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

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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 but not equity options. The resulting significant improvement of funding liquidity leads to an increase in trading volume, a decrease bid-ask spread, and a decrease in price impact for index options compared to the unaffected equity options. These results provide strong causal evidence in support of the theories presented by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009).

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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 traders 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 traders' funding constraints results in them 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 only applied to index options. Being exogenous to 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] To my knowledge, this is the first paper to use

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

[2] A quasi-experiment differs from a natural experiment in the way the treatment is assigned. In a natural

a purely exogenous funding liquidity shock to study this relation and provide causal evidence in support of the predictions put forth by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009).

The results of this paper are unanimous, strong, and robust: 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 on all three tested dimensions. First, the trading volume of index options increases by 18% 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, the result is stronger for out-of-the-money options for which also the reduction in margin requirements is largest.

Second, the improvement in funding liquidity of index options leads to a reduction in their bid-ask spreads. The index options' spreads narrow by one percentage point which corresponds to about one-eight of the average pre-treatment spread. This reduction in direct trading costs signifies a very sizable improvement in market liquidity resulting from the reduction in margin requirements. Third, the improved funding liquidity also decreases the indirect costs, or price impact, of trading index options. Amihud (2002) type price impact measures for index options decrease by 23% to 33% with the implementation of portfolio margining. Fourth, the improvement in funding liquidity also improves price efficiency by reducing the noise of option price changes. Overall, the results provide strong causal evidence of funding liquidity being a key driver of market liquidity.

From the theory point of view, this paper is motivated by Gromb and Vayanos (2002) and

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 apply 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 rather than equity options.

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 is 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 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.

In a related empirical paper, Kahraman and Tookes (2015) analyze the relation between funding liquidity and market liquidity using data on margin trading of stocks in India and find results similar to mine. However, using the implementation of portfolio margining in the US options markets has a number of advantages over the Indian stock market 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, 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. Third, and very importantly, the timing of the funding liquidity shock employed in this study is purely exogenous. On the contrary, the margin eligibility in the Indian stock market depends on the stocks' market liquidity itself. Hence, it is not absolutely clear in the setup of Kahraman and

Tookes (2015) whether the reported improvement in market liquidity following a stock becoming eligible for margin trading is a result of improvement in funding liquidity or some other source of autocorrelation in market liquidity.

The work of Hedegaard (2011) is also closely 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, on the other hand, 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 fuelled 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 leveraged stock purchases. These regulatory changes on 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. A notable exception is Hardouvelis and Theodossiou (2002) who find that in some market conditions higher margins result in lower volatility. Jylhä (2015) uses the federally mandated initial margin requirements to show that tighter funding constraints result in a flatter security market line.

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 lender from 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

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

12 of Regulation T) allowed for strategy-based margining of some predefined options strategies. Such strategy-based margining takes into account 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 success of the 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 her 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

[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.

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 in the investor's capital requirement and an 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 four main reasons reasons. First, the margin requirements are a very important aspect of option markets. In the stock market the margin

[5] For example, for index underlying the range is from -8% to +6% of current index value, and for 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 system and is provided as an example by CBOE (2007).

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 options' 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 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.

[Figure 1 here]

Fourth, the start of the pilot program happens during very calm market conditions. Figure 1 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.

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 spread–such as the TED spread.[7] 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, two other papers use changes in margins to test the causal effect from funding liquidity to market liquidity. Hedegaard (2011) uses variation in margin requirements on futures traded on the CME and Kahraman and Tookes (2015) measure variation in funding liquidity by changes in margin eligibility of Indian stocks. In both cases, however, the variation in funding liquidity is driven by market conditions–by past volatility in Hedegaard (2011) and by past market liquidity in Kahraman and Tookes (2015). Hence, it remains unclear whether any correlation between market liquidity and the funding liquidity measures is purely causal or

[7] 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).

driven by a common factor or autocorrelation of market liquidity. All these examples highlight the need for a truly exogenous funding liquidity shock, like one driven by a regulatory change as used in this paper.

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 asset is a stock (SEC, 2005). To reflect this, the treatment group used in the empirical tests contains a sample of 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.[8] 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 data from OptionMetrics to construct a set of variables that proxy for different dimensions of option market liquidity: trading volume, bid-ask spread, and price impact. 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 and delta.

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

The market liquidity measures used here are very similar to those used by Cao and Wei (2010) with some modifications and additions. The basic idea is to calculate different liquidity measures for each option for each day and then aggregate these for each underlying asset for each day. The first measure of market liquidity, $Vol_{i,t}$, is the contract volume, i.e. the number of contracts of option i traded during the trading day t. The second liquidity measure is the dollar trading volume ($DVol_{i,t}$), calculated as number of contracts traded on the day multiplied by the closing mid quote. These trading volume measures are summed over all options for each underlying asset each day to get and underlying-day level measure of trading volume.

The the third liquidity measure is the bid-ask spread, $BAS_{i,t}$: difference between the best bid and the best ask quote at market closing time divided by the mid quote. The spread is calculated for all observations in the sample and aggregated by taking a dollar volume weighted average of the individual options' spreads for each underlying for each day.

The final set of liquidity measures proxy for price impact of trading in the spirit of Amihud (2002) by relating magnitudes of absolute price changes to trading volumes. The original Amihud (2002) measure is calculated as the average of daily absolute return divided by daily trading volume. Two alterations need to be considered to this original measure to take into account the features of the options as opposed to stocks. First, even without any trading, option prices change as a result of changes in the prices of the underlying assets and this has to be incorporated into price impact calculations. The first way of doing this is to deduct from the change in the option price the change in the price of the underlying times the option's delta as is done in Cao and Wei (2010). The second approach is to examine changes in the implied volatility of the option, rather than changes in option price, and relate them to trading volume. The second consideration is that, due to skewness of option returns, it might make more sense to study changes in option prices rather than returns. These variation motivate three different measures of price impact.

The first price impact measure is the absolute price impact ($API_{i,t}$) which accounts for the option's delta exposure and relates the change in option price to the dollar trading volume. It is defined as the absolute value of option price change less delta times the change in the underlying divided by the dollar trading volume:

$$API_{i,t} = \frac{|(P_{i,t} - P_{i,t-1}) - \Delta_{i,t-1}\,(S_{i,t} - S_{i,t-1})|}{DVol_{i,t}}, \tag{1}$$

where $P_{i,t}$ is the price of the option i on day t, $S_{i,t}$ is the price of the underlying of option i on day t and $\Delta_{i,t-1}$ is the sensitivity of the option price to changes in the price of the underlying asset. $DVol_{i,t}$ is the dollar trading volume of the option. Relative price impact ($RPI_{i,t}$) is similar to the absolute price impact but focuses on option returns rather than price changes:

$$RPI_{i,t} = \frac{\left|(P_{i,t} - P_{i,t-1}) - \Delta_{i,t-1}\left(S_{i,t} - S_{i,t-1}\right)\right| / P_{i,t-1}}{DVol_{i,t}}. \quad (2)$$

The absolute and relative price changes are identical to the measures used by Cao and Wei (2010).

An alternative way to control for the effects of the underlying asset's price change–as well as time decay and changes in the risk-free rate–is to analyse the changes in implied volatilities. Equivalently to the Amihud (2002) price impact measure, I define implied volatility impact as the absolute change in implied volatility divided by dollar trading volume:

$$IVI_{i,t} = \frac{|IV_{i,t} - IV_{i,t-1}|}{DVol_{i,t}}, \quad (3)$$

where $IV_{i,t}$ is the implied volatility of the option i on day t. No correction for changes in the underlying price are needed as that is already included in the calculation of the implied volatilities. All the price impact measures are aggregated by taking a dollar trading volume-weighted average for each underlying each day.

Finally, to gauge the informational efficiency of option prices, I study the cross-sectional dispersion (standard deviation) of changes in implied volatility. If option prices are informationally efficient the implied volatilities will reflect the true volatility of the underlying asset. When the true volatility of the underlying asset changes, the implied volatilities of all its options will change in tandem to reflect the change in fundamentals and the cross-sectional dispersion of the implied volatility changes will be small. If, however, the option prices are informationally less efficient, the implied volatilities tend to change more randomly and the cross-sectional dispersion of these changes will be large. Operationally, the implied volatility dispersion, $IVD_{i,t}$ is defined for each underlying each trading day as the standard deviation of changes of implied volatilities of all options written on that underlying that day.

Table 1 presents the average correlations between the market liquidity measures. The correlations are of expected sign albeit the magnitudes are relatively low except for mechanically similar measures. The trading volume measures are negatively correlated with bid-ask spread and price impact measures, and the spread and the price impacts are positively correlated. The two trading volume measures are highly correlated with each others, as are the three price impact variables.

[Tables 1 and 2 here]

Table 2 provides the means and standard deviations of the different 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.

Some interesting observations and implications arise from the table. First, the index options have significantly higher trading volume 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, the rough magnitudes of the bid-ask spread and the price impact variables are similar for the two sets of options. Finally, and most 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. Trading volumes increase for both types but more for the index options. The average bid-ask spread tightens by 83 basis points (or by a tenth) for index options whereas it actually widens slightly for the equity options. The price impact measures of index options decrease by 23% to 33% whereas they either decrease a marginally or increase for the equity options. Also the implied volatility dispersion decreases for index options whereas it increases for equity options. All these results point to the conclusion that improved funding liquidity causes an improvement in market liquidity, as predicted by Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2009). Next, we move to the formal testing of this causal relation.

4 Results

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. Formally, I estimate difference-in-difference regressions of the following type:

$$Liquidity_{i,t} = \alpha + \beta_1\, Treated_i \times After_t + \beta_2\, Treated_i + \beta_3\, After_t + \gamma'\, Controls_{i,t}, \quad (4)$$

where $Treated$ equals one for index options and zero for 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 liquidity measure between index options and equity option before the treatment and β_3 gives the change in the liquidity measure 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 liquidity 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 particular liquidity measure. 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 market liquidity, rather than just statistical correlation between the two measures.

I estimate three versions of Equation (4) for each measure of market liquidity: one without any controls, one with security controls, and one with security controls, security fixed effects and time fixed effects. As security controls I use the lagged values of the dollar volume weighted implied volatility, the return of the underlying asset, and the squared return of the underlying. The CBOE equity and equity index options expire on the Saturday following the third Friday of the expiration month. Hence the third Friday of each month is the last day to trade the expiring options and is usually marked with very high volume in all options (expiring and non-expiring) and spikes in the liquidity measures. Therefore, every regression below will include a dummy variable for the third Friday of every month to control for these effects. To control for unobserved dependence across securities, the standard errors are clustered by time. In addition to the full sample, I estimate the causal effect of funding liquidity on market liquidity also separately for calls, puts, in-the-money options and out-of-the-money options to see whether there is any cross-sectional variation in the impacts.

4.1 Trading volume

I begin the empirical analysis by studying the effect of funding liquidity improvement on trading volumes. The upper panel of Table 3 presents the results of estimating Equation (4) using logarithm of contracts traded as the measure of liquidity. The coefficient of the $Treated$ dummy in column (1) of the upper panel highly significant and equal to 0.37 implying that the index options have, on average, 44.8% 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 3.73). As the dependent variable is logarithmized, the difference-in-difference coefficient of 0.169 implies that the improvement of funding liquidity causes the trading volume of index options to increase by 18.4% over and above the simultaneous change in equity option trading volume.[9]

[Table 3 here]

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 lagged 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 0.174 (t statistic 3.86) which is slightly higher than the one without controls and translates into portfolio margining

[9]Note that the results presented here differ slightly from those one would infer from Table 2. This is due to the fact that all the regression include a dummy variable for the third Friday of each month–i.e. the last trading day before option expiration–which is not controlled for in the descriptive statistics above.

increasing index option trading volume by 19.0%.[10] To control for any remaining unobservable security and time characteristics, column (3) adds security and time fixed effects to the list of controls. Again, the impact of additional controls on the estimates is limited. The interaction coefficient is equal to 0.139 (t statistic 2.95) which is marginally lower than without the fixed effects. This implies an increase of 14.9% in trading volume of the index option.[11] Overall, the funding liquidity improvement causes a sizeable 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 nearly identical to calls and puts. The increase in trading volume resulting from the portfolio margining introduction is 17.7% for call options and 20.0% for puts. However, there is a 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 22.5% (t-statistic 4.20) while the increase in the in-the-money volume is only 6.3% (t-statistic 0.90). This result is consistent with the observation that the decrease in margin requirements, i.e. the size of the funding liquidity shock, is largest 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 more the less liquid assets than the more liquid ones. These results highlight the importance of funding liquidity as a driver of market liquidity.

The lower panel of Table 3 presents the estimation results of Equation (4) using the logarithm of the dollar trading volume as the measure of liquidity. The increase in dollar trading volume of the index options resulting from the funding liquidity improvement is 8.8% in the specification without controls or fixed effects, 8.7% with controls, and 4.5% with controls and fixed effects. None of the estimated difference-in-difference coefficients using the full sample, however, is not

[10] In unreported results, the lagged implied volatility has a negative effect on trading volume whereas lagged squared return of the underlying asset increases the number of contracts traded.

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

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 call options, put options, and in-the-money options. Consistent with the contract volume results above, however, the difference-in-difference coefficient is significant positive (t-statistic 3.64) for the out-of-the-money options. The improvement in the funding liquidity of the index options, increases the dollar trading volume of index put options by 20.1%.

If the average price of the options does not change with the implementation of the portfolio margining, the results in the upper and lower panel of Table 3 would have similar results, i.e. growth in dollar volume should match the growth in contract volume. However, empirically, the funding liquidity improvement results in sizeable growth in in contract volume but only a small, and 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, Table 4 presents the results of difference-in-difference regressions where the dependent variable is the average moneyness of options traded. The moneyness variable is defined as the option strike price divided by the price of the underlying minus one for call options and as 1 minus the strike divided by the underlying for put options. Hence, a positive value means that the option is out-o-the-money and a negative value implies that the option is in-the-money.

[Table 4 here]

Consistent with the results above, Table 4 shows 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 increases meaning that more and deeper out-of-the-money options are traded as a result of the lower margin requirements. This impact is similar for call and put options but is much stronger for out-of-the-money options than for in-the-money options. These results, together with the increased dollar volume of out-of-the-money options presented above, are again fully consistent with the fact that the improvement in funding liquidity is larger for the out-of-the-money options.

As a summary of the results presented in Table 3, 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 deeper 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.

4.2 Bid-ask spread

Next, I estimate the different versions of Equation (4) using the bid-ask spread and the logarithm of the spread as measures of market liquidity. Before the approval of the portfolio margining, the bid-ask spreads are larger for the index option than for the equity options. This raises a concern regarding using the spread itself as the dependent variable in the difference-in-difference regressions. It is possible that the raw spread of the treated index options decreases by more than the the spread of the equity option. But given the higher initial level of the spread for the index options, the relative change in index option spread might actually be smaller than that of the equity options. To make sure that the results are robust, both raw spreads and logarithmic spreads are used as dependent variables. The results are presented in Table 5.

[Table 5 here]

From the first column of the upper panel, the average bid-ask spread of the equity options is 6.12%. The index options have a 2.01% higher spread, i.e. 8.13%. The difference in the spreads of the two types of options is highly significant. Concurrently with the index options' funding liquidity shock, the bid-ask spread of the equity options actually increases significantly by 0.20%. However, the index option spread decreases to 7.32% resulting in a difference-in-difference coefficient of -1.01 percentage points.[12] This coefficient is highly significant with associated t-statistic equal to -7.20. The first column of the lower panel presents similar results using the logarithm of the bid-ask spread as the dependent variable. Conceptually this corresponds to studying the relative, rather than absolute, changes in the spreads. The difference-in-difference coefficient is equal to -0.130 (t-statistic -6.53) which implies that the spread of the index option decreases by 12.2% compared to the simultaneous change in the spread of the equity options.

[12] Note that these numbers differ slightly from those presented above in Table 2 due to the regression including control for the last trading dates before option expiration.

This effect of funding liquidity improvement decreasing the bid-ask spreads 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 equal to 0.68 percentage points or 12.8%, whereas it is 1.82 percentage points, or 16.9%, 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.

Overall, the improvement in funding liquidity–and the ensuing increase in trading volume–cause a very large, significant, and robust reduction in the bid-ask spread.

4.3 Price impact

As the final set of market liquidity proxies, I use the measures of price impact of trading. Results presented in Table 6 deal with the absolute and relative price impact whereas results presented in Table 7 use the implied volatility impact as the dependent variable. In the upper panel of Table 6 the dependent variable is the absolute price impact, i.e. the average of absolute change in the option price divided by the dollar trading volume. In the lower panel, the dependent is the relative price impact which differs from the absolute impact by relating absolute values of option returns, rather than price changes, to the trading volume. In both measures the effect of contemporaneous changes in the price of the underlying taken into account, i.e. the option price changes are over and above that implied by the option delta.

[Table 6 here]

Starting from the first column of the top panel of Table 6, before the approval portfolio margining the equity options had an average absolute price impact equal to 0.86. This means that, on average, trading options for one million dollars causes the option price to change by 86 cents. For index options the price impact is larger by 2.64, i.e. one million dollars of trading changes their price, on average, by $3.50. With the implementation of portfolio margining for index options, the price impact of equity options decreases by 0.03 but this change is not statistically significant. The index options, on the contrary, experience a very large decrease

(β_1 equal to -1.09, t-statistic -2.21) in the price impact of trading. After the positive funding liquidity shock, the average price impact trading index options for one million dollars is \$2.37, which is 32% less than before the shock.

The results presented in the lower panel of the table–where the dependent is the percentage change in option price per dollar volume–help to understand the magnitudes of these results. In the before-period, one million dollars of trading changes equity options price by 63.3% and index options price by 84.7%. The funding liquidity shock has a small positive impact on the equity options but a significant negative effect on the price impact of index options. With the improved funding liquidity, trading one million dollars worth of index options causes the price to change by 66.3%, which is roughly one-fifth less than before. This improvement in funding liquidity is, again, clear evidence in support of the theories that funding liquidity drives market liquidity.

The result of improved funding liquidity decreasing price impacts of trading is robust to additional controls variables. Adding the lagged implied volatility, the lagged underlying return, and the lagged squared underlying return have no impact on the difference-in-difference coefficients. Neither does adding security and time fixed effects. In all three specifications, the coefficient of the interaction of the *treadted* and $after$ variables is between -1.11 and -1.08 for the absolute price impact and between -0.234 and -0.208 for the relative price impact. In the cross-section of options, the reduction in price impacts is significant for calls and both in-the-money and out-of-the-money sub-samples but not for put options.

[Table 7 here]

The results in Table 7 show how the portfolio margining affects the implied volatility impact, i.e. the change in implied volatility due to trading. A key issue with the price impact measures above is that the option prices change as the prices of the underlying asset changes. Above, this is dealt with by deducting from the option price change the change in the price of the underlying asset times the option's delta. Another way to bypass the effect of the changes in the underlying on option prices is to study the implied volatility of the option. The dependent variable in Table 7 is the implied volatility impact, i.e. the average of the absolute change in implied volatility divided by the dollar trading volume.

The results arising from 7 are very similar to those above in Table 6: the implementation of portfolio margining and the ensuing improvement in funding liquidity results in a significant reduction in the implied volatility impact for index option as compared to unaffected equity options. This result holds for all specifications and subsets of options. For example, based on the estimates in the first column, the implied volatility impact of index options decreases by 25% whereas the equity options actually experience a significant increase in the impact.

Overall, the improvement in funding liquidity significantly reduces the measures of price impact, or the indirect costs of trading, for the treated index options.

4.4 Price efficiency

Finally, it is of great interest to examine how the improvement in liquidity affects informational efficiency of the option prices. To measure the informational efficiency, I use the cross-sectional dispersion of daily changes in implied volatility of all options written on the given underlying asset. The intuition is simple. If option prices are informationally highly efficient the implied volatilities will reflect the tru volatility of the underlying asset. When the true volatility changes, all the implied volatilities change in tandem and the cross-sectional dispersion of the changes is low. If, however, the prices are less efficient and more noisy, the implied volatilities of individual options will change less in tandem and the cross-sectional dispersion of changes will be larger. Table 8 gives the results of the difference-in-difference regressions using the dispersion of implied volatility changes as the dependent variable.

[Table 8 here]

The improvement in funding liquidity results in a significant improvement in price efficiency: the dispersion of implied volatility changes decreases for the index options whereas it actually increases for the equity options. The effect is robust to different specifications for all options as well as for calls and puts. The improvement is not statistically significant for in-the-money options but highly significant for out-of-the money options.

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 higher number of options being traded, lower bid-ask spreads, lower price impacts of trading, and more efficient prices. 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, to my knowledge, this is the first paper to provide causal evidence that funding liquidity really is a driver of market liquidity. 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.

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Figure 1: 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.

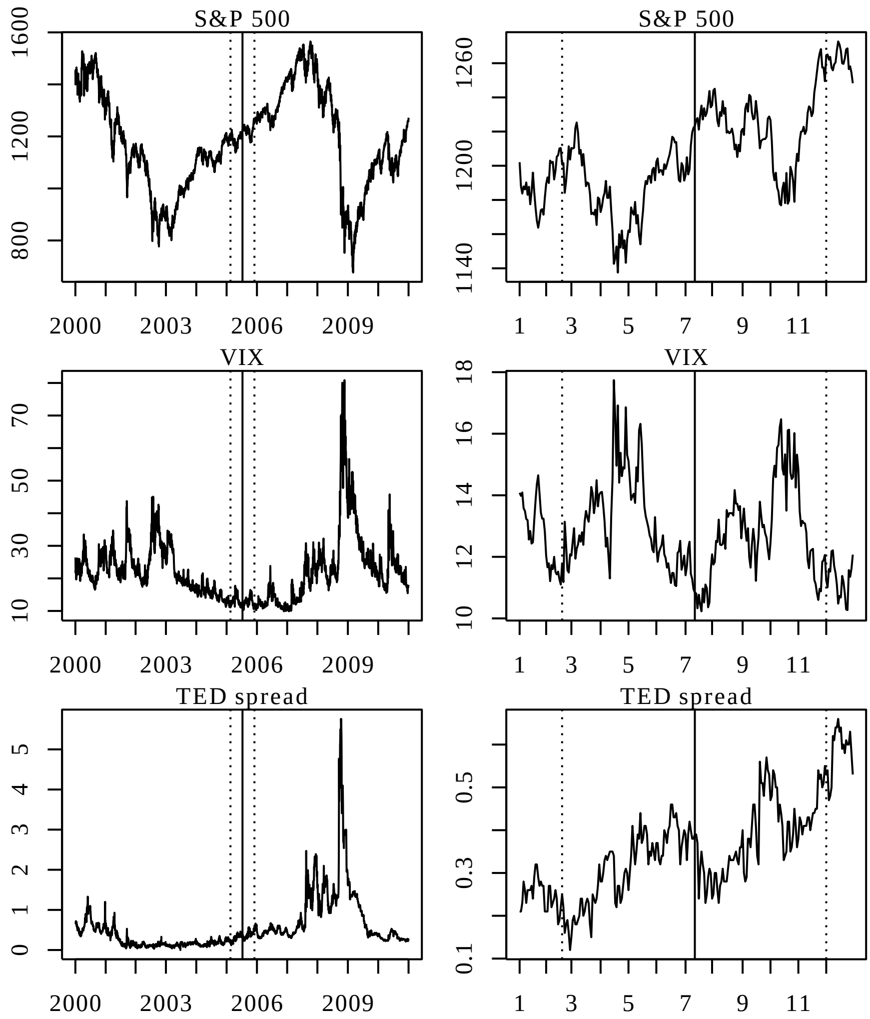

Table 1: Correlations

This table presents the cross-sectional means of the pairwise time series correlations of the market liquidity measures. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

	Vol	DVol	BAS	API	RPI	IVI
Dollar volume	0.860					
Bid-ask spread	-0.038	-0.260				
Absolute price impact	-0.325	-0.315	0.178			
Relative price impact	-0.364	-0.362	0.203	0.908		
Implied volatility impact	-0.354	-0.353	0.216	0.847	0.814	
Implied volatility dispersion	0.327	0.270	0.053	0.237	0.117	0.375

Table 2: 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 10^6. The data is on a daily frequency from February 18, 2005 through December 2, 2005.

Treatment group: index options				
	Before		After	
	Mean	StdDev	Mean	StdDev
Contract volume	59,072	75,511	72,256	101,244
Dollar volume	61,495	104,271	68,424	115,352
Bid-ask spread	8.116	2.538	7.289	2.561
Absolute price impact	3.482	11.025	2.338	4.015
Relative price impact	0.838	2.265	0.643	1.058
Implied volatility impact	0.081	0.220	0.059	0.109
Implied volatility dispersion	0.865	0.635	0.844	0.587
Control group: equity options				
	Before		After	
	Mean	StdDev	Mean	StdDev
Contract volume	25,767	29,214	28,701	37,525
Dollar volume	6,416	17,498	7,909	25,154
Bid-ask spread	6.104	2.005	6.284	2.417
Absolute price impact	0.842	0.847	0.789	0.905
Relative price impact	0.624	0.588	0.655	0.993
Implied volatility impact	0.156	0.181	0.195	0.490
Implied volatility dispersion	1.244	0.964	1.351	1.347

Table 3: Funding liquidity and trading volume

This table presents the difference-in-difference estimation results for measures of trading volume. The dependent variable is the logarithm of the number of options contracts traded in the upper panel, and the logarithm of the dollar value of those contracts in the lower panel. $Treated$ 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.

Dependent variable: log-contract volume	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**0.169**	**0.174**	**0.139**	**0.163**	**0.182**	0.061	**0.203**
	(3.73)	(3.86)	(2.95)	(3.07)	(3.62)	(0.90)	(4.20)
Treated	**0.378**	**0.324**					
	(12.10)	(9.81)					
After	0.020	0.014					
	(0.53)	(0.36)					
Intercept	**9.743**	**9.856**					
	(386.46)	(275.04)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.028	0.032	0.996	0.994	0.993	0.992	0.995
Dependent variable: log-dollar volume	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	0.085	0.084	0.044	0.106	0.106	0.027	**0.183**
	(1.67)	(1.65)	(0.84)	(1.74)	(1.82)	(0.39)	(3.64)
Treated	**1.727**	**1.834**					
	(48.39)	(48.36)					
After	0.027	0.030					
	(0.67)	(0.75)					
Intercept	**14.831**	**14.624**					
	(571.24)	(382.27)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.187	0.193	0.998	0.997	0.997	0.997	0.997

Table 4: Funding liquidity and option moneyness
This table presents the difference-in-difference estimation results for option moneyness. The dependent variable is the trade volume weighted average relative distance to strike price. Positive values indicate out-of-the-money options and negative values indicate in-of-the-money 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. 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.

Dependent variable: moneyness	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**0.878**	**0.908**	**0.954**	**0.678**	**0.663**	0.018	**0.764**
	(4.71)	(4.90)	(5.02)	(3.26)	(3.36)	(0.09)	(8.34)
Treated	**2.813**	**2.161**					
	(19.25)	(12.75)					
After	**-1.002**	**-1.044**					
	(-7.20)	(-7.66)					
Intercept	**-2.332**	**-1.051**					
	(-25.16)	(-4.95)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.073	0.086	0.350	0.276	0.370	0.812	0.893

Table 5: Funding liquidity and bid-ask spread
This table presents the difference-in-difference estimation results for measures of trading cost. The dependent variable is the bid-ask spread in the upper panel, and the logarithm of the bid-ask spread in the lower panel. *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.

Dependent variable: bid-ask spread							
	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**-1.007**	**-0.990**	**-0.963**	**-1.251**	**-1.063**	**-0.681**	**-1.818**
	(-7.20)	(-7.03)	(-6.65)	(-7.35)	(-5.88)	(-5.81)	(-9.16)
Treated	**2.012**	**1.608**					
	(18.98)	(14.18)					
After	**0.196**	**0.174**					
	(3.05)	(2.75)					
Intercept	**6.118**	**6.918**					
	(134.68)	(92.86)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.057	0.077	0.936	0.915	0.907	0.931	0.932

Dependent variable: log-bid-ask spread							
	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**-0.130**	**-0.126**	**-0.122**	**-0.150**	**-0.137**	**-0.137**	**-0.185**
	(-6.53)	(-6.33)	(-5.93)	(-6.15)	(-6.17)	(-5.89)	(-8.89)
Treated	**0.289**	**0.209**					
	(19.07)	(12.92)					
After	0.015	0.011					
	(1.45)	(1.04)					
Intercept	**1.756**	**1.915**					
	(246.62)	(171.61)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.049	0.080	0.980	0.975	0.973	0.968	0.986

Table 6: Funding liquidity and price impact

This table presents the difference-in-difference estimation results for measures of trading cost. The dependent variables are the absolute and relative price impacts in the upper and lower panel, respectively. $Treated$ 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.

Dependent variable: absolute price impact							
	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**-1.091**	**-1.108**	**-1.082**	**-4.713**	-1.470	**-8.599**	**-1.323**
	(-2.21)	(-2.24)	(-2.15)	(-4.20)	(-1.16)	(-2.23)	(-3.09)
Treated	**2.640**	**2.991**					
	(5.73)	(6.36)					
After	-0.035	-0.013					
	(-1.43)	(-0.48)					
Intercept	**0.857**	**0.161**					
	(51.88)	(3.09)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.053	0.060	0.289	0.243	0.091	0.072	0.390
Dependent variable: relative price impact							
	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**-0.226**	**-0.234**	-0.208	**-1.189**	-0.167	**-0.633**	**-0.470**
	(-2.13)	(-2.21)	(-1.92)	(-4.82)	(-0.75)	(-2.40)	(-3.06)
Treated	**0.214**	**0.355**					
	(2.29)	(3.59)					
After	**0.042**	**0.052**					
	(1.99)	(2.35)					
Intercept	**0.633**	**0.353**					
	(53.57)	(7.67)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.005	0.018	0.485	0.348	0.305	0.097	0.456

Table 7: Funding liquidity and implied volatility impact
This table presents the difference-in-difference estimation results for a measure of indirect trading cost. The dependent variable is the implied volatility impact. $Treated$ 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.

Dependent variable: implied volatility impact							
	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**-0.062**	**-0.069**	**-0.056**	**-0.139**	**-0.069**	**-0.226**	**-0.097**
	(-5.14)	(-5.66)	(-4.34)	(-5.13)	(-3.14)	(-3.40)	(-5.19)
Treated	**-0.074**	**0.077**					
	(-8.57)	(4.54)					
After	**0.042**	**0.052**					
	(4.88)	(5.60)					
Intercept	**0.158**	**-0.141**					
	(45.19)	(-5.08)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.014	0.138	0.480	0.468	0.360	0.276	0.324

Table 8: Funding liquidity and price efficiency
This table presents the difference-in-difference estimation results for a measure of price efficiency. The dependent variable is the cross-sectional dispersion of implied volatility changes. $Treated$ 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.

Dependent variable: implied volatility dispersion							
	All options			Calls	Puts	ITM	OTM
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treated × after	**-0.128**	**-0.151**	**-0.159**	**-0.116**	**-0.112**	-0.131	**-0.090**
	(-2.18)	(-2.63)	(-2.70)	(-2.09)	(-2.77)	(-1.28)	(-2.67)
Treated	**-0.379**	**0.202**					
	(-9.13)	(4.63)					
After	**0.099**	**0.133**					
	(2.48)	(3.54)					
Intercept	**1.238**	**0.100**					
	(48.46)	(2.46)					
Controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
Security fixed effects	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.021	0.204	0.664	0.658	0.697	0.603	0.709