From Funding Liquidity to Market Liquidity: Evidence from Index Options Market*

Chunbo Liu   Cheng Zhang   Zhiping Zhou

October 29, 2014

Abstract

This study examines the relationship between funding liquidity and market liquidity using daily data of the S&P 500 Index options market covering January 2003 - January 2012. We find that options market liquidity is positively correlated with funding liquidity during the periods of high market uncertainty. Besides, this paper finds a positive relationship between the options market liquidity and VIX. We also split the whole sample into two sub-samples of pre- and post- August 2007. Consistent with the theoretical predictions of Brunnermeier and Pedersen (2009), we find that when funding liquidity is low, option market liquidity becomes sensitive to changes in funding liquidity and tends to decline with funding liquidity. This study also uncovers several important features of the index options market liquidity. First, the impact of funding liquidity on puts liquidity is much higher than that on calls. Second, investors are inclined to trade short maturity options during the recent financial crisis and their liquidity is sensitive to funding liquidity.

Keywords: Options Market Liquidity, Funding Liquidity, VIX **JEL Codes:** G10; G12

*Chunbo Liu: Department of Finance, Norwegian School of Economics, Helleveien 30, 5045 Bergen, Email: chunbo.liu@nhh.no, Cheng Zhang: Department of Finance, London School of Economics and Political Science, London WC2A 2AE, Email: c.zhang14@lse.ac.uk, Zhiping Zhou: Department of Finance, Bocconi University, Milan 20142, Email: zhiping.zhou@phd.unibocconi.it. During the writing of this paper, the authors have benefited from suggestions from Jonas Andersson and Jens Dick-Nielsen.

1 Introduction

During the 2008 crisis, and especially the periods when Lehman Brothers and other important financial institutions failed, funding available to banks and non-financial firms was in short supply. In that period, a number of institutions failed because they had difficulties in raising funds in illiquid markets. It is thus timely and fitting to examine the dynamic changes in market liquidity in regards to changes in funding liquidity. This paper shows empirically that options market liquidity was strongly influenced by funding liquidity during the periods of high market uncertainty. More specifically, we find that liquidity in the S&P 500 Index options market is positively correlated with funding liquidity, after controlling VIX.

From a theoretical point of view, the idea that market declines cause asset illiquidity has received much attention. Brunnermeier and Pedersen (2009) provide a model that elaborates on the relationship between funding liquidity and market liquidity (FL-ML) and show that the two notions are mutually reinforcing, leading to liquidity spirals. They argue that a huge market-wide decline in prices reduces the ease with which market makers can obtain funding, which feeds back as higher comovement in market liquidity during the recessions. Garleanu and Pedersen (2007) focus on a feedback effect and argue that tighter risk management reduces liquidity, which in turn leads to tighter risk management. Their results help explain sudden drops in liquidity and in prices in connection with increased volatility or decreased risk-bearing capacity. More recently, Garleanu and Pedersen (2011) show that a funding liquidity crisis gives rise to a price gap between securities with identical cash-flows but different margins. In his 2010 AFA presidential address, Duffie (2010) argues that financial crisis and slow movement of investment capital increase the cost of intermediation and thus lead to increases in trading spreads. Moreover, Duffie (2012) points out that the 2008 financial crisis not only affected banks' lending function, but also had a major impact on market liquidity. He further argues that investors and issuers of securities would find it more costly to borrow, raise capital, invest, hedge risks, and obtain liquidity for their existing positions during the recent financial crisis.

The implications of these recent important theoretical findings have not been fully investigated from an empirical point of view and to date, to the best of our knowledge, there has not been a thorough empirical analysis of the relationship between market liquidity and funding liquidity over a long period of time. Chordia, Sarkar, and Subrahmanyam (2005) explore liquidity movements in stock and Treasury bond markets over a period of more than 1800 trading days and establish a link between macro liquidity, or money flows, and micro or transactions liquidity. Using a dummy variable to proxy for the period of low funding liquidity, Hameed, Kang, and Viswanathan (2010) test the relationship between funding liquidity and market liquidity in the stock market and their sample period is before the crisis. The Great Recession provides us with a laboratory to fully understand the dynamic changes in market liquidity in regards to changes in funding liquidity. Hu, Jain, and Jain (2013) provide the first empirical evidence of a non-linear relationship between FL-ML and show that the relationship weakens after the enactment of the Volcker Rule. Dick-Nielsen, Gyntelberg, and Lund (2013) examine how funding liquidity is driving the bond market liquidity in Denmark. They find that the ease of obtaining term funding in the money markets determines the liquidity in the bond market, for both long and short term bonds. Coffey, Hrung, and Sarkar (2009) investigate how funding liquidity conditions have affected deviations from Covered Interest Parity (CIP) in the major currency markets during the financial crisis. Mancini, Ranaldo, and Wrampelmeyer (2013) use intraday trading and order data to measure liquidity in the foreign exchange (FX) market and show that negative shocks in funding liquidity lead to significantly lower FX market liquidity and systematic FX liquidity comoves with equity liquidity. However, none of the previous literature has studied the dynamics of funding liquidity and options market liquidity during the crisis.

This paper presents one of the first systematic empirical studies of liquidity in the S&P 500 Index options market and analyzes the impact of funding liquidity on the index options market liquidity during the recent financial crisis. We measure liquidity in the index option market on a daily basis, relate index options market liquidity to measures of funding liquidity as well as liquidity of equity markets, and provide solid evidence to support the theoretical predictions of Brunnermeier and Pedersen (2009), namely higher comovement in liquidity and higher impact of funding liquidity on market liquidity during the crisis.

We compute options liquidity using a comprehensive dataset. Ranging from January 2003 to January 2012, our sample includes the financial crisis and is thus highly relevant for analyzing liquidity. Following Chordia, Roll, and Subrahmanyam (2000) and Cao and Wei (2010), we use proportional bid-ask (PBA) spread as our measure of index options liquidity in this paper. We compute the proportional bid-ask spread by dividing the difference between ask and bid quotes by the midquote. We adopt TED spread [1] (difference between the 3-month LIBOR and the 3-month U.S. Treasury bill rate) as a proxy for the level of funding liquidity, suggested by leading scholars in Hameed, Kang, and Viswanathan (2010), Boyson, Stahel, and Stulz (2010), Brunnermeier, Nagel, and Pedersen (2008) and Brunnermeier and Pedersen (2009).

Using an $ARMAX$ model to link the liquidity in the options market to funding costs and VIX over the entire sample period, we find a positive relationship between PBA spread and TED spread. And the coefficient is statistically significant at the 1% level. In particular, one standard deviation increase in TED spread can be translated into an increase in bid-ask spread as large as 0.95 basis point, which is about 22% of the standard deviation. Our empirical findings lend support to the hypothesis that market liquidity declines when liquidity providers face high funding costs. Moreover, we find that the liquidity of puts and calls responds asymmetrically to downward market movements. For instance, there is a statistically significant negative relationship between PBA spread and VIX for the subsample of puts over the entire sample period, while the coefficient of VIX for calls is not significant at all. Our empirical results illustrate that puts are favoured by informed traders to realize their information value during the recessions and are the investors' choice of trade in response to downward trends.

Next, to study the impact of funding liquidity on options market liquidity, we further split the whole sample according to maturity, forward-moneyness, and implied volatility of each

[1] An alternative proxy for funding liquidity in this paper is the LIBOR-OIS spread. The results based on this alternative spread are similar and are available upon request.

option. We maintain the same specification of $ARMAX$ model, linking the option market liquidity to funding liquidity and VIX. First, we find a positive relationship between PBA spread of short maturity option and TED spread. Thus, a reduction of funding liquidity are followed by lower short maturity option liquidity. This result might be due to the fact that trading in short-maturity options is the informed investors' choice. Second, the results show that TED spread is positively related to PBA spread and invariably significant in explaining the liquidity of options with different forward-moneyness. Therefore, the liquidity of options with different moneyness declines when investors face high funding costs consistent with predictions of Brunnermeier and Pedersen (2009). However, when we split the sample into five quintiles based on the implied volatility of each option, we cannot find such evidence.

Finally, to show that our results are not driven by the specific measure or sample period, we conduct several robustness test. First, we use alternative measures of investors' uncertainty, VXO, VXN and VXD provided by the CBOE. The results based on alternative measures are similar. Second, we split the whole sample into two sub-samples of pre- and post- August 2007 and add into our analysis two alternative measures for options market liquidity, namely transaction volume and total dollar volume. We also find similar results. Interestingly, the TED spread is strongly negatively related to the dollar trading volume for the sub-period of post-crisis, while its coefficient is not significant for the sub-period of pre-crisis. It means that a reduction of funding liquidity is followed by lower dollar trading volume, matching with the theoretical predictions of Brunnermeier and Pedersen (2009), who point out that when funding liquidity is low, market liquidity becomes sensitive to changes in funding liquidity and declines with a decline in funding liquidity.

Our empirical analysis is also related to the literature dealing with liquidity in options markets. While an extensive literature studying liquidity in equity markets exists, liquidity in the options market has mostly been neglected, although the options market is by far one of the most important markets. Cetin, Jarrow, Protter, and Warachka (2006) study the pricing of options in an extended Black-Scholes economy in which the underlying asset is not perfectly liquid and the liquidity risk is modelled as a stochastic supply curve. They show that liquidity costs account for a significant portion of the option price. Using Ivy DB's OptionMetrics data, Cao and Wei (2010) illustrate the commonality among various measures based on the bid-ask spread, volumes and price impact. They provide convincing evidence that the options liquidity responds asymmetrically to upward and downward market trends, with calls reacting more in up markets and puts reacting more in down markets.

The remainder of this paper is organized as follows. In section 2, we describe the data, define the liquidity measures and report the summary statistics. Section 3 presents the main results concerning the dynamics of market liquidity and funding liquidity during the crisis. Some additional robustness tests are provided in Section 4. The final section concludes.

2 Data and variables

2.1 Data

Our data consist of daily closing bid and ask quotes, daily volume and open interest on S&P 500 options traded on the CBOE market. We cover the period January 17th 2003 - January 31st 2012, for a total of 2,265 trading days. We extract the CBOE data from the OptionMetrics IVY DB, which also includes daily closing price, option strike price, implied volatility and actual days to expiration. In the S&P 500 sample, we have 223,447 observations, of which 104,502 are calls and 118,945 are puts. Hence, out of the 2,265 trading days we end up with an average of about 99 options per day.

Following Bakshi, Cao, and Chen (1997), we set up three option classes by time-to-maturity, measured in actual days to expiration ($ADTE_{i,t}$):

1. Short-term if $ADTE_{i,t} < 60$;
2. Medium-term if $60 \leq ADTE_{i,t} \leq 180$;
3. Long-term if $180 \leq ADTE_{i,t}$.

Following Goncalves and Guidolin (2006), we set up five option classes by forward-moneyness($m_{i,t}$):

1. Deep-out-of-the-money (DOTM) if the contract is a call and $m_{i,t} < 1.06$ or if the contract is a put and $m_{i,t} < 0.94$;
2. Out-of-the-money (OTM) if the contract is a call and $1.01 < m_{i,t} \leq 1.06$ or if the contract is a put and $0.94 \leq m_{i,t} < 0.99$;
3. At-the-money (ATM) if $0.99 \leq m_{i,t} \leq 1.01$ for either puts or calls;
4. In-the-money (ITM) if the contract is a call and $0.94 \leq m_{i,t} < 0.99$ or if the contract is a put and $1.01 < m_{i,t} \leq 1.06$;
5. Deep-in-the-money (DITM) if the contract is a call and $m_{i,t} < 0.94$ or if the contract is a put and $m_{i,t} > 1.06$.

Following Cao and Wei (2010), we set up five option classes by implied volatility ($LogIV_{i,t}$):

1. LogIV1 if $LogIV_{i,t}$ <-2.0112;
2. LogIV2 if -2.0112$\leq$ $LogIV_{i,t}$ <-1.7787;
3. LogIV3 if -1.7787$\leq$ $LogIV_{i,t}$ <-1.5716;
4. LogIV4 if -1.5716$\leq$ $LogIV_{i,t}$ <-1.3543;
5. LogIV5 if -1.3543$\leq$ $LogIV_{i,t}$ $\leq$-0.1716.

We adopt the option liquidity measures used in Cao and Wei (2010). We use the bid-ask spread (PBA) as the order-based measure and the dollar trading volume (DVOL) as the transaction-based measure. Since our data is a pooled sample, we cannot include Amihud's ILLIQ as the price impact measure. Appendix I includes the definitions of the option liquidity measures.

Our primary funding liquidity measures: (1) the TED spread from the Federal Reserve Bank in St. Louis, (2) net acquisition of financial assets by security brokers and dealers from the flow of funds account provided by Federal Reserve Statistical Release. Adrian and Shin (2010) argue that the change of the aggregate balance sheet of financial intermediaries reflects the aggregate liquidity. We collect the net acquisition of financial assets by security brokers and dealers which is used in Hu, Jain, and Jain (2013) when studying the relation between funding liquidity and equity market liquidity, (3) return on security brokers, dealers and flotation companies, as in Hameed, Kang, and Viswanathan (2010).

Figure 1 depicts the evolution of options liquidity, the TED spread and VIX from January 2003 to January 2012. Both TED spread and VIX shoot up during the financial crisis. However, the options market bid-ask spread seems to reach its lowest level in the crisis. Before the crisis when both the TED and VIX stay at low levels, the options bid-ask spread is almost twice as high as its level during the crisis. The "cooling down" in boom and "heating up" in crisis of options market transactions point directly to the distinctive feature of this market. A similar pattern can also be observed in figure 2 which displays the options market liquidity along with equity market liquidity. Figure 2 illustrates that these two liquidity measures are negatively correlated.

2.2 Summary statistics

Table 1 presents the summary statistics of both the various options market bid-ask spread and the key explanatory variables. During our sample period, the mean bid-ask spread for all options is 12 basis points. It is consistent with the calculation in Cao and Wei (2010) who find a 13-bps bid-ask spread during the period from 1996 to 2004. Since our sample period has spanned the financial crisis when the options market was relatively more liquid, the options market liquidity measure should be higher in this study[2]. The standard deviation is also quite close to the one in Cao and Wei (2010). Compared with call options, put options have a smaller bid-ask spread and a larger trading volume in terms of both the mean and the median. The higher liquidity for puts in our paper might be attributed to the high transaction activities

[2]The transaction and dollar volume should be higher, while the bid-ask spread should be lower correspondingly.

during the financial crisis. In the rest of the rows in Panel A, all options are classified into several categories based on different characteristics, such as maturity, moneyness and implied volatility. Consistent with the stylized fact, the liquidity of options decreases when moneyness fades away. Options that are deep in the money have a bid-ask spread as small as 3 bps while those deep out of the money ones are traded with a 20-bps bid-ask spread. The monotonic pattern cannot be found in options categorized by implied volatility. Out of the 5 quintiles, options with implied volatility in the second quintile are most liquid and the fifth quintile has the highest bid-ask spread.

Panel B contains the mean, median and standard deviation for the following sub-periods: the pre-crisis (01/2003 - 07/2007), within-crisis (08/2007 - 06/2009) and post-crisis period (07/2009 - 01/2012). Interestingly, in the crisis sub-period, the options market becomes most liquid. The options bid-ask spread is 3 bps lower than before the crisis and 2 bps lower than after the crisis. While options volume is not that different during the crisis, the total dollar volume is much higher, which is caused by the fact that the bid-ask spread declines in the crisis sub-period. Both TED and VIX increase dramatically as the crisis unfolds. The TED spread is more than ten times higher during the crisis, indicating that the funding liquidity suddenly drops in this period. We also notice that the VIX is twice as high as that before the crisis, implying that the market uncertainty perceived by investors increases during the crisis.

3 Empirical results

To model the relationship between options market liquidity and funding liquidity as well as market uncertainty, we first have to test for the stationarity of these several time series. The Augmented Dickey Fuller (ADF) test result is shown in table 2, revealing that all of the variables of interest are stationary. The null hypothesis of unit root is rejected at 1% for all of our series. Therefore, we choose $ARMAX$ to model the effect of funding liquidity and market uncertainty on options market liquidity. An $ARMAX(p,q)$ is specified as follows.

$$BASpread_t = \alpha + \sum_{i=1}^{p} \pi_i BASpread_{t-i} + \sum_{j=1}^{q} \theta_j \epsilon_{t-j} + \beta TED_{t-1} + \gamma VIX_{t-1} + \epsilon_t \quad (1)$$

where p and q are the number of lags for autoregression and moving average terms. β and γ are the coefficient of TED spread and the Chicago Board Options Exchange Volatility Index (VIX), respectively. The VIX is frequently used as a proxy for investors' fear and uncertainty in financial markets. We use AIC and BIC to determine the optimal lags.

3.1 Main results

Table 3 shows results of ARMAX regressions linking the liquidity in the options market to funding costs and VIX over the entire sample period from January 17th 2003 to January 31st 2012. After controlling for two lags of the proportional bid-ask (PBA) spread, we first regress PBA spread on TED spread and VIX using simple OLS. The results are presented in column (1). Interestingly, we find a negative relationship between PBA spread and VIX. When the market uncertainty increases by one standard deviation (9.88) yesterday, current option market bid-ask spreads respond by declining 1.08 basis points which is about 25% of one standard deviation(4.34). This effect is essentially different from what Mancini, Ranaldo, and Wrampelmeyer (2013) find in the currency market where increase in market uncertainty is followed by a decline in FX market liquidity. We interpret this finding as the distinctive function of options, which are primarily used to hedge or speculate during the crisis. Given that the demand for hedging or speculation is higher when investors are more uncertain about the future, any increase in implied volatility will lead to higher options market transactions and thus higher options market liquidity. Note that this effect is the net of controlling for two lags of proportional bid-ask spread. The magnitude of this effect estimated from OLS regressions without controlling for lags of PBA spread is actually doubled. In line with our hypothesis, we find a positive relationship between the current PBA spread and the previous day's TED spread. And the coefficient is statistically significant at the 1% level. One-standard deviation increase in funding liquidity (0.5) can be translated into an increase in options bid-ask spread as high as 0.46, which is about 7.5% of the standard deviation of proportional bid-ask spread. Therefore, after controlling VIX, options market liquidity declines when liquidity providers face higher funding costs, consistent with the theoretical prediction of Brunnermeier and Pedersen (2009).

In column (2), we estimate an ARMAX(4,3) with four autoregressive and three moving average terms. VIX and TED spread lagged for one day are included as exogenous variables. The results are similar to those in the OLS estimation. However, the magnitude of the effect of TED on bid-ask spread is more than twice as high as in the first column, highlighting the necessity of taking into account the moving average part when we fit the process of bid-ask spread. Here one standard deviation increase in TED spread can be translated into an increase in bid-ask spread as large as 0.76 basis point, which is about 18% of the standard deviation of the PBA spread. Column (3) and (4) add two additional variables into the regression, maintaining initial number of autoregressive and moving average terms. *Acq2* captures the funding liquidity of dealers and brokers by measuring the amount of asset acquisition each quarter by these market participants. Although its coefficient is not significant in either of these two models, it has the expected sign. In the fourth column, we also add into a recession dummy (NBER recession) to capture any systematic difference in options bid-ask spread during recession periods from December 2007 to June 2009. However, the coefficient on the dummy variable is not significant[3].

In Column (5) and (6), we further distinguish between call and put options to see if there is any difference in the pattern of how funding liquidity and market uncertainty affect options liquidity for calls and puts. As in previous regressions, we find a statistically significant negative relationship between the PBA spread and VIX, in both the call and the put sample. This suggests that rising market-wide uncertainty contributes to a higher bid-ask spread in both the call and the put options market, despite the distinctive functions of these two markets. The magnitude of VIX's effect on the PBA in terms of standard deviation is higher in the put sam-

[3]Note that PBA spreads during the recession is 9.7 basis points, lower than the spreads during non-recession times by 3 basis points, and the difference is significant at 1% level.

ple. For call options, one-standard-deviation change in VIX is followed by a decrease in the call PBA spread by 0.24 standard deviation. For puts, the magnitude is slightly higher and is equal to 0.32. It illustrate that puts are favoured by informed traders to realize their information value during recessions and are the investors' choice of trade in response to downward trends. These results are consistent with empirical findings of Cao and Wei (2010). Strikingly, we can only find a positive relationship between the PBA spread and TED spread for the subsample of puts. A one-standard-deviation increase in TED spread is followed by an increase in the PBA spread as large as 1.43 basis points, which is equivalent to 0.3 of the standard deviation. This effect is much higher than that for options in the whole sample. It again lends support to Brunnermeier and Pedersen (2009). Overall, the results using daily options market liquidity support our hypothesis that market liquidity deteriorates when the supply of capital is tight during the periods of high market uncertainty.

3.2 Subsample analysis

To study the dynamic changes in options market liquidity in regards to changes in funding liquidity, we further split the sample three ways. In table 4, we split the sample according to maturity (Short-term if $ADTE_{i,t} < 60$; Medium-term if $60 \leq ADTE_{i,t} \leq 180$; Long-term if $180 \leq ADTE_{i,t}$). In table 5, we set up five options classes by forward-moneyness (DOTM if the contract is a call and $m_{i,t} < 1.06$ or if the contract is a put and $m_{i,t} < 0.94$; OTM if the contract is a call and $1.01 < m_{i,t} \leq 1.06$ or if the contract is a put and $0.94 \leq m_{i,t} < 0.99$; ATM if $0.99 \leq m_{i,t} \leq 1.01$ for either puts or calls; ITM if the contract is a call and $0.94 \leq m_{i,t} < 0.99$or if the contract is a put and $1.01 < m_{i,t} \leq 1.06$; DITM if the contract is a call and $m_{i,t} < 0.94$ or if the contract is a put and $m_{i,t} > 1.06$). In table 6, we split the sample into 5 quintiles according to implied volatility.

We first categorize the whole options sample into 3 subsamples based on the maturity. Table 4 shows results of ARMAX regressions linking the liquidity of short, medium and long options to funding costs and VIX over the entire sample period. We maintain the same specification of the ARMAX model except the lags of autoregressive and moving average terms. Samples for all maturities are fitted by the ARMAX(4,3) model which is selected on the basis of information criteria. Again, VIX is strongly negatively related to short and medium maturity options. However, its coefficient is not significant for long maturity options. Also, the magnitude of the effect of VIX on bid-ask spread for short maturity options is more than twice as high as that for medium maturity options. As a result, the liquidity of different maturity options responds asymmetrically to downward market movements. It illustrates that short maturity options are favoured by informed traders to realize their information value and are the investors' choice of trade during periods of high market uncertainty. We also find a positive relationship between the PBA spread of short maturity option and TED spread which is significant at the 10% level. Thus, a reduction of funding liquidity is followed by lower short maturity options liquidity. But the coefficients are not significant for options with medium and long maturity.

Next, we split our sample according to forward-moneyness. The options are divided into 5 categories based on the forward-moneyness of each option, namely deep out of the money (DOTM), out of the money (OTM), at the money (ATM), in the money (ITM) and deep in the money (DITM). Table 5 shows results of ARMAX regressions linking the liquidity of DOTM, OTM, ATM, ITM, DITM to funding liquidity. TED spread is positively related to the PBA spread. And in most cases, it is significant in explaining the liquidity of options with different moneyness. Therefore, the liquidity of options with different moneyness declines when investors face high funding costs consistent with predictions of Brunnermeier and Pedersen (2009). Interestingly, there is a monotonic decline on magnitude of coefficient from out-of-the-money options to in-the-money options. VIX is negatively correlated with market liquidity of these three types of options, as displayed from column (1) to (3). It means that increase in market uncertainty is followed by an increase in market liquidity of OTM, ATM and ITM. Surprisingly, the estimated coefficients become significantly positive for DITM options and positive but insignificant for DOTM. It might be due to the fact that investors have to afford a high cost in transactions of DOTM and DITM and therefore the liquidity of these options declines during the periods of high market uncertainty.

We further split the sample into 5 quintiles based on the implied volatility of each option, namely IV1, IV2, IV3, IV4, and IV5. Table 6 shows results of ARMAX regressions linking the liquidity of these types of options to funding cost and market uncertainty. Unfortunately, we cannot find significant relationships between funding liquidity and market liquidity, except for the IV2 and IV3 quintile. There is an almost monotonic decline on magnitude of TED spread coefficients from IV1 to IV 5. Interestingly, we also find a monotonic decline of VIX coefficients from IV1 to IV5. When the market uncertainty increases, the PBA spread of options with low implied volatility increases while that of options with high implied volatility decreases. One possible explanation would be that investors would like to sell options with high implied volatility levels during the periods of high market uncertainty. As a result, the liquidity of options with high implied volatility increases.

3.3 Relation to liquidity of the US equity market

Even though we document a negative relationship between options market liquidity and funding liquidity, we cannot rule out the possibility that this effect is driven by the third confounding factor. A plausible candidate is the stock market liquidity, which is related to the liquidity of options. In this section, we control for stock market liquidity to investigate whether funding liquidity still survives. There are a number of reasons to expect a connection between equity and index options market liquidity. First, the market-wide liquidity is closely linked to the movements of the overall stock market (Cao and Wei (2010)). Second, an interdependence between liquidity in the two markets is consistent with the interaction of the market and funding liquidity during liquidity spirals predicted by Brunnermeier and Pedersen (2009). We choose three similar variables to proxy for aggregate daily stock market liquidity, namely the bid-ask spread, the trading volume and the dollar volume. The data is from the CRSP. The way that we calculate the bid-ask spread of stocks can be found in appendix I.

Table 7 shows results of an $ARMAX$ model linking the options market liquidity, stock market liquidity, and funding liquidity. We use equally- and value-weighted stock market bid-ask spread bid-ask spread as equity liquidity measures. The first two columns use bid-ask spread derived from the high ask and low bid prices, which are from CRSP. Consistent with the results of Cao and Wei (2010), the liquidity in the options market is closely linked to the liquidity of the equity market. The coefficient of stock market liquidity is highly significant and positive, implying the effectiveness in explaining the options market liquidity. When there is an one-standard-deviation increase in the equally-weighted (value-weighted) stock bid-ask spread, the liquidity of the options market responds by decreasing 18% (20%) of a one standard deviation. The coefficients on lagged TED spread are not significant, though their signs are still positive. In the next two columns, we adopt alternative equity bid-ask spreads measured at the closing spot each trading day. The coefficients on TED spread are marginally significant and their signs are positive in both column (3) and (4), implying that the effect of the funding liquidity on options liquidity remains stable. After controlling for stock market liquidity, we still find that options market liquidity is positively correlated with funding liquidity. In column (5) and (6), we use volume and dollar volume and obtain the same results. After controlling the VIX and the equity market liquidity, there is still a positive relationship between options market liquidity and funding liquidity.

4 Robustness

To show that our results are not driven by the specific measure or sample period, we conduct several robustness tests in this section. In table 8, we use alternative measures of investors' uncertainty, VXO, VXN and VXD. The results based on alternative measures are similar. Given that the demand for hedging or speculation is higher when investors are more uncertain about the future, any increase in volatility of the market will lead to an increase in options market transactions and higher options market liquidity.

4.1 Split sample pre-post financial crisis

Table 9 shows the results for different options liquidity measures for sub-samples of pre- and post- August 2007. The sample preceding the financial crisis spans from January 2003 to July 2007 and the post financial crisis sample spans from August 2007 to January 2012. We also add into our analysis two alternative measures for options market liquidity, transaction volume and total dollar volume. To facilitate the comparison among different sample periods, we also display the baseline results of the whole sample period. In column (1)-(3), we use proportional bid-ask spread as the dependent variable and find that TED is not significant in each sub-period even though its sign is in line with our expectation. Both proportional bid-ask spread of pre-crisis and that of post-crisis are strongly negatively related to VIX. In column (4)-(6), we adopt dollar trading volume as the dependent variable and find significantly positive relationship between VIX and dollar trading volume of pre-crisis and post-crisis. Thus, an increase in investors' uncertainty is followed by significantly higher options market liquidity. This is in line with what we find using PBA spread as the proxy for options market liquidity. Interestingly, the TED spread is strongly negatively related to the dollar trading volume for the sub-period of post-crisis, while its coefficient is not significant for the sub-period of pre-crisis. It means that a reduction of funding liquidity is followed by lower dollar trading volume, matching with the theoretical predictions of Brunnermeier and Pedersen (2009); namely higher comovement in liquidity and higher impact of funding liquidity on market liquidity during the crisis. Using volume as the proxy for options market liquidity, we get similar results in column (7)-(9).

4.2 Weekly data sample

Table 10 uses weekly data and shows the results of the ARMAX regressions linking the liquidity in the options market to funding costs and VIX over the entire sample period. The results are similar to that of the daily sample. Consistent with the results in column (2) of Table 3, increase in market uncertainty in week t-1 is followed by a decrease in the PBA spread, i.e.

an increase in options market liquidity. Also, the TED spread is positively related to the PBA spread, lending support to Brunnermeier and Pedersen (2009). However, the magnitude of the effect of TED spread on the PBA spread is much less than that of daily data sample, reflecting that option market is a highly sensitive market. In column (3) and (4), we split our sample into calls and puts. Consistent with the empirical findings in table 3, TED spread is significantly positively related to the PBA spread of puts, while its coefficient is marginally significant for the subsample of calls. Moreover, we find a negative relationship between the PBA spread and VIX for both calls and puts. However, the magnitude of the effect of VIX on the PBA spread of puts is twice as high as that of calls, revealing that the options market liquidity responds asymmetrically to market uncertainty.

5 Conclusion

Funding liquidity and its impact on market liquidity have become a major focus in the academic literature. Most studies investigate the relationship between FL-ML from a theoretical point of view. For instance, Brunnermeier and Pedersen (2009) explain that a huge market-wide decline in prices reduces the ease with which market makers can obtain funding, which feeds back as higher comovement in market liquidity during the recessions. Recently, some studies have emerged that examine the relationship between funding liquidity and market liquidity in stock, corporate bond, and foreign exchange markets. However, none of the previous literature studies the relationship of funding liquidity and options market liquidity during the crisis. This paper presents one of the first empirical analysis of liquidity in the S&P 500 Index options market, and studies the relationship between FL-ML.

Using data of the S&P 500 Index options traded on the CBOE market covering the period from January 17th 2003 to January 31st 2012, we establish convincing evidence of a positive relationship between funding liquidity and options market liquidity during the periods of high market uncertainty. More specifically, we find a positive relationship between the PBA spread of and TED spread and the coefficient is statistically significant at the 1% level. In particular, one standard deviation increase in TED spread can be translated into an increase in the bid-ask spread as large as 0.95 basis point, which is about 22% of the standard deviation. These empirical findings lend support to the hypothesis that market liquidity declines when liquidity providers face high funding costs during the periods of high market uncertainty.

Moreover, we split the whole sample into two sub-samples of pre- and post- August 2007 and add into our analysis two alternative measures for options market liquidity, namely transaction volume and total dollar volume. We also find similar results. Interestingly, the TED spread is strongly negatively related to the dollar trading volume for the sub-period of post-crisis, while its coefficient is not significant for the sub-period of pre-crisis. It means that a reduction of funding liquidity is followed by lower dollar trading volume, matching with the theoretical predictions of Brunnermeier and Pedersen (2009), who point out that when funding liquidity is low during the recessions, market liquidity becomes sensitive to changes in funding liquidity and declines with a decline in funding liquidity.

Aside from documenting the positive relationship between funding liquidity and options market liquidity during the periods of high market uncertainty, this study also uncovers several important features of the index options market liquidity. First, information asymmetry plays an important role as a driving force of market liquidity. This paper shows the evidence that the liquidity of puts and calls responds asymmetrically to downward market movements and the impact of funding liquidity on puts liquidity is much higher than that on calls. The results illustrate that puts are favoured by informed traders to realize their information value during the recessions and are the investors' choice of trade in response to downward trends. These empirical findings support the previous finding that informed traders may choose to trade in the options market, suggested by Easley, O'hara, and Srinivas (1998), Pan and Poteshman (2006), and Cao and Wei (2010). Second, when we spilt the sample according to maturity of each option, we find a positive relationship between the PBA spread of short maturity options and TED spread. Thus, a reduction of funding liquidity is followed by lower short maturity options liquidity. This result shows that short maturity options are the informed investors' choice of trade during recessions and their liquidity is sensitive to changes in funding liquidity.

This paper serves as a first step toward understanding the relationship of funding liquidity and index options market liquidity during periods of high market uncertainty. It opens up several avenues for future research. One natural extension would be the in-depth examination of the relationship of funding liquidity and options market liquidity using a panel data sample. Another area of future research would be to investigate the effect of funding constraints on the pricing of index options.

References

Adrian, T., and H. S. Shin, 2010, Liquidity and leverage, *Journal of Financial Intermediation* 19, 418–437.

Bakshi, Gurdip, Charles Cao, and Zhiwu Chen, 1997, Empirical performance of alternative option pricing models, *The Journal of Finance* 52, 2003–2049.

Boyson, Nicole M, Christof W Stahel, and Rene M Stulz, 2010, Hedge fund contagion and liquidity shocks, *The Journal of Finance* 65, 1789–1816.

Brunnermeier, Markus K, Stefan Nagel, and Lasse H Pedersen, 2008, Carry trades and currency crashes, Discussion paper, National Bureau of Economic Research.

Brunnermeier, Markus K., and Lasse Heje Pedersen, 2009, Market liquidity and funding liquidity, *Review of Financial Studies* 22, 2201–2238.

Cao, Melanie, and Jason Wei, 2010, Option market liquidity: Commonality and other characteristics, *Journal of Financial Markets* 13, 20–48.

Cetin, Umut, Robert Jarrow, Philip Protter, and Mitch Warachka, 2006, Pricing options in an extended black scholes economy with illiquidity: Theory and empirical evidence, *Review of Financial Studies* 19, 493–529.

Chordia, Tarun, Richard Roll, and Avanidhar Subrahmanyam, 2000, Commonality in liquidity, *Journal of Financial Economics* 56, 3–28.

Chordia, Tarun, Asani Sarkar, and Avanidhar Subrahmanyam, 2005, An empirical analysis of stock and bond market liquidity, *Review of Financial Studies* 18, 85–129.

Coffey, Niall, Warren B Hrung, and Asani Sarkar, 2009, Capital constraints, counterparty risk, and deviations from covered interest rate parity, Discussion paper, Staff Report, Federal Reserve Bank of New York.

Dick-Nielsen, Jens, Jacob Gyntelberg, and Jesper Lund, 2013, From funding liquidity to market liquidity: Evidence from danish bond markets, *Copenhagen Business School Working Paper*.

Duffie, Darrell, 2010, Presidential address: Asset price dynamics with slow-moving capital, *The Journal of finance* 65, 1237–1267.

——— , 2012, Market making under the proposed volcker rule, *Rock Center for Corporate Governance at Stanford University Working Paper*.

Easley, David, Maureen O'hara, and Pulle Subrahmanya Srinivas, 1998, Option volume and stock prices: Evidence on where informed traders trade, *The Journal of Finance* 53, 431–465.

Garleanu, Nicolae, and Lasse Heje Pedersen, 2007, Liquidity and risk management, *American Economic Review* 97, 193–197.

——— , 2011, Margin-based asset pricing and deviations from the law of one price, *Review of Financial Studies* 24, 1980–2022.

Goncalves, Silvia, and Massimo Guidolin, 2006, Predictable dynamics in the s&p 500 index options implied volatility surface*, *The Journal of Business* 79, 1591–1635.

Hameed, Allaudeen, Wenjin Kang, and Shivesh Viswanathan, 2010, Stock market declines and liquidity, *The Journal of Finance* 65, 257–293.

Hu, Bill, Chinmay Jain, and Pankaj Jain, 2013, Dynamics of market liquidity and funding liquidity during the crisis, its resolution, and the volcker rule, *Akansas State University working paper*.

Mancini, Loriano, Angelo Ranaldo, and Jan Wrampelmeyer, 2013, Liquidity in the foreign exchange market: Measurement, commonality, and risk premiums, *The Journal of Finance* 68, 1805–1841.

Pan, Jun, and Allen M Poteshman, 2006, The information in option volume for future stock prices, *Review of Financial Studies* 19, 871–908.

Appendix I: Variable Definitions

Variable	Definition
Dependent variables	
Proportional Bid-ask spread (PBA)	$$\frac{\sum_{j=1}^{J} VOL_j * \frac{ask_j - bid_j}{(ask_j + bid_j)/2}}{\sum_{j=1}^{J} VOL_j}$$ where j is one specific trade
Trading Volume (VOL)	$$\sum_{j=1}^{J} VOL_j$$
Dollar trading volume (DVOL)	$$\sum_{j=1}^{J} VOL_j \left(ask_j + bid_j\right)/2$$
Independent variables	
Bid-ask spread of stocks (equally weighted)	$$\frac{\sum_{i=1}^{N} \left(ask_i - bid_i\right)}{N}$$ where i is one specific stock traded on a certain day
Bid-ask spread of stocks (volume weighted)	$$\frac{\sum_{i=1}^{N} VOL_i \left(ask_i - bid_i\right)}{\sum_{i=1}^{N} VOL_i}$$ where i is one specific stock traded on a certain day
TED Spread	The difference between three-month LIBOR and the three-month U.S. Treasury bill rate
VIX	CBOE volatility index
VXO	CBOE S&P 100 volatility index
VXN	CBOE NASDAQ volatility index
VXD	CBOE DJIA volatility index
Asset acquisition	The amount of financial assets acquired by brokers and dealers in any quarter
d_recession	Recession period defined by NBER, from December 2007 to June 2009

Table 1: Summary Statistics

This table shows summary statistics for the main variables used in this study. Panel A gives a summary of daily option market liquidity which is measured by bid-ask spread, volume and dollar volume. The bid-ask spread is in basis points. Aside from showing the liquidity measures of call and puts, this table also reports the basic statistics of liquidity measures for options with different maturity, moneyness and implied volatility. Panel B provides the basic statistics for option and stock liquidity, as well as VIX and TED spread, with the sample period being divided into three sub-periods. Specifically, the three sub-sample periods are defined as the pre-crisis (01/2003-07/2007), within-crisis (08/2007-06/2009) and post-crisis period (07/2009-01/2012).

Panel A: Option Liquidity									
	Bid-ask spread			*Volume*			*Dollar Volume*		
Statistics	Mean	Med.	Std.	Mean	Med.	Std.	Mean	Med.	Std.
All options	11.84	11.40	4.34	2.86	2.71	1.24	7.03	5.46	5.87
Call option	12.67	11.99	5.21	2.54	2.37	1.15	6.32	4.99	5.02
Put options	11.19	10.44	4.62	3.14	2.94	1.47	7.58	5.60	6.94
Short-maturity	13.64	13.09	5.10	3.35	3.07	1.72	5.83	4.02	5.90
Medium-maturity	7.82	7.61	2.87	2.27	1.97	1.29	8.57	6.06	7.73
Long-maturity	4.96	4.76	1.81	1.22	0.99	0.89	8.16	5.80	7.80
Out of the money	12.60	11.88	5.08	2.88	2.67	1.42	5.42	3.75	5.41
At the money	6.92	6.88	2.11	3.92	3.49	2.18	12.91	9.98	10.79
In the money	4.96	4.84	1.56	1.91	1.40	1.60	10.38	6.97	9.97
Deep out of the money	19.94	18.29	8.52	2.62	2.19	2.01	2.62	1.83	2.86
Deep in the money	2.69	2.47	1.08	1.38	0.64	2.10	14.09	6.29	21.24
1st quintile of implied vol.	18.39	14.42	14.44	2.28	2.08	1.32	2.61	2.18	3.70
2nd quintile of implied vol.	15.80	12.47	10.94	2.38	2.00	1.57	3.68	2.47	3.73
3rd quintile of implied vol.	17.35	12.89	13.50	3.37	2.33	5.69	4.46	2.67	6.19
4th quintile of implied vol.	17.98	12.45	17.06	3.14	2.49	4.34	6.07	3.84	7.63
5th quintile of implied vol.	19.55	12.67	20.16	3.28	2.99	2.49	7.48	4.61	8.63
Panel B: The Level of Key Variables in Sub-Periods									
	Jan. 2003 - Jul. 2007			*Aug. 2007 - Jun. 2009*			*Jul. 2009 - Jan. 2012*		
Statistics	Mean	Med.	Std.	Mean	Med.	Std.	Mean	Med.	Std.
Option bid-ask spread	12.82	12.37	4.75	9.69	9.18	3.52	11.68	11.54	3.46
Option volume	2.28	1.90	1.18	3.62	3.46	1.05	3.32	3.21	0.94
Option dollar volume	3.46	2.87	2.08	13.51	11.45	7.58	8.58	7.57	3.93
TED spread	0.10	0.10	0.18	1.09	0.91	0.56	0.70	0.61	0.17
VIX	15.42	14.32	4.61	31.50	26.22	13.06	23.46	22.22	6.21
Stock bid-ask spread (HL)	0.80	0.76	0.16	1.48	1.34	0.58	0.82	0.75	0.28
Stock bid-ask spread (close)	0.02	0.02	0.01	0.04	0.03	0.02	0.01	0.01	0.00
Stock volume	4.29	4.18	0.96	8.66	8.33	2.54	8.10	7.82	1.89
Stock dollar volume	128.74	118.05	49.11	273.21	260.80	70.62	234.06	225.97	57.03

Table 2: Stationarity test for key variables

This table shows results of stationarity test for key variables used in this paper, namely proportional bid-ask spread, dollar volume, TED spread, VIX and several stock market liquidity measures. The Augmented Dickey-Fuller test statistics and the 1% critical value is reported in column (3) and (4). And the corresponding p-value is shown in the last column. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

Variable	# observations	Dickey-Fuller test statistic	1% value	p-value
Bid-ask spread	2263	-21.678***	-3.430	0.000
Volume	2263	-19.657***	-3.430	0.000
Dollar volume	2263	-12.075***	-3.430	0.000
TED spread	2263	-3.873***	-3.430	0.002
VIX	2263	-4.557***	-3.430	0.000
BAClose_ew	2263	-46.758***	-3.430	0.000
BAHL_ew	2263	-16.498***	-3.430	0.000
Stock_Volume	2263	-11.009***	-3.430	0.000
Stock_Dollar	2263	-11.038***	-3.430	0.000

Table 3: Option liquidity, TED and VIX

This table shows results of *ARMAX* regressions linking the liquidity in the option market to funding costs and VIX. For each ARMAX regression, we choose the optimal lags of AR and MA terms according to BIC and AIC information criterion. *VIX* is the CBOE S&P 500 volatility index. TED spread is the difference between three-month LIBOR rate and U.S. Treasury bill with the same maturity. Both the VIX and TED spread are lagged for one period (day). *Acq2* is the total amount of assets acquired by dealers and brokers measured on a quarterly basis which partially reflects funding liquidity. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. T-statistics are shown below the coefficient estimates inside parentheses. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent var.	bid-ask	bid-ask	bid-ask	bid-ask	bid-ask	bid-ask
Sample	All	All	All	All	Call	Put
L.vix	-0.109***	-0.117***	-0.124***	-0.125***	-0.099***	-0.132***
	(-8.47)	(-4.31)	(-4.49)	(-4.50)	(-2.73)	(-4.15)
L.TED_Spread	0.649***	1.527**	1.358*	1.215	0.644	2.036**
	(2.76)	(1.98)	(1.71)	(1.49)	(0.61)	(2.40)
Acq2			-0.001	-0.001		
			(-0.80)	(-0.86)		
d_recession				0.871		
				(0.81)		
ARMA						
L.ar	0.330***	2.385***	2.385***	2.392***	1.524***	2.114***
	(16.03)	(33.52)	(33.51)	(33.99)	(16.86)	(13.78)
L2.ar	0.209***	-2.226***	-2.227***	-2.239***	-0.525***	-1.572***
	(10.21)	(-15.50)	(-15.49)	(-15.71)	(-5.84)	(-6.26)
L3.ar		0.914***	0.916***	0.921***		0.457***
		(8.05)	(8.04)	(8.16)		(4.56)
L4.ar		-0.074**	-0.075**	-0.074**		
		(-2.24)	(-2.25)	(-2.26)		
Model	OLS	ARMAX(4,3)	ARMAX(4,3)	ARMAX(4,3)	ARMAX(2,2)	ARMAX(3,3)
N	1302	2264	2264	2264	2264	2264

Table 4: Option liquidity, funding liquidity and VIX: Maturity

This table shows results of *ARMAX* regressions on the liquidity of options with different maturities. An option is considered to be short-term if $ADTE_{i,t} < 60$, medium-term if $60 \leq ADTE_{i,t} \leq 180$, long-term if $180 \leq ADTE_{i,t}$. T-statistics are shown below the coefficient estimates inside parentheses. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1) Short	(2) Medium	(3) Long
L.TED_Spread	1.572*	-0.149	-0.249
	(1.72)	(-0.30)	(-0.82)
L.vix	-0.154***	-0.062***	-0.016
	(-4.63)	(-2.88)	(-1.24)
ARMA			
L.ar	2.366***	-0.375	-0.617***
	(32.60)	(-0.58)	(-7.77)
L2.ar	-2.222***	0.945***	0.490***
	(-15.78)	(12.74)	(8.19)
L3.ar	0.946***	0.295	0.785***
	(8.69)	(0.50)	(10.36)
L4.ar	-0.091***	-0.030	0.076***
	(-2.77)	(-0.95)	(2.60)
N	2263	2263	2257
Model	ARMAX(4,3)	ARMAX(4,3)	ARMAX(4,3)

Table 5: Option liquidity, funding liquidity and VIX: Moneyness

This table shows results of *ARMAX* regressions on the liquidity of options with different extent of moneyness. An option is considered to be deep-out-of-the-money (DOTM) if the contract is a call and $m_{i,t} < 1.06$ or if the contract is a put and $m_{i,t} < 0.94$, out-of-the-money (OTM) if the contract is a call and $1.01 < m_{i,t} \leq 1.06$ or if the contract is a put and $0.94 \leq m_{i,t} < 0.99$, at-the-money (ATM) if $0.99 \leq m_{i,t} \leq 1.01$ for either puts or calls, in-the-money (ITM) if the contract is a call and $0.94 \leq m_{i,t} < 0.99$ or if the contract is a put and $1.01 < m_{i,t} \leq 1.06$, deep-in-the-money (DITM) if the contract is a call and $m_{i,t} < 0.94$ or if the contract is a put and $m_{i,t} > 1.06$. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. T-statistics are shown below the coefficient estimates inside parentheses. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1) OTM	(2) ATM	(3) ITM	(4) DOTM	(5) DITM
L.TED_Spread	3.136**	1.682*	0.490	0.101	0.410***
	(2.16)	(1.85)	(1.40)	(0.43)	(3.30)
L.vix	-0.275***	-0.123***	-0.002	0.016	0.032***
	(-4.53)	(-3.76)	(-0.15)	(1.53)	(5.94)
ARMA					
L.ar	1.451***	2.484***	1.740***	0.956***	0.979
	(4.21)	(43.11)	(42.00)	(23.41)	(1.03)
L2.ar	-0.686	-2.426***	-0.741***	-0.952***	-0.035
	(-1.24)	(-19.55)	(-18.06)	(-29.33)	(-0.04)
L3.ar	0.345	1.030***		0.955***	
	(1.40)	(10.36)		(27.52)	
L4.ar	-0.112***	-0.089***		-0.087***	
	(-2.78)	(-3.04)		(-3.16)	
Model	ARMAX(2,3)	ARMAX(2,1)	ARMAX(1,2)	ARMAX(1,1)	ARMAX(3,2)
N	2264	2264	2262	2262	1639

Table 6: Option liquidity, funding liquidity and VIX: Implied Volatility

This table shows results of *ARMAX* regressions on the liquidity of options with different levels of implied volatility. Following Cao and Wei (2010), we set up five implied volatility classes with $LogIV_{i,t}$ lying in the interval $(-\infty, -2.0112)$, $[-2.0112, -1.7787)$, $[-1.7787, -1.5716)$, $[-1.5716, -1.3543)$ and $[-1.3543, -0.1716)$ respectively. T-statistics are shown below the coefficient estimates inside parentheses. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1) IV1	(2) IV2	(3) IV3	(4) IV4	(5) IV5
L.TED_Spread	10.008*	9.518***	9.790***	3.427	-4.226
	(1.70)	(3.67)	(3.63)	(0.95)	(-1.03)
L.vix	1.109***	0.608***	-0.021	-0.447*	-0.762***
	(5.36)	(7.23)	(-0.13)	(-1.84)	(-4.22)
ARMA					
L.ar	0.994***	1.160***	1.702***	1.599***	-0.841***
	(3.79)	(33.95)	(40.80)	(24.79)	(-58.03)
L2.ar	-0.017	-0.208***	-0.704***	-0.492***	0.398***
	(-0.07)	(-7.35)	(-17.07)	(-5.34)	(16.94)
L3.ar				-0.108***	0.786***
				(-3.70)	(59.74)
Model	ARMAX(2,3)	ARMAX(2,1)	ARMAX(2,2)	ARMAX(3,2)	ARMAX(3,2)
N	1166	1648	1919	1788	1279

Table 7: Option liquidity and stock market liquidity

This table shows results of *ARMAX* regressions linking the liquidity in the option market to stock market liquidity. *BAHL_ew* and *BAHL_vw* are equally- and value-weighted stock market bid-ask spread using high ask and low bid of all the stocks in NYSE, NASDAQ and AMEX. *BAClose_ew* and *BAClose_vw* are equally- and value-weighted closing stock bid-ask spread for the whole market. The other two exgoenous variables are *Stock_Volume* and *Stock_Dollar* which denote the trading volume and dollar volume of the whole stock market, both scaled down by 1 billion. T-statistics are shown below the coefficient estimates inside parentheses. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1)	(2)	(3)	(4)	(5)	(6)
Liquidity measure	High-Low	High-Low	Close	Close	Volume	Dollar
Weight	equal	volume	equal	volume		
L.vix	-0.155***	-0.160***	-0.117***	-0.128***	-0.138***	-0.139***
	(-5.38)	(-5.28)	(-4.31)	(-4.76)	(-4.54)	(-4.62)
L.TED_Spread	1.093	1.244	1.527*	1.450*	1.391*	1.587*
	(1.31)	(1.44)	(1.94)	(1.77)	(1.66)	(1.90)
BAHL_ew	1.982***					
	(9.14)					
BAHL_vw		2.075***				
		(8.94)				
BAClose_ew			0.504			
			(0.74)			
BAClose_vw				25.011***		
				(3.15)		
Stock_Volume					0.280***	
					(4.95)	
Stock_Dollar						0.010***
						(5.86)
ARMA						
L.ar	2.373***	2.394***	2.384***	2.396***	2.373***	2.379***
	(33.09)	(35.57)	(33.50)	(36.61)	(33.89)	(34.56)
L2.ar	-2.206***	-2.250***	-2.225***	-2.256***	-2.204***	-2.216***
	(-15.25)	(-16.42)	(-15.49)	(-16.90)	(-15.69)	(-15.97)
L3.ar	0.904***	0.933***	0.913***	0.937***	0.904***	0.910***
	(7.87)	(8.51)	(8.04)	(8.76)	(8.12)	(8.25)
L4.ar	-0.073**	-0.079**	-0.074**	-0.078**	-0.074**	-0.074**
	(-2.17)	(-2.43)	(-2.23)	(-2.46)	(-2.23)	(-2.27)
ARMAX(p,q)	(4,3)	(4,3)	(4,3)	(4,3)	(4,3)	(4,3)
N	2263	2263	2263	2263	2263	2263

Table 8: Robustness I: Alternative volatility measures

This table shows results of *ARMAX* regressions linking the liquidity in the option market to funding costs and VIX. *VIX* is the CBOE S&P 500 volatility index. *VXO* is CBOE S&P 100 volatility index. *VXN* is volatility of NASDAQ and *VXD* measures the volatility of DJIA. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. T-statistics are shown below the coefficient estimates inside parentheses. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1) VIX	(2) VXO	(3) VXN	(4) VXD
L.vix	-0.122***			
	(-4.31)			
L.vxo		-0.117***		
		(-4.58)		
L.vxn			-0.190***	
			(-7.02)	
L.vxd				-0.136***
				(-4.36)
L.TED_Spread	1.506*	1.532*	0.055	1.471*
	(1.86)	(1.87)	(0.10)	(1.82)
ARMA				
L.ar	1.493***	1.390***	-0.036	1.494***
	(18.49)	(9.47)	(-0.10)	(18.51)
L2.ar	-0.495***	-0.302	0.672**	-0.495***
	(-6.15)	(-1.60)	(2.25)	(-6.16)
L3.ar		-0.089**		
		(-1.99)		
Model	ARMAX(2,3)	ARMAX(3,2)	ARMAX(2,2)	ARMAX(2,3)
N	2263	2263	2261	2263

Table 9: Option liquidity, TED and VIX: Sub-periods

This table shows results of *ARMAX* regressions linking the liquidity in the option market to funding costs and VIX. The whole sample period is divided into two sub-periods, the pre-crisis period (01/2003-07/2007) and crisis onward (07/2007-01/2012). T-statistics are shown below the coefficient estimates inside parentheses. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Bid-ask spread			*Dollar volume*			*Volume*		
Sample Period	All	Pre-Crisis	Crisis onward	All	Pre-Crisis	Crisis onward	All	Pre-Crisis	Crisis onward
vix	-0.131***	-0.374***	-0.104***	0.533***	0.386***	0.567***	0.049***	0.066***	0.055***
	(-5.13)	(-5.28)	(-4.17)	(38.67)	(17.29)	(22.40)	(6.85)	(4.40)	(7.35)
TED_Spread	1.901**	0.701	0.023	0.960*	0.619	-2.306***	0.321	0.316	-0.362*
	(2.33)	(0.44)	(0.03)	(1.95)	(0.97)	(-3.08)	(1.61)	(0.72)	(-1.76)
ARMA									
L.ar	1.676***	1.162***	0.785	0.950***	1.283***	1.448***	0.946***	1.578***	1.781***
	(30.93)	(33.69)	(1.12)	(219.85)	(28.00)	(12.96)	(122.66)	(69.49)	(22.58)
L2.ar	-0.677***	-0.167***	0.041		-0.291***	-0.513***		-0.578***	-0.785***
	(-12.53)	(-4.97)	(0.07)		(-6.59)	(-5.07)		(-25.52)	(-10.40)
ARMAX(p,q)	(2,3)	(2,1)	(2,3)	(1,1)	(2,1)	(2,2)	(1,1)	(2,1)	(2,2)
N	2264	1140	1124	2264	1140	1124	2264	1140	1124

Table 10: Option liquidity, funding liquidity and VIX: Weekly Data

This table uses weekly data and shows results of OLS and *ARMAX* regressions linking the liquidity in the option market to funding costs and VIX. The first two columns use bid-ask spread for all of the options as the dependent variable. Column (3) and (4) examine call and put option liquidity respectively. T-statistics are shown below the coefficient estimates inside parentheses. Below the exogenous regressors are several autoregressive terms for each *ARMAX* model. For brevity, the moving averaging terms are not displayed. ***, ** and * denote significance level at 1 %, 5 % and 10 %.

	(1)	(2)	(3)	(4)
Option Type	All	All	Call	Put
TED_Spread	-0.502**	0.896**	0.873*	0.990**
	(-2.32)	(2.07)	(1.74)	(2.00)
week_VIX		-0.134***	-0.096***	-0.207***
		(-5.08)	(-3.65)	(-6.49)
ARMA				
L.ar	0.623***	-0.804***	1.196***	0.373**
	(17.41)	(-27.51)	(72.37)	(2.13)
L2.ar		0.833***	-1.187***	-0.388**
		(33.63)	(-59.18)	(-1.97)
L3.ar		0.877***	0.967***	0.007
		(31.99)	(58.99)	(0.03)
L4.ar				0.607***
				(3.84)
Model	OLS	ARMAX(3,3)	ARMAX(3,3)	ARMAX(4,4)
N	470	471	471	471

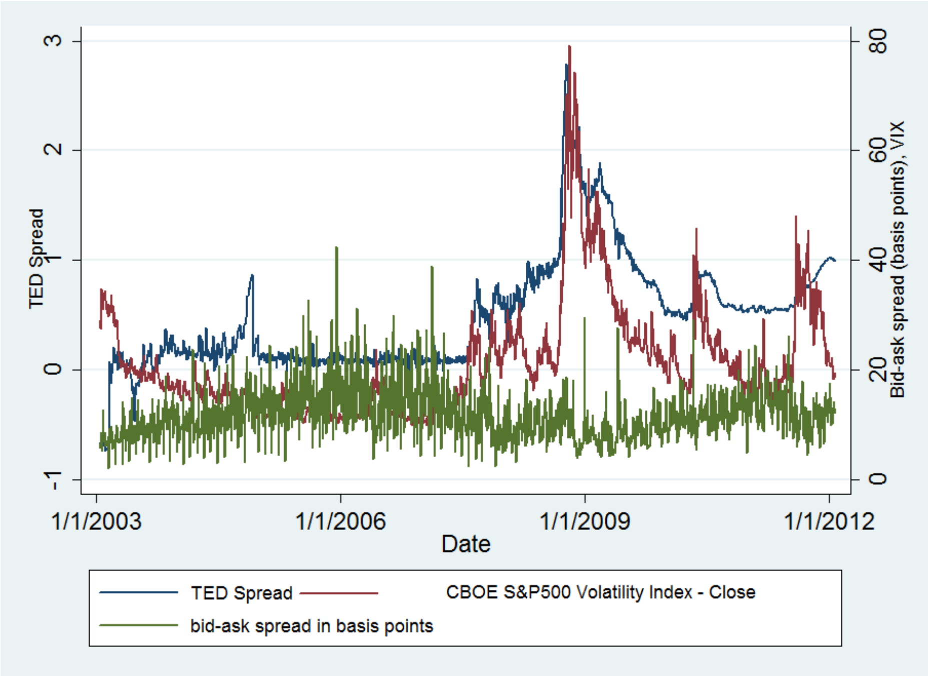

Figure 1: **The evolution of option market liquidity, TED spread and VIX.**This figure illustrates the evolution of option liquidity, the TED spread and VIX from January 2003 to January 2012. The way that we measure option market liquidity can be found in appendix I.

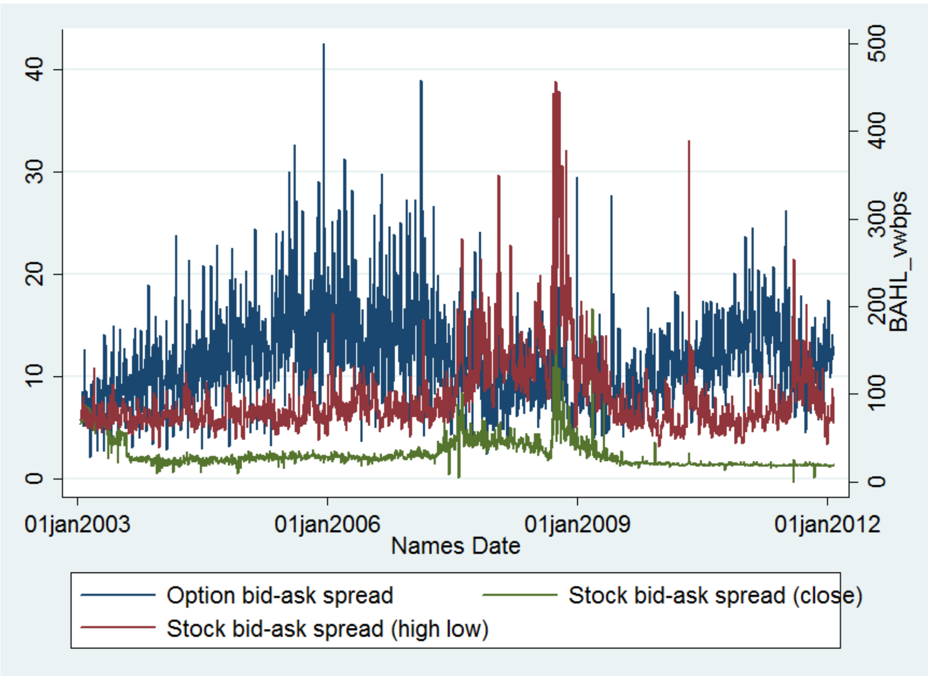

Figure 2: **The evolution of option market bid-ask spread, TED spread and VIX.** This figure illustrates the evolution of option and stock market liquidity from January 2003 to January 2012. The bid-ask spread is used as the proxy for liquidity and is defined in appendix I.