variables.

[Table 6 here]

The first column of Table 6 reports the results without controls. Consistent with the results above, the portfolio margining implementation significantly lowers the bid-ask spreads of index options. The real power of Table 6 is in the last two columns which control for option-day level characteristics as determinants of the spread. The controls include the option's time to maturity, moneyness, a dummy variable which equals 1 for call options and 0 for puts, the option's lagged implied volatility, and the underlying assets lagged return and lagged squared return. Including these controls somewhat increases the estimate of the causal effect of margin requirement reduction on bid-ask spread. The interaction coefficient in the second column equals -0.12 (t-statistic -3.07) which corresponds to an 11.3% reduction in the spread.

The third column adds the logarithm of the contemporaneous dollar volume as a control variable. Trading volume has a very large negative impact on the spread. However, the inclusion of volume does not affect the coefficient of the difference-in-difference variable. This implies that the reduction in bid-ask spreads is not merely due to increased volume, but market making traders seem to offer tighter spreads as a result of the funding liquidity improvement.

To provide further evidence on the mechanism, I include in regression (4) a measure of the magnitude of margin requirement reduction. More specifically, I interact $Treated_i \times After_t$ with variable $Reduction_{i,j,t}$ which is the relative difference between the strategy-based and portfolio-based margins on naked writing of option j on underlying i on day t. This measure captures the cross-sectional variation in the treatment intensity across the treated index options. Table 7 presents the results.

[Table 7 here]

The coefficient of most interest is the triple interaction term $Treated \times After \times Reduction$. This coefficient is negative and statistically significant. This implies that the reduction in the bid-ask spread is larger for those index option for which the reduction in the margin requirement is the largest.

Figure 4 illustrates the effect of margin reduction based on the estimates in the second column of Table 7. It plots the coefficient of $Treated \times After$, which corresponds to the change in log-bid-ask spread of index options, as a function of the reduction in margin requirement. The change in spread is naturally decreasing in margin reduction. It is statistically significantly negative (at the 5% level) for observations where the reduction in margin is greater than 68%. This accounts for roughly 57% of all the observations. For observations where the margin reduction is less than 68%, there is no significant effect on the bid-ask spread from the portfolio margin implementation.

[Figure 4 here]

Overall, the improvement in funding liquidity cause a very large, significant, and robust reduction in the bid-ask spread. This reduction is significantly larger for options that experience larger reduction in margin requirements. These results provide strong causal evidence in support of the theories of Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009).

5 Conclusions

This paper provides robust causal evidence that funding liquidity drives market liquidity as predicted by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009). The key innovation is to use the approval of portfolio margining of index options—which greatly reduced the margin requirements on index options while having no impact on equity options—as an exogenous funding liquidity shock in a difference-in-difference framework. The empirical results are clear, significant and robust: improved funding liquidity results in more trading and lower bid-ask spreads. These effects are stronger for options that experience a larger reduction in margin requirements. These results highlight the role of traders' funding liquidity as a key ingredient of liquid asset markets.

The results of this paper have implications for researchers and practitioners alike. First, the results presented in this paper provide strong empirical credibility for the theories of Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009), and the large literature that builds on these early works. Second, this paper shows that the portfolio margining pilot program of 2005-2007 can be used as a powerful exogenous shock to funding liquidity and may be used in other setting to study causal effects of margin requirement changes. For market regulators this paper provides evidence of the benefits of lower margin requirements which hopefully are weighted against the potential risks associated with lower margins when margin requirements are set either at the national, exchange, or broker level.

References

Asness, C. S., T. J. Moskowitz, and L. H. Pedersen (2013): "Value and Momentum Everywhere," *Journal of Finance*, 68(3), 929–985.

Black, F., and M. Scholes (1973): "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy*, 81(3), 637–654.

Brunnermeier, M. K., S. Nagel, and L. H. Pedersen (2009): "Carry Trades and Currency Crashes," in *NBER Macroeconomics Annual 2008*, ed. by D. Acemoglu, K. Rogoff, and M. Woodford, vol. 23, pp. 313–348. University of Chicago Press.

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

Cao, M., and J. Wei (2010): "Option Market Liquidity: Commonality and Other Characteristics," *Journal of Financial Markets*, 13(1), 20–48.

CBOE (2007): "Margin Requirement Examples for Sample Options-based Positions," available at `http://www.cboe.com/micro/margin/margin_req_examples.pdf`.

Cornett, M. M., J. J. McNutt, P. E. Strahan, and H. Tehranian (2011): "Liquidity Risk Management and Credit Supply in the Financial Crisis," *Journal of Financial Economics*, 101(2), 297–312.

Drehmann, M., and K. Nikolaou (2013): "Funding Liquidity Risk: Definition and Measurement," *Journal of Banking and Finance*, 37(7), 2173–2182.

Fortune, P. (2003): "Margin Requirements Across Equity-Related Instruments: How Level Is the Playing Field?," *New England Economic Review*, pp. 31–51.

Frazzini, A., and L. H. Pedersen (2014): "Betting Against Beta," *Journal of Financial Economics*, 111(1), 1–25.

Gârleanu, N., and L. H. Pedersen (2011): "Margin-based Asset Pricing and Deviations from the Law of One Price," *Review of Financial Studies*, 24(6), 1980–2022.

Gromb, D., and D. Vayanos (2002): "Equilibrium and Welfare in Markets with Financially Constrained Arbitrageurs," *Journal of Financial Economics*, 66(2-3), 361–407.

Hedegaard, E. (2011): "How Margins Are Set and Affect Asset Prices," Working paper.

Heimer, R. Z., and A. Simsek (2017): "Should Retail Investors' Leverage Be Limited?," *Journal of Financial Economics*, forthcoming.

Jylhä, P. (2018): "Margin Requirements and the Security Market Line," *Journal of Finance*, 73(3), 1281–1321.

Kahraman, B., and H. Tookes (2017): "Trader Leverage and Liquidity," *Journal of Finance*, 72(4), 1567–1610.

Kupiec, P. H. (1997): "Margin Requirements, Volatility, and Market Integrity: What Have We Learned Since The Crash?," Board of Governors of the Federal Reserve System Research Paper Series, 97-22.

Matsypura, D., and L. L. Pauwels (2014): "Margin Debt and Portfolio Margin Requirements," Working paper.

Moskowitz, T. J., Y. H. Ooi, and L. H. Pedersen (2012): "Time Series Momentum," *Journal of Financial Economics*, 104(2), 228–250.

Officer, R. R. (1973): "The Variability of the Market Factor of New York Stock Exchange," *Journal of Business*, 46(3), 434–453.

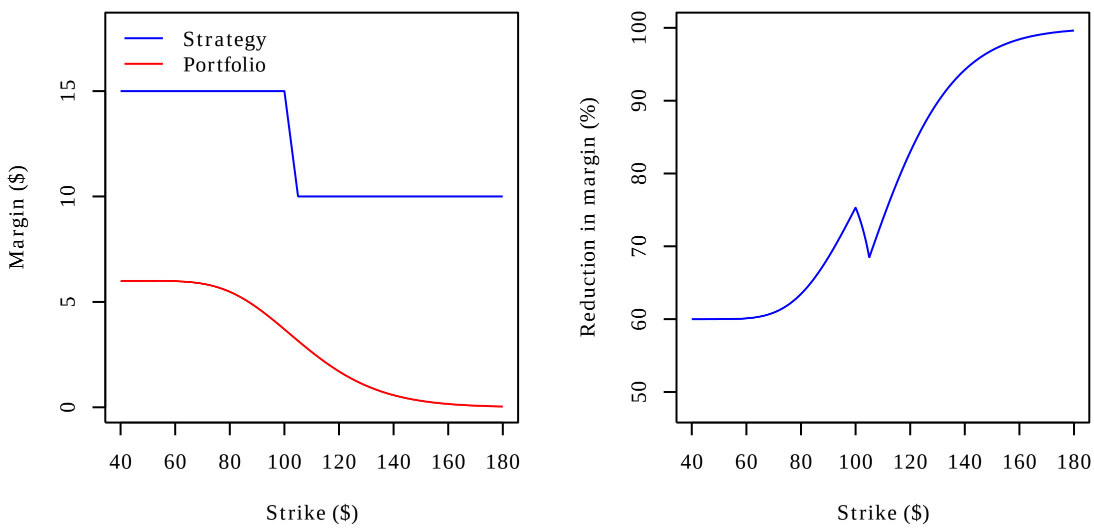
Ranaldo, A., and P. Söderlind (2010): "Safe Haven Currencies," *Review of Finance*, 14(3), 385–407.

SEC (2005): "Order Approving a Proposed Rule Change and Amendment Nos. 1 and 2 Thereto Relating to Customer Portfolio and Cross-Margining Requirements," Release No. 34-52032, available at `http://www.sec.gov/rules/sro/cboe/34-52032.pdf`.

——— (2008): "Notice of Filing and Immediate Effectiveness of Proposed Rule Change Relating to Making the Portfolio Margin Pilot Permanent," Release No. 34-58251, available at `http://www.sec.gov/rules/sro/finra/2008/34-58251.pdf`.

Figure 1: Reduction in margin requirement.
The left panel presents the strategy-based and portfolio-based margin requirements, in dollars, for naked writing of option with six months to maturity, price of underlying \$100, volatility of underlying 30%, and risk-free rate 2%. The dashed line gives the strategy based margin and the solid line gives the portfolio-based margin. The portfolio-based margin is based on a second order approximation of the Black and Scholes (1973) value with constant volatility. The right panel presents the relative reduction in margin when moving from strategy-based to portfolio-based margin. The top is for call options and the bottom panel for puts.

Call options



Put options

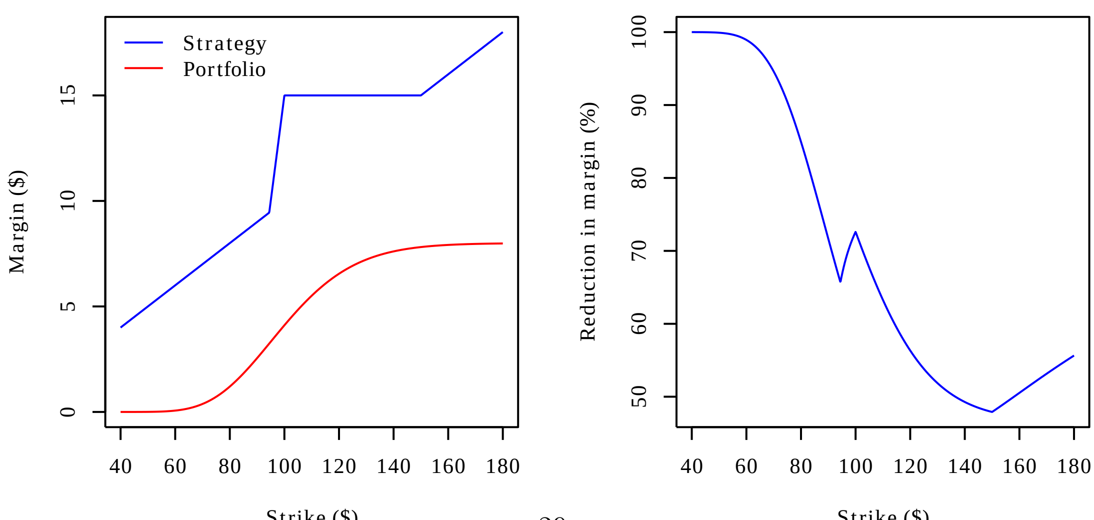


Figure 2: Market conditions around funding liquidity shock. This graph shows the development of the S&P 500 index, the VIX volatility index, and the 3-month USD LIBOR interest rate around the estimation window used in this study. In the left column, the time frame is from January 2000 to December 2010, and in the right column from January 2005 to December 2005. The solid vertical line marks July 14, 2005, the approval date of the portfolio margining pilot program. The dotted vertical lines give the start and end points of the 200 trading day estimation window.

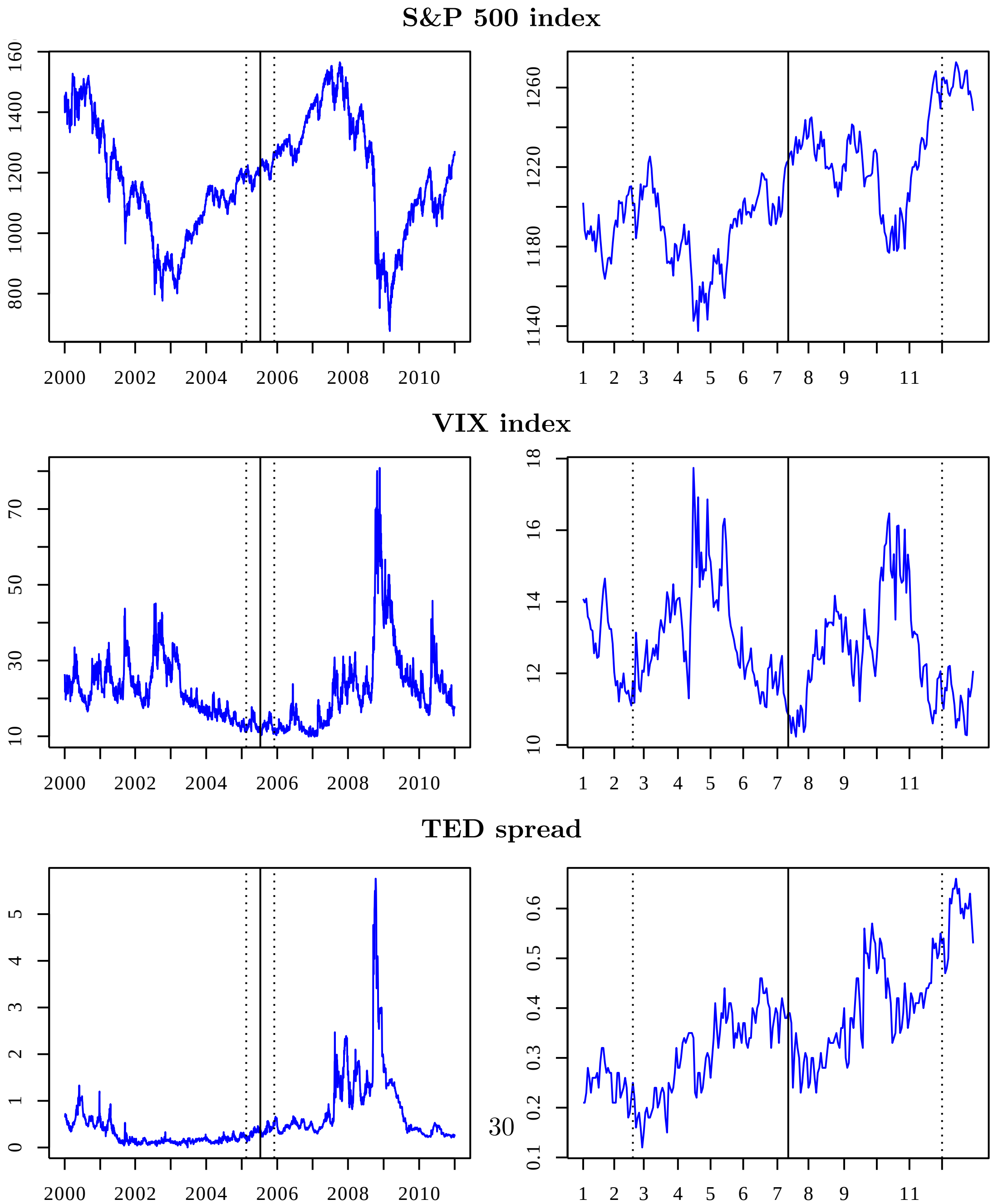


Figure 3: Trends in market liquidity.
This graph shows the monthly averages of the market liquidity measures for the treatment group (index options) and control group (equity options) for two years before and after the implementation of portfolio margining in July 2005. In the left panel, the measure of market liquidity is the logarithm of contract volume, and in the right panel the logarithm of bid-ask spread. The dotted lines represent the linear time trends.

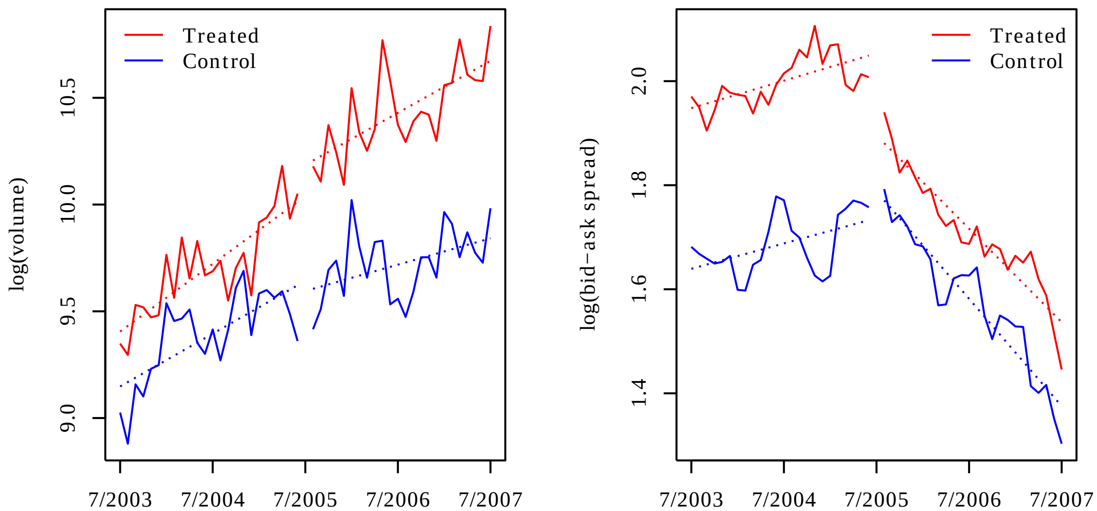


Figure 4: Reduction in margin and bid-ask spread.
This figure plots the reduction of index option bid-ask spread as a function of the reduction in margin requirement. Formally, the figure presents the figure plots the coefficient of $Treated \times After$ as a function of the margin reduction based on column (2) of Table 7. The gray area represents the 95% confidence interval.

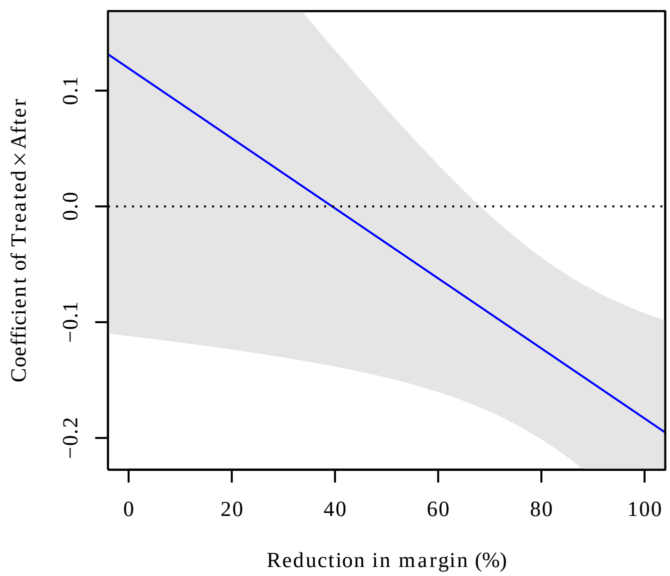


Table 1: Descriptive statistics
This table presents the descriptive statistics of the market liquidity measures for the treatment group of index options and the control group of equity options. The statistics are provided for the periods before the treatment and after the treatment. The dollar volumes is given in thousands of dollars and bid-ask spreads in percentages. The measures of price and implied volatility impacts are multiplied by 106. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

Treatment group: index options	Before		After	
	Mean	St. dev.	Mean	St. dev.
Contract volume	10.036	1.378	10.216	1.297
Dollar volume	11.804	1.673	11.896	1.647
Bid-ask spread	1.981	0.339	1.887	0.355
Control group: equity options	Before		After	
	Mean	St. dev.	Mean	St. dev.
Contract volume	9.493	0.894	9.605	0.974
Dollar volume	9.911	1.121	10.010	1.227
Bid-ask spread	1.790	0.349	1.820	0.381

Table 2: Funding liquidity and contract volume
This table presents the difference-in-difference estimation results for contract trading volume. The dependent variable is the logarithm of the number of options contracts traded. *Treated* equals one for index options and zero for equity options. *After* equals one after the implementation of portfolio margining for index options, i.e. July 14, 2005, and zero before that date. Columns (1) through (3) present the results for the full sample, column (4) for call options, column (5) for put options, column (6) for in-the-money options, and column (7) for out-of-the-money-options. Note that the intercept, *Treated*, and *After* are absorbed by the fixed effects in columns (3) through (7). Standard errors are clustered by time, t-statistics are reported in parentheses, and values in boldface are significant at a 5% level. R^2s are adjusted for degrees of freedom. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × After	**0.146**	**0.147**	**0.165**	**0.165**	**0.225**	0.056	**0.245**
	(3.30)	(3.32)	(3.64)	(3.27)	(4.61)	(0.88)	(5.15)
Treated	**0.381**	**0.340**					
	(12.97)	(10.86)					
After	0.034	0.030					
	(0.87)	(0.76)					
Lagged IV		**-0.349**	**3.045**	**2.360**	**3.761**	**2.916**	**2.718**
		(-4.10)	(11.66)	(9.83)	(10.89)	(11.52)	(9.23)
Lagged return		0.522	0.777	**1.760**	-1.079	1.340	0.319
		(0.56)	(1.20)	(2.60)	(-1.57)	(1.77)	(0.46)
Lagged return^2		**37.001**	**37.760**	**39.593**	**38.753**	**37.093**	**43.021**
		(3.10)	(3.54)	(3.46)	(3.83)	(3.18)	(3.97)
Intercept	**9.760**	**9.855**					
	(381.25)	(272.42)					
Fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.028	0.032	0.067	0.041	0.071	0.041	0.049

Table 3: Funding liquidity and dollar volume
This table presents the difference-in-difference estimation results for dollar trading volume. The dependent variable is the logarithm of the dollar value of the options contracts traded. $Treated$ equals one for index options and zero for equity options. $After$ equals one after the implementation of portfolio margining for index options, i.e. July 14, 2005, and zero before that date. Columns (1) through (3) present the results for the full sample, column (4) for call options, column (5) for put options, column (6) for in-the-money options, and column (7) for out-of-the-money-options. Note that the intercept, $Treated$, and $After$ are absorbed by the fixed effects in columns (3) through (7). Standard errors are clustered by time, t-statistics are reported in parentheses, and values in boldface are significant at a 5% level. R^2s are adjusted for degrees of freedom. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × After	0.028	0.036	0.063	0.096	**0.143**	0.023	**0.215**
	(0.56)	(0.73)	(1.21)	(1.69)	(2.42)	(0.35)	(4.22)
Treated	**1.629**	**1.764**					
	(45.76)	(47.32)					
After	0.048	0.048					
	(1.15)	(1.19)					
Lagged IV		**0.909**	**5.814**	**3.494**	**6.579**	**6.278**	**3.265**
		(9.56)	(18.29)	(11.60)	(12.51)	(19.50)	(9.36)
Lagged return		2.337	**1.648**	**3.700**	**-1.896**	**1.947**	0.804
		(1.96)	(2.25)	(4.87)	(-2.45)	(2.40)	(1.01)
Lagged return^2		25.524	**34.304**	**39.438**	**38.089**	**34.465**	**46.523**
		(1.60)	(3.00)	(2.98)	(3.77)	(2.82)	(3.91)
Intercept	**10.260**	**9.976**					
	(380.93)	(256.26)					
Fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.185	0.195	0.156	0.060	0.154	0.135	0.055

Table 4: Funding liquidity, option moneyness, and margin reduction

This table presents the difference-in-difference estimation results for option moneyness and margin reduction. The dependent variable in columns (1)-(3) is the trade volume weighted average relative distance to strike price. Negative values indicate out-of-the-money options and positive values indicate in-of-the-money options. In columns (4)-(6) the dependent variable is the trade volume weighted theoretical reduction in margin requirements of the options. $Treated$ equals one for index options and zero for equity options. $After$ equals one after the implementation of portfolio margining for index options, i.e. July 14, 2005, and zero before that date. Note that the intercept, $Treated$, and $After$ are absorbed by the fixed effects in columns (3) and (6). Standard errors are clustered by time, t-statistics are reported in parentheses, and values in boldface are significant at a 5% level. R^2s are adjusted for degrees of freedom. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	Moneyness			Margin reduction		
	(1)	(2)	(3)	(4)	(5)	(6)
Treated × After	**-0.014**	**-0.013**	**-0.011**	**0.008**	**0.008**	0.007
	(-4.82)	(-5.21)	(-4.64)	(2.30)	(2.34)	(1.89)
Treated	**-0.034**	-0.002		**-0.030**	**-0.031**	
	(-14.20)	(-0.61)		(-11.63)	(-12.00)	
After	**0.011**	**0.013**		**-0.009**	**-0.009**	
	(6.38)	(7.54)		(-6.19)	(-6.31)	
Lagged IV		**0.233**	**0.608**		-0.003	**-0.266**
		(20.52)	(16.30)		(-0.35)	(-8.94)
Lagged return		-0.020	0.059		**0.192**	**0.089**
		(-0.38)	(1.05)		(4.70)	(2.35)
Lagged return^2		**-1.757**	**-1.807**		0.422	**0.719**
		(-3.02)	(-3.28)		(0.93)	(2.03)
Intercept	**0.035**	**-0.035**		**0.660**	**0.660**	
	(29.61)	(-10.84)		(679.83)	(266.96)	
Fixed effects	No	No	Yes	No	No	Yes
R^2	0.059	0.263	0.278	0.040	0.045	0.095

Table 5: Funding liquidity and bid-ask spread

This table presents the difference-in-difference estimation results for bid ask spread at the underlying-day level. The dependent variable is the logarithm of the trade value weighted bid-ask spread. $Treated$ equals one for index options and zero for equity options. $After$ equals one after the implementation of portfolio margining for index options, i.e. July 14, 2005, and zero before that date. Columns (1) through (3) present the results for the full sample, column (4) for call options, column (5) for put options, column (6) for in-the-money options, and column (7) for out-of-the-money-options. Note that the intercept, $Treated$, and $After$ are absorbed by the fixed effects in columns (3) through (7). Standard errors are clustered by time, t-statistics are reported in parentheses, and values in boldface are significant at a 5% level. R^2s are adjusted for degrees of freedom. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × After	**-0.097**	**-0.101**	**-0.108**	**-0.130**	**-0.129**	**-0.129**	**-0.170**
	(-4.84)	(-5.18)	(-5.43)	(-5.94)	(-5.71)	(-5.86)	(-9.00)
Treated	**0.236**	**0.131**					
	(15.42)	(8.47)					
After	0.009	0.006					
	(0.79)	(0.58)					
Lagged IV		**-0.756**	**-2.058**	**-0.822**	**-2.052**	**-2.337**	**-0.383**
		(-23.07)	(-19.60)	(-6.38)	(-11.26)	(-23.90)	(-5.60)
Lagged return		**-1.071**	**-0.500**	**-1.246**	**0.785**	-0.386	-0.176
		(-3.42)	(-2.14)	(-4.95)	(2.85)	(-1.67)	(-0.71)
Lagged return^2		**9.769**	**3.523**	0.741	1.362	**5.910**	**-4.026**
		(2.74)	(2.08)	(0.39)	(0.69)	(3.10)	(-2.04)
Intercept	**1.741**	**1.968**					
	(238.03)	(171.09)					
Fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.036	0.103	0.143	0.030	0.102	0.166	0.021

Table 6: Funding liquidity and bid-ask spread

This table presents the difference-in-difference estimation results for bid-ask spread at the option-day level. The dependent variable is the logarithm of the bid-ask spread. *Treated* equals one for index options and zero for equity options. *After* equals one after the implementation of portfolio margining for index options, i.e. July 14, 2005, and zero before that date. All specifications include underlying and day fixed effects. Note that the *Treated*, and *After* are absorbed by the fixed effects. Standard errors are clustered by underlying and time, t-statistics are reported in parentheses, and values in boldface are significant at a 5% level. R^2s are adjusted for degrees of freedom. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	(1)	(2)	(3)
Treated × After	**-0.078**	**-0.120**	**-0.120**
	(-2.00)	(-3.07)	(-3.26)
Time to maturity		**-0.250**	**-0.301**
		(-16.05)	(-24.62)
Moneyness		**-3.917**	**-3.578**
		(-14.37)	(-13.50)
Call		-0.009	0.008
		(-0.46)	(0.34)
Lagged IV		0.413	0.073
		(1.92)	(0.37)
Lagged return		0.052	-0.004
		(0.27)	(-0.02)
Lagged return^2		-2.167	2.118
		(-1.90)	(1.47)
Volume			**-0.086**
			(-12.03)
Fixed effects	Yes	Yes	Yes
R^2	0.000	0.595	0.630

Table 7: Funding liquidity and bid-ask spread – interactions
This table presents the difference-in-difference estimation results for bid-ask spread at the option-day level. The dependent variable is the logarithm of the bid-ask spread. *Treated* equals one for index options and zero for equity options. Reduction is the theoretical reduction in margin requirements of the options. *After* equals one after the implementation of portfolio margining for index options, i.e. July 14, 2005, and zero before that date. All specifications include underlying and day fixed effects. Note that the *Treated*, and *After* are absorbed by the fixed effects. Standard errors are clustered by underlying and time, t-statistics are reported in parentheses, and values in boldface are significant at a 5% level. R^2s are adjusted for degrees of freedom. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	(1)	(2)
Treated × After	**-0.093**	**-0.094**
	(-2.10)	(-2.20)
Treated × After × Reduction	**-0.283**	**-0.302**
	(-2.10)	(-2.25)
Reduction	**4.403**	**4.118**
	(31.72)	(32.06)
Treated × Reduction	**-0.531**	**-0.494**
	(-2.90)	(-2.89)
After × Reduction	**0.278**	**0.271**
	(3.08)	(3.13)
Time to maturity	**-0.364**	**-0.386**
	(-20.49)	(-30.37)
Moneyness	**-1.294**	**-1.263**
	(-9.55)	(-9.53)
Call	**-0.342**	**-0.311**
	(-15.17)	(-12.51)
Lagged IV	**-1.338**	**-1.423**
	(-3.00)	(-3.34)
Lagged return	**-0.416**	**-0.419**
	(-2.65)	(-2.52)
Lagged return^2	1.988	**4.232**
	(1.32)	(2.79)
Volume		**-0.051**
		(-8.31)
Fixed effects	Yes	Yes
R^2	0.733	0.745