Two order books are better than one? Trading at settlement (TAS) in VIX futures

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TWO ORDER BOOKS ARE BETTER THAN ONE? TRADING AT SETTLEMENT (TAS) IN VIX FUTURES

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We examine the effects from the Trading At Settlement (TAS) introduction on VIX futures market quality. We find that the VIX futures market exhibits higher trading activity and better liquidity after the TAS introduction. VIX futures traders use the TAS limit order book to execute large transactions, and TAS helps limit order traders from being picked off by informed traders when the VIX futures price volatility is high. The TAS introduction has created a highly liquid, low-cost, trading venue. Although the TAS introduction fragments VIX futures trading into two order books, liquidity in the regular order book is not hurt. © 2014 The Authors. *Journal of Futures Markets* published by Wiley Periodicals, Inc. Jrl Fut Mark

1. INTRODUCTION

Since March 2004, Chicago Board Options Exchange (CBOE) Volatility Index (VIX) futures are traded on the CBOE Futures Exchange (CFE).[1] Trading is completely electronic, and the main trading venue constitutes a limit order book. On November 4, 2011, the CFE introduced an additional VIX futures trading facility, namely the opportunity to apply Trade At Settlement (TAS), starting with the futures contract maturing in November 2011.[2] Since then, futures traders can at any time during exchange trading hours enter limit orders in the TAS limit order

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[1]At a given time, the VIX represents an expected annualized volatility (in %) of the S&P 500 index over the subsequent 30 calendar days. It is the leading benchmark for U.S. stock market volatility and is often referred to as the "fear index." For more information about the VIX, see the VIX White paper at http://www.cboe.com/micro/vix/vixwhite.pdf.
[2]TAS is also permitted in, for example, energy futures (crude oil, heating oil, and natural gas), agriculture futures (cocoa, cotton, coffee sugar, and corn) and precious metals futures (gold and silver). For more information, see http://www.cmegroup.com.

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book, which is entirely separate from the regular VIX futures limit order book. Completed TAS transactions are confirmed in real time during the trading session, and the final transaction price is confirmed when the settlement price is established subsequent to the close of trading.

The VIX futures settlement price is widely used as a reference price to determine the value of other VIX derivatives contracts, such as VIX options, and for marking investment portfolios to market value (e.g., to measure performance of portfolio managers and investment funds with exposure to market volatility). Hagströmer and Nordén (2014) argue that many futures market investors have incentives to execute their trades as close to the settlement price as possible. In this setting, this includes, for example, issuers of exchange-traded notes and exchange-traded funds, related to VIX futures, and arbitrageurs who need to trade futures close to the settlement price. According to the CFE, TAS transactions are aimed at helping traders to even out end-of-day price exposures in VIX futures, by allowing users to hedge their VIX futures position throughout the trading day and receive greater price certainty relative the daily settlement price.[3]

In this paper, we analyze the effects from the introduction of TAS on VIX futures trading activity and market liquidity. First, we document to what extent trading and quoting in the TAS limit order book actually is utilized relative to activities in the regular VIX futures limit order book over the first year since the introduction. Moreover, we examine if, and to what extent, TAS transactions indeed enable futures traders to trade closer to the daily VIX futures settlement price than comparable alternatives. Specifically, we compare trades in the TAS limit order book with trades in the regular order book, made either directly at the prevailing quotes, or postponed to the daily closing quotes.

Second, we investigate under which circumstances traders demand and supply liquidity in the TAS limit order book relative the regular VIX futures order book. The introduction of TAS provides VIX futures market participants with an opportunity, at any time during the trading hours, to choose between two alternative options: to trade or quote in the regular limit order book at a known futures price, or to trade or quote in the TAS limit order book. In the latter case, a trade is made at the daily futures settlement price, which is unknown until the closing time of the trading session. This choice resembles the common equity market situation, in which a trader can choose between trading directly in the continuous limit order book and postponing trading to the closing call auction; albeit with the difference that the TAS order book is open throughout the trading day, making participants in intraday TAS transactions to commit to trading at the settlement price prior to the closing of continuous trading.

Third, we investigate if the introduction of TAS has any effects on the quality of the VIX futures market. Specifically, we analyze whether the TAS introduction leads to improvements in trading activity and liquidity at the VIX futures market. In this part of the analysis, we use a difference-in-difference methodology, by which we benchmark the change in futures trading activity and liquidity to corresponding changes in trading activity and liquidity at the VIX options market. We argue that at-the-money VIX options are particularly useful as benchmarks since they have the same underlying asset and maturity cycle as the VIX futures, and thus, can be used to create synthetic VIX futures contracts. At the same time, while the TAS limit order book is added to the VIX futures market, the structure of the VIX options market stays the same.

We find that TAS transactions account for approximately 10% of the total VIX futures trading volume, and less than 1% of the total number of VIX futures transactions. This indicates that VIX futures traders use the TAS order book to execute large transactions. The

[3]See the CFE rules' amendments made to provide for TAS transactions in the submission to the Commodity Futures Trading Commission, Submission Number CFE-2011-23, available at http://cfe.cboe.com/publish/CFErulefilings/SR-CFE-2011-023.pdf (retrieved on September 14, 2014).

TAS order book exhibits on average better liquidity than the regular VIX futures order book, both in terms of a relatively narrower bid-ask spread and more depth at the best quotes. Compared to alternative ways to trade VIX futures, TAS is the cheapest and safest one to trade close to the daily VIX futures settlement price. In this respect, TAS transactions exhibit the smallest effective spread and the smallest risk that the traded price diverges from the futures settlement price.

The results also show that relative TAS liquidity supply is increasing in volatility, which we argue is because TAS helps limit order traders from being picked off by informed traders when the volatility in the VIX futures price is high and regular limit orders are likely to become stale. Conversely, relative TAS liquidity demand is decreasing in volatility, which is in line with the notion that traders demand relatively more liquidity in the regular order book when they believe that there are quick potential profits to be made from large price swings.

Finally, our market quality analysis reveals a significantly increased trading activity and liquidity at the VIX futures market following the TAS introduction, and more so than at the VIX options market. Thus, we can conclude that the introduction of TAS has created a highly liquid, low-cost, transparent trading venue, on which investors can trade large orders directly in the TAS limit order book. Although the introduction of the TAS order book fragments the VIX futures trading and quoting into two order books, liquidity in the regular order book is not hurt in the process.

The paper is organized as follows. We first describe the VIX futures market and the data. We then compare the activity and liquidity in the two order books, and examine if and to what extent greater price certainty can be obtained with TAS. Thereafter, we investigate the circumstances when traders demand and supply liquidity in the TAS order book, and analyze if the TAS introduction has any effects on the VIX futures market quality. Finally, we provide concluding remarks.

2. THE MARKET FOR VIX FUTURES

This section describes the structure of the VIX futures market and the data used for the empirical analyses.

2.1. VIX Futures Market Structure

The CBOE introduced VIX futures in March 2004. At any time, the VIX measures the expected annualized percentage volatility of the S&P 500 index over the next 30 calendar days. As such, the VIX corresponds to the implied volatility of S&P 500 index options and is widely recognized as an important forward-looking indicator of uncertainty faced by financial market participants. The VIX futures market consists of contracts with different maturities and final settlement dates. Throughout a calendar year, trading is typically possible in nine futures contract series, with between one and nine months left to maturity. One contract series matures every month. The maturity date, and final settlement date, is the Wednesday 30 days before the third Friday of the calendar month immediately following the maturity month.[4] Following the maturity of one futures contract series a new contract series, with nine months remaining until maturity, is listed. For example, in February, the February contracts expire

[4]If the third Friday of the month subsequent to expiration of the applicable VIX futures contract is a CBOE holiday, the final settlement date for the contract shall be 30 days prior to the CBOE business day immediately preceding that Friday (VIX futures contract specifications, retrieved on October 14, 2013, from the website http://cfe.cboe.com/Products/Spec_VIX.aspx).

and are subsequently replaced with newly issued November contracts. At the same time, contracts maturing in March (with about one month left to expiration) up to October (with about eight months left to expiration) are also listed. All VIX futures are cash settled at maturity.

The VIX futures are traded at the CFE within an electronic limit order book. The order book is open for trading on weekdays between 7:00 a.m. and 3:15 p.m. CST.[5] Orders allowed in the VIX futures limit order book include regular liquidity-consuming market orders and liquidity-providing limit orders.[6] The contract multiplier is $1,000 for each VIX futures contract. For a regular order or trade the minimum price increment is 0.05 index points, which corresponds to a $50 contract value per tick. The CFE allows for block trades, with a minimum trade size of 200 futures contracts, to be executed outside the limit order book. Block trades must be reported to the exchange within ten minutes after the trade, if the trade is agreed upon within the regular trading hours, and within ten minutes after the commencement of trading on the following business day, if the trade is done after the closing time. The minimum price increment for block trades is 0.01 index points.

On November 4, 2011, the CFE introduced the TAS facility in the VIX futures market. As of then, VIX futures trading is possible at two disparate venues; the regular limit order book and the TAS order book, where the latter is open between 7:00 a.m. and 3:12 p.m.[7] Throughout the trading day, the TAS limit order book operates in a similar way as the regular book, but with the important difference that all TAS prices are quoted in terms of the daily futures settlement price. Thus, although TAS transactions are confirmed in real time, the resulting futures prices are not confirmed until the futures settlement price is determined following the closing of the regular VIX futures trading session at 3:15 p.m.[8] The allowed price range for TAS transactions in VIX futures is from $100 (0.10 index points times $1,000) below the daily settlement price to $100 above the daily futures settlement price, and the minimum price increment for TAS transactions is 0.01 index points.[9]

Figure 1 (top graph) illustrates the state of the limit order book at 3:00 p.m. on June 6, 2013, for the June VIX futures contract. The order book displays liquidity in terms of volume on offer to, at best, buy futures for $16.65 and sell futures for $16.70 per contract. The best bid-ask spread equals the minimum futures price increment at 0.05. Thus, at this point in time, a trader could have bought, say 100 futures contracts, for $16.70 per contract, and,

[5]The CFE considers 8:30 a.m. to 3:15 p.m. as regular trading hours and 7:00 a.m. to 8:30 a.m. as extended trading hours. Extended trading hours were introduced on December 10, 2010, between 7:20 a.m. and 8:30 a.m., and then further extended on September 26, 2011, when the opening time was set to 7:00 instead of 7:20.

[6]See the CFE Rule Book (retrieved on October 14, 2013, from the website http://cfe.cboe.com/publish/CFERuleBook/CFERuleBook.pdf) for a detailed description of all order types allowed in the VIX futures limit order book.

[7]In March 2009 the CFE introduced trading in Mini-VIX futures. The Mini-VIX futures contracts are similar to the regular VIX futures contracts, except for the smaller contract size ($100 times the VIX) and, thus, the smaller contract value per tick ($5). During our sample period, the Mini-VIX futures are seldom traded with very low liquidity, and are not considered in our empirical analyses. In fact, the CFE decided to delist the Mini-VIX futures in 2013.

[8]The daily VIX futures settlement price for each contract is set as the midpoint of the final bid quote and the final ask quote for the contract in the regular futures limit order book at the close of trading. However, if the midpoint quote is not at a minimum increment for the VIX futures contract, the daily settlement price is rounded up to the nearest minimum increment, that is, the final ask quote.

[9]In November 2011, when TAS transactions were first allowed, the permissible minimum price increment was set at 0.05 index points. However, from February 21, 2012, the CFE reduced the minimum trading increment from 0.05 to 0.01 index points. The CFE stated that the more granular pricing for TAS transactions is needed to parallel this with the existing pricing structure in the markets for exchange traded notes and exchange traded funds, which allow for penny pricing. See the CFE rules' amendments made to permit TAS transactions to occur in increments of 0.01 index points in the submission to the Commodity Futures Trading Commission, Submission Number CFE-2012-04, available at http://www.cboe.org/publish/cferulefilings/sr-cfe-2012-004.pdf (retrieved on September 14, 2014).

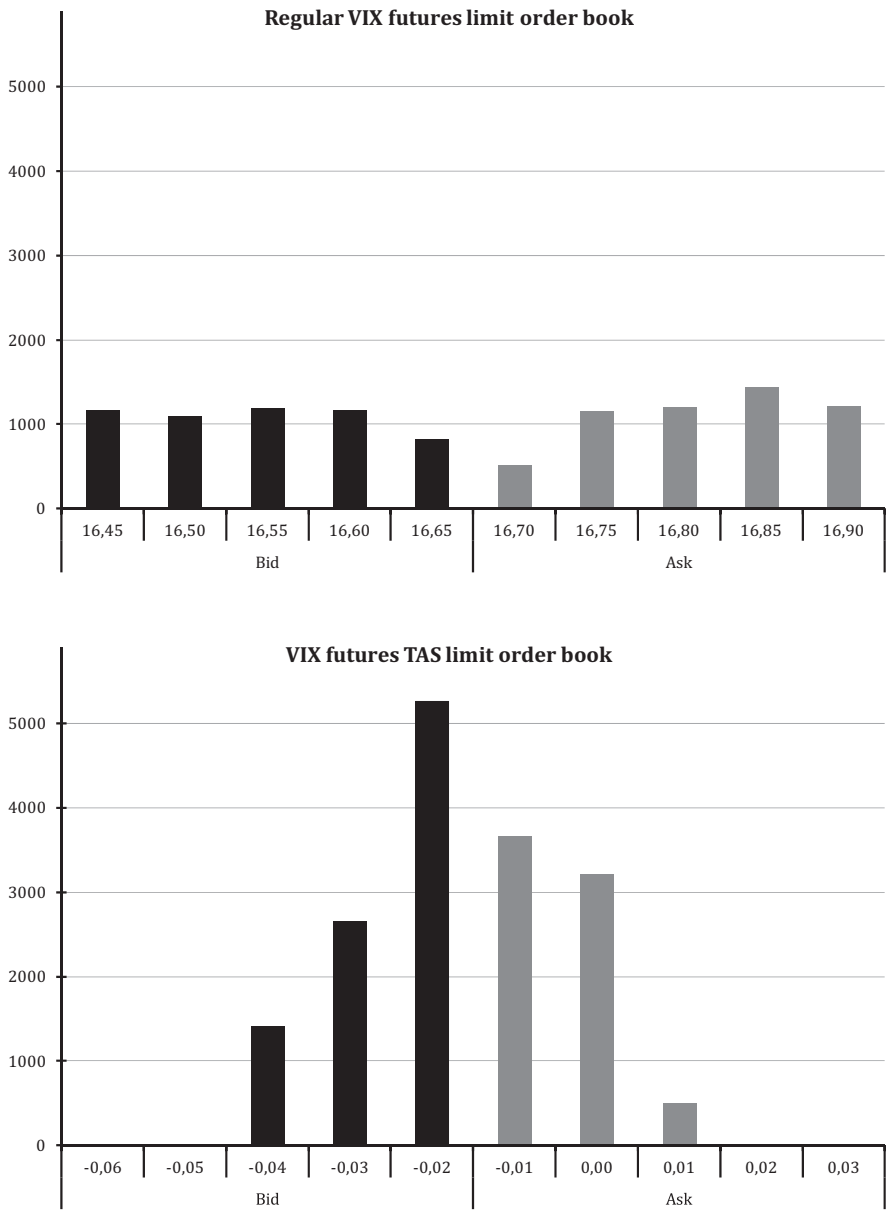

FIGURE 1

The regular VIX futures limit order book, and the corresponding TAS limit order book, for the June 2013 contract on June 6, 2013, at 3:00 p.m.

likewise, have sold the same amount of contracts for $16.65 per contract. At the same time, the corresponding TAS limit order book, displayed in Figure 1 (bottom graph), shows the prevailing liquidity at the best bid −0.02 and the best ask −0.01. Evidently, a trader with an intention to buy (sell) 100 futures contracts could have done so at a price equal to the daily futures settlement price less 0.01 (0.02) index points. The best bid-ask spread is 0.01, which equals the minimum price increment allowed in the TAS limit order book.

2.2. Data

We use a data set that consists of all VIX futures trades and quotes in the regular and TAS limit order books between January 3, 2011, and December 31, 2012. The data are obtained from the Thomson Reuters Tick History database, maintained by the Securities Research Centre of Asia-Pacific (SIRCA), and include microsecond accurate timing information on transaction price, trading volume and order book depth (the five best bid and ask quotes and the associated sizes). From the same database, we also obtain corresponding information on trades and quotes for VIX options.[10] We exclude records outside the official exchange opening hours (8:30 a.m. to 3:15 p.m. for regular futures trading, and 8:30 a.m. to 3:12 p.m. for TAS trading) and records that lack either the closing bid or ask quote, as well as non-business and other non-trading days.

3. THE ORDER BOOKS AND PRICE CERTAINTY

3.1. VIX Futures Trading Activity and Liquidity

Our first objective is to examine the extent to which trading and quoting in the TAS limit order book is utilized relative to the regular VIX futures limit order book. In this analysis, we use the futures of the three nearest contract months during two different sub-periods: Period I is before the TAS introduction (January 3, 2011–October 31, 2011) while Period II is after the introduction (May 1, 2012–December 31, 2012).[11] The front month contract is rolled over at its expiration. Table I provides summary statistics (daily averages) for regular and TAS trading volume, number of transactions and trade size for each of the three contract months. The proportion of TAS activity to total activity (regular + TAS) is also provided (denoted by Relative TAS in the table).

Regular VIX futures transactions exhibit a significant increase in volume and trade frequency across the periods, and most of this trading is concentrated in the front month contract. Since the TAS introduction, the daily average proportion of TAS volume is around 10% in the front month contract, and much lower in the second and third contracts. The relative TAS trade frequency is very low, with an average of 0.51% in the front month contract.

Regular futures transactions have the largest size in the front month contract, whereas TAS transactions have the largest size in the second contract. In Period II, the daily average size of TAS transactions is many times larger than that of regular trades, and TAS accounts for approximately 96% of the total trade size. This clearly shows that VIX futures traders use the TAS order book to execute large trades.

It is interesting to see the intraday volume pattern in the regular limit order book before and after the introduction of TAS, and how it differs from that in the TAS limit order book. To this end, we show in Figure 2 the intraday (five minutes) average trading volume for the front month contract for the regular and TAS order books before (top graph) and after (bottom graph) the TAS introduction.

Regular trading volume shows, similar to many other markets, a U-shaped pattern during the trading hours.[12] The shape is more pronounced after the TAS introduction, with relatively high volume at 8:30 p.m. (the opening of the regular trading hours), reaching a minimum at

[10]For the VIX options, the Thomson Reuters Tick History database provides order book depth only at the best levels.
[11]The period between October 31, 2011, and May 1, 2012, is discarded because activity in the TAS order book appear in the Thomson Reuters Tick History database only from May 1, 2012. Note that the minimum price increment for TAS transactions is 0.01 index points for the entire Period II.
[12]Examples of empirical studies finding this U-shape in volume are Wood, McInish, and Ord (1985), Jain and Joh (1988), and Eaves and Williams (2010).

TABLE I
VIX Futures Trading Activity

	Trading volume			*Number of trades*			*Trade size*		
	Regular	*TAS*	*Relative TAS*	*Regular*	*TAS*	*Relative TAS*	*Regular*	*TAS*	*Relative TAS*
Period I: January 3, 2011–October 31, 2011									
Nearby contract	19,739	NA	NA	4,841	NA	NA	5	NA	NA
Second contract	13,708	NA	NA	3,972	NA	NA	4	NA	NA
Third contract	5,269	NA	NA	1,716	NA	NA	3	NA	NA
Period II: May 1, 2012–December 31, 2012									
Nearby contract	34,680	3,846	0.1026	6,907	32	0.0051	5	146	0.9565
Second contract	26,587	730	0.0237	5,840	5	0.0008	5	425	0.9738
Third contract	10,099	64	0.0066	2,733	1	0.0006	4	64	0.9116
t-test (*p*-value) for difference between Period I and II									
Nearby contract	0.0000	NA	NA	0.0000	NA	NA	0.0000	NA	NA
Second contract	0.0000	NA	NA	0.0000	NA	NA	0.0000	NA	NA
Third contract	0.0000	NA	NA	0.0000	NA	NA	0.0000	NA	NA

Note. Summary statistics (daily averages) for futures trading volume (number of traded contracts), number of transactions, and trade size. Relative TAS is the daily average proportion of TAS trading volume, number of transactions, and trade size, respectively. Trading volume, number of trades, and trade size are obtained during the official exchange opening hours, 8:30 a.m. to 3:15 p.m. CST for regular futures trading, and 8:30 a.m. to 3:12 p.m. CST for TAS trading, and exclude off-exchange trades.

around 12:30 p.m., and then jumping substantially just prior to the close of trading. An explanation for the jump at the open is traders' reactions to news and events that occurred after the close of the previous day's trading, whereas the jump at the end of the day is probably due to traders not wanting overnight risk and therefore liquidating their positions.[13] The TAS limit order book has a different volume pattern, with most of the trading taking place in the afternoon, especially toward the close. This could be due to traders' reluctance to take on the higher risk of committing to trade at the unknown daily settlement price too far in advance.

Table II reports summary statistics (daily averages) for the three contract months' bid-ask spread and depth in each order book and period. We report the best level depth (obtained as the average volume available on the bid and ask side) and the three best levels together. All liquidity measures are observed at the end of one-minute intervals during regular trading hours.

The regular VIX futures bid-ask spread has tightened significantly across the periods and is almost equal to the level implied by its minimum tick size. In Period II, the daily average ratio between the TAS bid-ask spread and the corresponding regular spread (denoted by TAS/Regular in the table) for the two nearest contracts is close to 0.2. Hence, the TAS order book exhibits a roughly five times as narrow bid-ask spread as the regular order book, which of course is driven by the tick size regulations, and stipulates a one to five ratio between the minimum bid-ask spreads.

[13]For theoretical studies providing explanations for this pattern; see, for example, Admati and Pfleiderer (1988) and Foster and Viswanathan (1993).

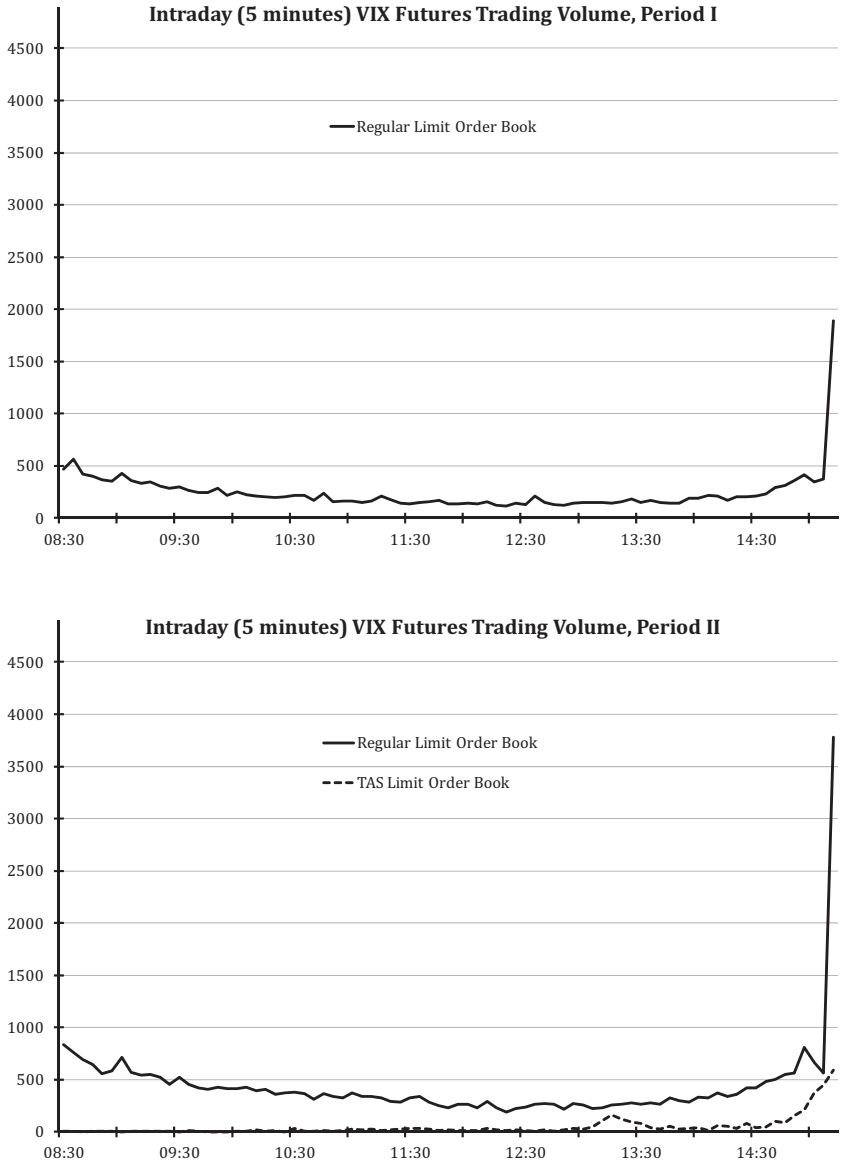

FIGURE 2

Intraday (five minutes) average VIX futures trading volume in the regular and TAS limit order books, before the TAS introduction (Period I, January 3, 2011–October 31, 2011) and after (Period II, May 1, 2012–December 31, 2012).

Regular VIX futures depth at both the best level and at the three best levels has increased significantly between Periods I and II. At the best level, the regular order book is deepest in the nearby series across both periods. This is also true for the TAS order book depth in Period II, although the second contract almost matches the first. The depth for the three best levels in the regular order book are also mainly in the nearby contract during Period I. However, in Period II, depth for the best three levels is more concentrated in the second contract month for both regular futures and TAS. Except for the third contract, the TAS order book exhibits

TABLE II
VIX Futures Market Liquidity

	Bid-ask spread			*Depth (best level)*			*Depth (three best levels)*		
	Regular	*TAS*	*TAS/ regular*	*Regular*	*TAS*	*Relative TAS*	*Regular*	*TAS*	*Relative TAS*
Period I: January 3, 2011–October 31, 2011									
Nearby contract	0.0542	NA	NA	74	NA	NA	326	NA	NA
Second contract	0.0551	NA	NA	64	NA	NA	288	NA	NA
Third contract	0.0616	NA	NA	30	NA	NA	148	NA	NA
Period II: May 1, 2012–December 31, 2012									
Nearby contract	0.0517	0.0103	0.1971	163	2,079	0.9272	772	2,853	0.7796
Second contract	0.0524	0.0111	0.2125	155	2,009	0.9221	783	3,065	0.7964
Third contract	0.0546	0.0149	0.2764	72	149	0.6468	376	303	0.4465
t-test (*p*-value) for difference between Period I and II									
Nearby contract	0.0000	NA	NA	0.0000	NA	NA	0.0000	NA	NA
Second contract	0.0000	NA	NA	0.0000	NA	NA	0.0000	NA	NA
Third contract	0.0000	NA	NA	0.0000	NA	NA	0.0000	NA	NA

Note. Summary statistics (daily averages) for futures bid-ask spread and futures depth. Bid-ask spreads and depths are observed at the end of one-minute intervals during the official exchange opening hours, 8:30 a.m. to 3:15 p.m. CST for regular futures trading, and 8:30 a.m. to 3:12 p.m. CST for TAS trading. Depth is obtained as the average volume available on the bid and ask side, for the best level in the order book, and the three best levels. TAS/regular is the daily average ratio between the TAS bid-ask spread and the corresponding regular spread. Relative TAS is the daily average proportion of TAS depth to total depth (regular + TAS).

considerably more depth than the regular order book, with a proportion of more than 90% (just below 80%) of total best level (best three levels') depth in Period II.

3.2. Trading Close to the Settlement Price

We also investigate to what extent trading in the TAS limit order book achieves its main purpose; namely, whether TAS actually represents a low-cost alternative to trade closer to the daily futures settlement price than comparable alternatives.

We examine a scenario where a trader wishes to trade as close to the settlement price as possible, and chooses between three alternative ways to trade VIX futures at any given time during the exchange trading hours. The first alternative is to trade in the TAS limit order book and the other two involve trading in the regular order book, either directly at the prevailing quotes, or to wait and trade at the daily closing quotes. Thus, we first record each actual TAS transaction in our data set, and classify it as a buyer initiated or seller initiated transaction by matching the transaction price to the prevailing TAS limit order book. Then, we consider each respective hypothetical alternative to trade the same futures volume in the regular limit order book, at either the same time or just before the closing time on the same day. Accordingly, if the volume at the best quote in the regular order book is lower than the corresponding TAS volume, we allow the trader to climb the order book and trade the missing volume at the second level quote, and if that is not enough, to trade at the third level quote, and so on. The alternatives are compared on the basis of cost and risk, where cost is measured by the effective spread, that is, the absolute difference between the midpoint of the bid and ask quote

TABLE III
Effective Spread and Risk for Different Transactions

	Alt. 1	*Alt. 2*	*Alt. 3*
Effective spread	0.0050	0.0374	0.0394
Effective normalized spread	0.0276	0.2040	0.2175
Risk (normalized)	0.0071	1.3455	0.2923

Note. Summary statistics (averages) for the effective spread (the absolute difference between the midpoint of the bid and ask quote and the volume-weighted transaction price) and risk (the absolute difference between the settlement price and the volume-weighted transaction price) for actual futures TAS transactions (Alt. 1), hypothetical transactions of the same futures volume (as the actual TAS transactions) in the regular order book; at the same time (Alt. 2), and just before closing time on the same trading day (Alt. 3). Statistics are obtained for Period II; between May 1, 2012 and December 31, 2012. "Normalized" means divided by the corresponding daily settlement price.

and the volume-weighted transaction price, and risk is measured by the absolute difference between the settlement price and the volume-weighted transaction price. We normalize each measure by dividing it by the corresponding daily settlement price.[14]

Table III provides the mean for each measure of cost and risk during Period II, that is, since the introduction of TAS. Trading in the TAS limit order book (Alt. 1) is clearly the cheapest alternative, with a mean effective normalized spread of 0.0276. This is to be compared with a mean level of around 0.20 for the other two alternatives. Based on the mean level of effective spread, trading directly at the prevailing quotes (Alt. 2) is more or less equally costly as waiting to trade at the closing quotes (Alt. 3).

The TAS alternative also represents the lowest risk of deviating from trading at the futures settlement price. This risk is almost non-existent, and estimated at a mean level of 0.0071. The alternative to wait to trade at the closing quotes is far less risky than trading directly at the prevailing quotes. The mean level for the "waiting alternative" is 0.2923, while corresponding mean level for the "direct alternative" is 1.3455.

4. DEMAND AND SUPPLY OF LIQUIDITY IN VIX FUTURES

We now investigate under which circumstances traders demand and supply liquidity in the TAS limit order book relative the regular VIX futures order book. In this analysis, we use the front month contract and data from Period II. We approximate liquidity demand with the daily number of traded futures contracts, and liquidity supply with limit order book depth. Relative liquidity demand is obtained as the relative volume, measured as the daily proportion of TAS trading volume to total VIX futures trading volume; and relative liquidity supply is obtained using relative best depth and relative deep depth, where relative best (deep) depth is measured as the daily proportion of TAS depth to total depth at the best level (three best levels') quotes. Depth is again obtained from end-of-minute snapshots of each limit order book.

We hypothesize that the demand and supply of liquidity in the TAS limit order book, relative the regular VIX futures order book, is related to uncertainty in the VIX futures price. When a trader submits a limit order to the regular VIX futures order book, he in fact provides a free option to a potential counterparty to trade at the limit order quote (Copeland & Galai, 1983). Hence, he is exposed to a potential loss from trading with a better-informed

[14]Note that this analysis produces partial equilibrium results as the decision to trade (take liquidity) in the TAS limit order book clearly is endogenous in the sense that the trader has optimized his decision given the state of the TAS order book, and relative alternative ways to execute the trade. We undertake a full equilibrium analysis of the decision to trade in the TAS limit order book in the subsequent section.

counterparty. The higher the volatility in the VIX futures price, the more likely it is that the limit order becomes stale, and the more costly it is to provide liquidity in the regular futures market. However, a limit order submitted to the TAS order book is not as heavily exposed to informed traders, as the TAS limit order price is quoted in terms of the unknown futures settlement price. In other words, TAS helps limit order traders from being picked off by informed traders when the volatility in the VIX futures price is high. Thus, we expect that relative TAS depth is increasing in volatility. On the other hand, when a trader believes that there is a quick potential profit to be made from the larger price swings, he will place a liquidity-consuming market order in the regular VIX futures order book. Accordingly, we expect relative TAS volume to be decreasing in volatility.

Each relative measure of liquidity demand and supply is related to VIX futures volatility in the following regression:

$$y_t = \beta_0 + \beta_1 Futures\,Volatility_t + \beta_2 Maturity_t + u_t \quad (1)$$

where y_t is either *Relative Volume*, *Relative Best Depth*, or *Relative Deep Depth*. *Futures Volatility* is the daily sum of squared minute-by-minute regular VIX futures midpoint quote returns (realized volatility), and *Maturity* is the time left to maturity of the futures contracts, measured as days divided by 365. Time to maturity is added as a control variable for both the relative demand and relative supply of liquidity in VIX futures.

Table IV reports descriptive statistics for the relative TAS futures trading activity and liquidity measures, as well as for VIX futures realized volatility. The mean, median, max, min, and standard deviation for each variable is reported, as well as the MacKinnon (1996) unit root p-value. The augmented Dickey-Fuller test (denoted by Unit Root Test in the table) is used to test the null hypothesis of a unit root in each daily time series, which based on the low MacKinnon (1996) p-values shows that each variable is stationary (see Fuller, 1996).

We include five moving average error terms in Equation (1) to account for residual autocorrelation. The estimation results are reported in Table V. For each regression, we report the estimated coefficients, the statistical significances (marked with asterisks) and the standard errors (within parentheses). The coefficient relating futures volatility to relative volume is significantly negative at the 10% level. This result supports our argument that traders place relatively fewer market orders in the TAS order book and relatively more in the

TABLE IV
Relative Trading Activity and Liquidity Measures for TAS

	Relative Volume	*Relative Best Depth*	*Relative Deep Depth*	*Futures Volatility*
Mean	0.1026	0.9136	0.7796	0.0016
Median	0.0975	0.9241	0.7893	0.0015
Maximum	0.2597	0.9794	0.9481	0.0059
Minimum	0.0000	0.6800	0.4754	0.0004
SD	0.0499	0.0478	0.0643	0.0007
Unit root test	0.0001	0.0000	0.0000	0.0000

Note. Summary statistics for relative TAS futures trading activity and liquidity measures, and for VIX futures realized volatility. Statistics are obtained for Period II; between May 1, 2012 and December 31, 2012. *Relative Volume* is the daily proportion of TAS trading volume (number of traded contracts) to total VIX futures trading volume. *Relative Best* (*Deep*) *Depth* is the daily proportion of TAS depth to total depth (regular + TAS) at the best level (three best levels') quotes. Depth is obtained as the average volume available on the bid and ask side using end-of-minute snapshots of the order book. *Futures Volatility* is the daily sum of squared minute regular VIX futures midpoint quote returns. The augmented Dickey–Fuller test (Fuller, 1996) is used to test the null hypothesis that each time series has a unit root. For each series and time period, a MacKinnon (1996) one-sided p-value under each null hypothesis is reported.

TABLE V
Regression Results

	Relative Volume	*Relative Best Depth*	*Relative Deep Depth*
Constant	0.1365***	0.9352***	0.8033***
	(0.0164)	(0.0126)	(0.0164)
Futures Volatility	−11.3866*	10.4482**	12.7123**
	(6.2421)	(4.3303)	(6.2658)
Maturity	−0.3411*	−0.8779***	−1.0138***
	(0.1786)	(0.1941)	(0.2043)
MA (5)	YES	YES	YES
$\bar{R}^2$	0.3161	0.4816	0.3802

Note. Regression results for relative TAS futures trading activity and liquidity measures during Period II; between May 1, 2012 and December 31, 2012. *Relative Volume* is the daily proportion of TAS trading volume (number of traded contracts) to total VIX futures trading volume. *Relative Best* (*Deep*) *Depth* is the daily proportion of TAS depth to total depth (regular + TAS) at the best level (three best levels') quotes. Depth is obtained as the average volume available on the bid and ask side using end-of-minute snapshots of the order book. Each regression is of the form:

$$y_t = \beta_0 + \beta_1 Futures\,Volatility_t + \beta_2 Maturity_t + u_t;\ u_t = e_t + \sum_{i=1}^{5} \theta_i e_{t-1}$$

where y_t is either *Relative Volume*, *Relative Best Depth*, or *Relative Deep Depth*. *Futures Volatility* is the daily sum of squared minute regular VIX futures midpoint quote returns. *Maturity* is the time left to maturity of the futures contracts, measured as days/365. Standard errors (within parentheses) used for statistical tests are estimated using the Newey and West (1987, 1994) HAC covariance matrix. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

regular order book when there are quick potential profits to be made from the increased volatility in the VIX futures price.

The coefficients relating futures volatility to relative best depth and relative deep depth are both positive and significant at the 5% level, which is also in line with our hypothesis that traders supply relatively more liquidity in the TAS order book when the volatility in the VIX futures price increases. We argue that this is because TAS orders make them less exposed to informed traders compared to what they would be if they instead would submit limit orders in the regular order book.

5. INTRODUCTION OF TAS AND VIX FUTURES MARKET QUALITY

The TAS introduction has established an alternative-trading venue to the regular VIX futures limit order book. Although the CFE manages both the regular order book and the TAS order book the TAS introduction leads to a potential fragmentation of the VIX futures trading. Degryse, Van Achter, and Wuyts (2009) recognize two distinct scenarios when an alternative-trading venue is introduced. Firstly, the introduction of a new trading venue might generate new orders from investors who, for some reason, are reluctant to submit orders to the main trading venue. As a result, total trading activity will increase, and liquidity at the main trading venue will not worsen. Secondly, some investors might be diverted away from the main venue and instead post their orders and trade at the newly introduced venue. In the latter case, total trading activity will not decrease while liquidity at the main venue will suffer. In the case of the TAS introduction, uninformed investors might prefer the TAS order book, and, thus, migrate from the regular VIX futures trading venue. If so, the regular limit order book will exhibit lower liquidity.

To analyze the effects from the TAS introduction on futures market quality, we compare VIX futures market trading activity and liquidity before and after the event. However, it is clear

from the descriptive statistics presented in Tables I and II that VIX futures trading activity and liquidity is increasing strongly from Period I to II, which of course might be for other reasons than the TAS introduction per se. Hence, to be able to isolate the effects from the TAS introduction we must account for other factors that might influence VIX futures trading activity and liquidity over our sample periods.

We turn to the VIX options market for a suitable benchmark. Like VIX futures, VIX options can be used to trade stock market volatility. From the well-known put-call parity relationship, an investor can replicate a VIX futures position with appropriate positions in at-the-money VIX calls and puts, since the VIX futures and options have the same underlying asset and maturity cycle. Thus, it is reasonable to assume that VIX futures and options are exposed to the same information flows during our sample period, and that both markets experience a similar general trend when it comes to trading activity and liquidity. In addition, only the VIX futures market experiences the fragmentation due to the TAS introduction, while the VIX options market's structure remains intact.[15]

In a difference-in-difference analysis, we investigate how measures of VIX futures trading activity and liquidity differ from corresponding measures of VIX options trading activity and liquidity, after the TAS introduction (Period II) relative to before the event (Period I). Formally, we run the following regression for each market quality measure:

$$y_t = \beta_0 + \beta_1 Q_{2,t} + u_t \tag{2}$$

where y_t is equal to the difference between the logarithm of the VIX futures market quality measure and the logarithm of the corresponding VIX options market quality measure on day t, $Q_{2,t}$ takes the value 1 after the TAS introduction event (Period II), and u_t is a residual term.[16] The difference-in-difference coefficient β_1 is equal to zero under the null hypothesis that VIX futures market quality is unaffected by the TAS introduction.

The results from the difference-in-difference analysis of VIX futures trading volume are presented in Table VI. In Period I, the average daily VIX futures trading volume in the regular limit order book (excl. TAS) is equal to 19,739 contracts, while the matching average daily VIX options trading volume is 26,489 contracts (at-the-money calls and puts together). The average Period I difference between the logarithm of futures volume and the logarithm of options volume equals −0.0738 (Log Ratio in Table VI). In Period II, after the TAS introduction, we note that the average daily futures trading volume of 34,680 contracts exceeds the corresponding average options volume of 29,291 contracts. This difference is confirmed by the fact that the average Period II Log Ratio is positive and equal to 0.4398. Moreover, the difference-in-difference coefficient β_1 is estimated to 0.5136, and the null hypothesis that $\beta_1 = 0$ can be rejected at the 1% significance level. Hence, we conclude that futures trading activity in the regular limit order book is not hurt by the TAS introduction and market fragmentation. Instead, VIX futures trading activity increases significantly following the event.[17]

[15]One difference is the contract multiplier, which is $1,000 for each VIX futures contract and only $100 for each VIX options contract. The minimum price increment is 0.05 index points for both futures and options.

[16]For robustness, we perform a set of more extensive difference-in-difference tests similar to those in Bertrand, Duflo, and Mullainathan (2004), using realized volatility, maturity, and residual autocorrelation terms as controls. The more robust regression specifications do not alter any of the subsequently reported results. Hence, we keep the relatively simple regression framework of Equation (2). The unreported more extensive regression results are available from the authors on request.

[17]The results of the difference-in-difference analysis are reinforced when futures trading volume includes TAS. See second part of Table VI.

TABLE VI
Diff-in-Diff Analysis of VIX Futures Trading Volume

	Trading volume (excl. TAS)			*Trading volume (incl. TAS)*		
	Futures	*Options*	*Log Ratio*	*Futures*	*Options*	*Log Ratio*
Period I	19,739	26,489	−0.0738	19,739	26,489	−0.0738
Period II	34,680	29,291	0.4398	38,526	29,291	0.5496
Difference	14,941	2,802	0.5136***	18,787	2,802	0.6234***

Note. Difference-in-difference analysis of VIX futures trading volume (daily number of traded contracts), both excluding and including TAS trading volume, before and after the introduction of TAS, benchmarked to trading volume for VIX options (the at-the-money call and put with the same maturity as the futures contract). The table shows daily averages of futures trading volume (*Futures*), options trading volume (*Options*), and the difference between the logarithm of the futures trading volume and the logarithm of the options trading volume (*Log Ratio*). Significance of the difference-in-difference measure is supported by the *t*-test of the hypothesis $\beta_1 = 0$ in the following regression analysis:

$$y_t = \beta_0 + \beta_1 Q_{2,t} + u_t$$

where y_t is equal to ln(*futures volume*)–ln(*options volume*) on day *t*, $Q_{2,t}$ takes the value 1 after the TAS introduction event, and u_t is a residual term. Standard errors used for statistical tests are estimated using the Newey and West (1987, 1994) HAC covariance matrix. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Turning to the investigation of the effects of the TAS introduction on futures market liquidity, we report the results from the difference-in-difference analysis of VIX futures bid-ask spread relative the VIX options spread in Table VII. The futures bid-ask spread is the same as reported in Table II and the options spread is obtained as the average spread for the at-the-money call and put with the same maturity as the futures contract. As in our previous analyses, bid-ask spreads are observed at the end of one-minute intervals during regular exchange trading hours.

TABLE VII
Diff-in-Diff Analysis of VIX Futures Bid-Ask Spread

	Bid-ask spread		
	Futures	*Options*	*Log Ratio*
Period I	0.0542	0.1099	−0.6697
Period II	0.0517	0.0882	−0.5205
Difference	−0.0025	−0.0217	0.1492***

Note. Difference-in-difference analysis of VIX futures bid-ask spread, before and after the introduction of TAS, benchmarked to bid-ask spread for VIX options (the average of the spreads for the at-the-money call and put with the same maturity as the futures contract). Bid-ask spreads are observed at the end of one-minute intervals during the official exchange opening hours, 8:30 a.m. to 3:15 p.m. CST for regular futures trading and options trading. The table shows daily averages of futures bid-ask spread (*Futures*), options bid-ask spread (*Options*), and the difference between the logarithm of the futures spread and the logarithm of the options spread (*Log Ratio*). Significance of the difference-in-difference measure is supported by the *t*-test of the hypothesis $\beta_1 = 0$ in the following regression analysis:

$$y_t = \beta_0 + \beta_1 Q_{2,t} + u_t$$

where y_t is equal to ln(*futures spread*)–ln(*options spread*) on day *t*, $Q_{2,t}$ takes the value 1 after the TAS introduction event, and u_t is a residual term. Standard errors used for statistical tests are estimated using the Newey and West (1987, 1994) HAC covariance matrix. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

In Period I, we observe that the average futures bid-ask spread is very close to 0.05, which is the minimum spread implied by the tick size rules (same for VIX futures and options), while the average option spread is about twice as large. Hence, in terms of the trading cost dimension, liquidity is much better at the futures market than at the options market during Period I (Log Ratio equals −0.6697). In Period II the average futures spread is even closer to the minimum level, while the average options spread is equal to 0.0882. Hence, the futures market still exhibits the best liquidity (Log Ratio equals −0.5205). In terms of change from Period I to II, we note that the options spread improves significantly more than the futures spread. The difference-in-difference coefficient is significantly positive at the 1% level, and is estimated at 0.1492. However, since the minimum tick size rule typically is binding at the futures market, and not at the options market, we argue that the bid-ask spread is not an appropriate candidate for a market quality measure in this setting. There is simply not much room for improvement in the transaction cost dimension of futures market liquidity following the TAS introduction.

Table VIII holds the results from the difference-in-difference analysis of VIX futures order book depth. Like in Table II, each depth measure is observed at the end of one-minute intervals. Here, we obtain depth as the average volume available on the bid and ask side, for the best level in the order book. Average depth in the regular futures limit order book is 74 contracts in Period I, while corresponding average option depth is 6,856 contracts. Thus, we record an average difference between the logarithm of futures depth and the logarithm of options depth of −4.6055 (Log Ratio) for Period I. Period II average depth is higher for both futures and options, at 163 (excluding TAS) and 10,167 contracts, respectively, and the Log Ratio is −4.1828. In addition, the difference-in-difference coefficient is significantly positive at the 1% level, and estimated at 0.4227. Note that if we include TAS in the futures depth measure, the difference-in-difference becomes much larger. Thus, we conclude that the TAS introduction clearly leads to a more liquid (deeper) VIX futures market.

TABLE VIII
Diff-in-Diff Analysis of VIX Futures Depth

	Depth (excl. TAS)			*Depth (incl. TAS)*		
	Futures	*Options*	*Log Ratio*	*Futures*	*Options*	*Log Ratio*
Period I	74	6,856	−4.6055	74	6,856	−4.6055
Period II	163	10,167	−4.1828	2,242	10,167	−1.6078
Difference	89	3,311	0.4227***	2,168	3,311	2.9977***

Note. Difference-in-difference analysis of VIX futures depth, both excluding and including TAS trading volume, before and after the introduction of TAS, benchmarked to depth for VIX options (the at-the-money call and put with the same maturity as the futures contract). Depths are observed at the end of one-minute intervals during the official exchange opening hours, 8:30 a.m. to 3:15 p.m. CST for regular futures trading and options trading, and 8:30 a.m. to 3:12 p.m. CST for TAS trading. Depth is obtained as the average volume available on the bid and ask side, for the best level in the order book. The table shows daily averages of futures depth (*Futures*), options depth (*Options*), and the difference between the logarithm of the futures depth and the logarithm of the options depth (*Log Ratio*). Significance of the difference-in-difference measure is supported by the *t*-test of the hypothesis $\beta_1 = 0$ in the following regression analysis:

$$y_t = \beta_0 + \beta_1 Q_{2,t} + u_t$$

where y_t is equal to ln(*futures depth*)–ln(*options depth*) on day t, $Q_{2,t}$ takes the value 1 after the TAS introduction event, and u_t is a residual term. Standard errors used for statistical tests are estimated using the Newey and West (1987, 1994) HAC covariance matrix. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

6. CONCLUDING REMARKS

In this study, we analyze the effects from the introduction of TAS transactions in VIX futures on VIX futures market quality. The CFE introduced TAS in November 2011 with the purpose of helping traders to even out end-of-day price exposures in VIX futures.

We find evidence showing that TAS is a low-cost alternative for trading closer to the daily futures settlement price than comparable alternatives using the regular VIX futures order book. This shows that TAS serves its main purpose of helping traders to even out end-of-day price exposures in VIX futures. Another advantage we find in using TAS is that it helps limit order traders from being picked off by informed traders when the volatility in the VIX futures price is high. Furthermore, the TAS introduction has not had a negative impact on trading activity and liquidity in the regular limit order book; on the contrary, VIX futures trading activity and liquidity increase significantly following the introduction.

The implications of introducing TAS in other futures markets are notable. Our results clearly suggest that introducing such a trading venue will benefit futures traders and improve market quality.

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