HOUSE OF FINANCE

WORKING PAPER SERIES

Benjamin Clapham – Peter Gomber – Sven Panz

Coordination of Circuit Breakers? Volume Migration and Volatility Spillover in Fragmented Markets

SAFE Working Paper No. 196

SAFE | Sustainable Architecture for Finance in Europe
A cooperation of the Center for Financial Studies and Goethe University Frankfurt

House of Finance | Goethe University
Theodor-W.-Adorno-Platz 3 | 60323 Frankfurt am Main

Tel. +49 69 798 34006 | Fax +49 69 798 33910
info@safe-frankfurt.de | www.safe-frankfurt.de

Non-Technical Summary

The introduction of the Markets in Financial Instruments Directive (MiFID I) in November 2007 fostered the competition between incumbent exchanges and emerging alternative venues. This increased competition resulted in a fragmented market landscape, which benefits market participants due to decreasing explicit transaction costs. However, market fragmentation is also associated with drawbacks for regulators and market participants since liquidity and price discovery are split across different trading venues.

One particular issue in fragmented markets are safeguards such as circuit breakers, which aim to prevent extreme price jumps and excessive volatility. If a stock is traded on multiple venues, these circuit breakers might forfeit their effectiveness to manage excess volatility when they are not coordinated among different venues.

Therefore, we provide new empirical insights concerning the discussion of circuit breaker coordination and analyze volume migration, shifts in market shares, and volatility spillovers during volatility interruptions in European securities markets. A volatility interruption is a specific type of circuit breaker that interrupts continuous trading with an unscheduled call auction. We observe that during volatility interruptions on the main market, turnover on the alternative venues almost dries out although there is no active circuit breaker on the alternative venues. Moreover, the market share of the main market increases sharply during the auction of the volatility interruption. Thus, the main market is therefore of major importance during turbulent times. By analyzing factors influencing the shift of market shares during volatility interruptions on the main market, we are able to trace back the increasing importance of the main market during these times to two different phenomena: the level of market fragmentation and the level of HFT activity.

On the one hand, our results reveal that if a circuit breaker is triggered, traders either refrain from trading on the alternative venues or, if they trade, they prefer to participate in the call auction on the main market. On the other hand, we highlight that multi-market market making and arbitrage trading strategies of high-frequency traders get constrained and become more risky in the absence of the main market because an important price signal is missing and rebalancing their inventories gets too expensive.

Consequently, our results provide empirical support against the hypothesis and often claimed concern that volume migrates from the main market to alternative venues during a circuit breaker on the main market. A coordination of circuit breakers among venues does not seem to be necessary because markets are implicitly coordinated due to traders' behavior.

Coordination of Circuit Breakers? Volume Migration and Volatility Spillover in Fragmented Markets

Benjamin Clapham[a], Peter Gomber[b], and Sven Panz[c]

[a] *Goethe University Frankfurt, clapham@wiwi.uni-frankfurt.de*

[b] *Goethe University Frankfurt, gomber@wiwi.uni-frankfurt.de*

[c] *Goethe University Frankfurt, panz@wiwi.uni-frankfurt.de*

January 27, 2017

Abstract

We study circuit breakers in a fragmented, multi-market environment and investigate whether a coordination of circuit breakers is necessary to ensure their effectiveness. In doing so, we analyze 2,337 volatility interruptions on Deutsche Boerse and research whether a volume migration and an accompanying volatility spillover to alternative venues that continue trading can be observed. Different to prevailing theoretical rationale, trading volume on alternative venues significantly decreases during circuit breakers on the main market and we do not find any evidence for volatility spillover. Moreover, we show that the market share of the main market increases sharply during a circuit breaker. Surprisingly, this is amplified with increasing levels of fragmentation. We identify high-frequency trading as a major reason for the vanishing trading activity on the alternative venues and give empirical evidence that a coordination of circuit breakers is not essential for their effectiveness as long as market participants shift to the dominant venue during market stress.

Keywords: Circuit Breaker, Volatility Interruption, Market Fragmentation, High-Frequency Trading, Stock Market, Regulation, Liquidity

JEL Classification: G14, G15, G18, G28

The authors acknowledge financial support from the Frankfurt Institute for Risk Management and Regulation (FIRM).

1 Introduction

Equity markets in the US and Europe have become increasingly fragmented with the emergence of alternative trading venues such as electronic communication networks (ECNs) in the US and multilateral trading facilities (MTFs) in Europe. Unlike in the US, where fragmentation of investors' order flow has a long tradition due to regional exchanges, fragmentation of European order flow started with the introduction of the Markets in Financial Instruments Directive (MiFID I) in November 2007, which fostered competition between incumbent exchanges and emerging alternative venues. Increased competition benefits market participants due to decreasing explicit transaction costs. However, market fragmentation is associated with drawbacks for regulators and market participants since liquidity, price discovery and therefore monitoring of the market status are split across venues.

One particular issue in fragmented markets are safeguards such as circuit breakers (CBs), which are aimed to prevent extreme price jumps and resulting market turmoil. If a stock is traded on multiple venues, these CBs might forfeit their effectiveness to manage excess volatility when they are not coordinated among these venues. If there is no coordination of CBs across venues, volatility might spill over to other venues without active CB, thereby leading to additional market-wide volatility instead of reducing it. This is especially relevant in light of the increased intermarket connectivity due to high-frequency trading (HFT) and smart order routing systems. Therefore, traders and trading volume can easily migrate to alternative venues where no CB is active and thereby lead to a possible volatility spillover, which harms the effectiveness of this market safeguard.

Coordinated inter-market safeguards have hardly been adopted although research (e.g., Subrahmanyam, 1994) suggests that a coordination of CB in a fragmented market environment is essential in order to ensure the performance of the CB. On the one hand, most incumbent national exchanges in Europe apply rule-based CB mechanisms on their markets. European MTFs, on the other hand, have not implemented CBs and only suspend trading due to regulatory guidance. Therefore, we make use of this environment to analyze the effects of volatility and volume migration if CBs are not coordinated.

Although the theoretical and empirical literature on CBs in general is quite extensive, research on the coordination of CBs is scarce. However, the question of coordinating CBs is of fundamental importance given the increasing equity market fragmentation in the US and in Europe. Moreover, the revision of the European Markets in Financial Instruments Directive (MiFID II) requires all trading venues to implement mechanisms *"to be able to temporarily halt or constrain trading if there is a significant price movement in a financial instrument"* and that a trading venue has *"the necessary systems and procedures in place to ensure that it will notify competent authorities in order for them to coordinate a market-wide response"*

(European Parliament and Council, 2014). Consequently, this paper contributes to academic research on coordinating CBs and discusses whether a coordination of CBs should be implemented driven by regulation or initiative of the venues themselves.

The goal of this paper is to investigate whether a volume migration and an accompanying volatility spillover to alternative venues can be observed during an active CB on the main market (i.e., most liquid market). Therefore, we focus on stocks listed in the German blue chip index DAX30. Trading in DAX30 securities is predominantly fragmented between Deutsche Boerse and three alternative venues. Moreover, we investigate whether an increase in the level of fragmentation changes the behavior of traders and the functioning of alternative markets during CBs. As our observation period covers almost five years, we are able to analyze the effects of different levels of fragmentation because the alternative venues have significantly increased their market share during that time. Additionally, we examine the role of HFT during a CB and whether different levels of HFT activity influence a possible volume migration.

The paper is structured as follows: Section 2 presents related literature on market fragmentation and the coordination of CBs in fragmented markets. Section 3 provides information on the data as well as descriptive statistics. Section 4 outlines the methodological approach as well as the results of our empirical analysis. The results are discussed in section 5 and the paper concludes in section 6.

2 Related Literature

There are two research streams which are relevant for the analysis conducted in this study. On the one hand, our research relates to studies about the impact of market fragmentation on market quality. On the other hand, we particularly contribute to research on the coordination of CBs across different venues.

2.1 Market Fragmentation

The level of fragmentation among European trading venues has grown rapidly over the last decade since the introduction of MiFID I (European Parliament and Council, 2004). In the US, there is a long tradition of fragmented order flow as several regional exchanges besides the New York Stock Exchange (NYSE) already existed before the emergence of alternative trading venues. Besides regulatory changes, which fostered competition between market operators, technological improvements such as HFT, a higher awareness of trading costs and an increasing demand for sophisticated trading mechanisms further contributed to the competitive dynamics, leading to new trading concepts and platforms in the past years (Gomber and Gsell, 2006).

Alternative venues aim at traders who require low-latency trading infrastructure combined with low trading fees and innovative order types (Riordan et al., 2011).

Regarding the effect of fragmentation on market quality, the early academic literature reasons in favor of consolidation while more recent papers focus on the positive competitive effects that accompany increased fragmentation.[1] Based on different market models, Mendelson (1987) shows that fragmentation reduces liquidity and increases price volatility. Moreover, Pagano (1989) proposes that there is no stable market equilibrium with more than one venue since all orders will be submitted to the most liquid market. Chowdhry and Nanda (1991) reason that adverse selection costs of trading a stock rise with the number of markets on which identical instruments are traded. Madhavan (1995) draws the conclusion that consolidated markets would not fragment if there were mandatory trade disclosure rules. Especially informed traders with large orders benefit from hiding their trades. Therefore, market fragmentation increases price volatility and is accompanied by other distortions.

More recent papers focus on the positive effects of market fragmentation: Economides (1996) reasons that venues have a monopoly status without fragmentation. Welfare losses resulting from a monopoly cannot be offset by higher liquidity of one single venue due to network effects. Harris (1993) suggests that securities markets fragment since there are various types of traders with different problems and needs. Parlour and Seppi (2003) build a microstructure model of liquidity based competition and show that fragmentation can reduce the cost of liquidity and thereby increase overall welfare. Degryse (2009) confirms this result with his dynamic market model using the example of a dealer market and a crossing network. There are also several empirical studies showing that market fragmentation increases liquidity (e.g., Battalio, 1997; Boehmer and Boehmer, 2003; Foucault and Menkveld, 2008; Hengelbrock and Theissen, 2009) and decreases transaction costs (e.g., Bennett and Wei, 2006; O'Hara and Ye, 2011).

Although there is strong support for positive effects of fragmentation on market quality, market fragmentation might undermine the effectiveness of CBs due to possible volume migration and volatility spillover if CBs are not coordinated across all venues on which an instrument is traded.

2.2 Coordination of Circuit Breakers

While academic research on single market CBs is quite extensive, research on the coordination of CBs in fragmented markets is scarce. In the seminal paper on CBs, Subrahmanyam (1994) provides the theoretical rationale for the necessity of coordinating CBs in fragmented markets. In his model, he shows that traders switch to

[1] O'Hara and Ye (2011) as well as Gomber et al. (2016) provide comprehensive overviews of the existing literature in this field.

alternative markets if there is a CB on the dominant market leading to an increasing demand of liquidity and price volatility on the alternative market. Consequently, CBs have to be coordinated in fragmented markets in order to ensure their effectiveness.

A coordination of CBs across venues is also proposed by Morris (1990). However, he focuses on the coordination of CBs between the cash market (NYSE) and the futures market (CME) rather than on multiple venues on which identical instruments are traded. In an argumentative approach, he concludes that CBs have to be activated at the same time on each venue in order to be effective. Uncoordinated CBs are likely to harm market quality due to a rising demand in liquidity and corresponding higher volatility on the venue where no CB is active.

Turning the view to empirical studies, Fabozzi and Ma (1988) are the first to provide empirical evidence on the effects of CBs in a fragmented market environment. Specifically, they investigate the volatility of stock prices in the over-the-counter (OTC) market while trading of the identical stock is halted on the NYSE. Although trading volume declines in the non-halting OTC market, they find a significant increase of volatility in the OTC market during NYSE trading halts. Fabozzi and Ma (1988) conclude that since volatile OTC prices still follow a random walk and do not provide arbitrage opportunities, the results of their study do not support a coordination of CBs on all trading locations.

Chakrabarty et al. (2011) provide indications how alternative markets react in the absence of the dominant market, which is highly similar to the case of uncoordinated CBs on main venues. In their empirical study, they analyze trading halts in the form of delayed openings on the NYSE while alternative venues already offer trading possibilities. They find that off-NYSE trading during NYSE halts significantly increases in terms of trading volume and contributes to the price discovery process. However, the informational benefits of continued trading on alternative venues are associated with extremely higher execution costs and volatility on off-NYSE venues. Although the authors provide evidence for a volatility spillover due to uncoordinated CBs as proposed by Subrahmanyam (1994), they conclude that continued trading on alternative venues during NYSE halts may benefit the market from an informational perspective even at the cost of extremely high spreads on off-NYSE venues.

Studying CBs in the fragmented European market system, Gomber et al. (2013) investigate whether there are trading volume shifts to the largest alternative venues during times of activated CBs in the form of volatility interruptions on the dominant market Deutsche Boerse. Based on their data of 2009, a period of early and relatively low fragmentation in Europe, they reject the hypothesis of inter-market volume migration in case of non-coordinated CBs and consequently do not find evidence for a volatility spillover. The authors conclude that traders retreat from trading on alternative venues when the main venue does not provide liquidity and valid price signals from executed trades due to a CB.

Regarding the coordination of CBs between cash and derivatives markets, Chou et al. (2003) come to conclusions in favor of coordination. They study the coordination of price limits in cash and futures markets showing that additional spot price limits coordinated with futures price limits lower the margin requirements of a futures contract even further.

Our literature review highlights that several academic studies reason in favor of coordinating CBs to prevent volume migration and volatility spillover to alternative venues. Others, however, emphasize the price informativeness of continued trading on alternative venues or even do not find evidence for an increase of volume or volatility on alternative venues during main market CBs. Different from previous studies that focus on a two-market setup, we analyze potential volume migration and volatility spillover in a multi-market setting covering the main as well as the largest three alternative trading venues for DAX30 stocks. Thereby, we add evidence to the scarce empirical research on the coordination of CBs in fragmented markets. Moreover, we investigate whether possible volume migration and volatility spillover effects depend on the level of market fragmentation and on HFT activity by investigating a large sample of CBs in the form of volatility interruptions over a five year observation period.

3 Data and Descriptive Statistics

In this section, we give a short overview of the analyzed trading venues, provide general information about our data set, and discuss descriptive statistics concerning the sample including descriptives on fragmentation and HFT activity.

3.1 Institutional Background

In the following, we analyze trading of DAX30 stocks on Deutsche Boerse's trading system Xetra as the main market and on the three most important alternative venues, which are Bats (BXE), Chi-X (CXE)[2], and Turquoise (TQ). Together, these four venues have a market share of DAX30 trading volume in lit order books of at least 98.7% in each quarter from 2011 until 2015 and of 99.0% on average for the whole observation period. Therefore, we cover almost the entire market of lit trading in DAX30 stocks which enables us to draw reliable conclusions on CBs in times of fragmented order flow.

Each of these trading venues has implemented different kinds of safeguards to ensure market integrity and to protect investors. It is important to note that only

[2]Both markets (BXE and CXE) are operated by Bats Europe.

Xetra is equipped with a CB that interrupts trading while Bats, Chi-X and Turquoise employ order rejection mechanisms that just reject individual orders in case the order limits are far away from current market prices. This setup of a main market with an implemented CB and three alternative venues with no CB in place serves to analyze the effects of volume migration and accompanying volatility spillover if CBs are not coordinated.

Xetra has implemented a rule-based CB in the form of so-called volatility interruptions. Unlike trading halts in the US, these volatility interruptions do not completely suspend trading. Instead, they only interrupt continuous trading and shift to an unscheduled call auction whenever a stock meets or exceeds predetermined price thresholds. Consequently, these interruptions are applied at single-stock level and do not halt the entire market. On Xetra, volatility interruptions last two minutes and are equipped with a random end within additional 30 seconds. The width of the triggering thresholds is not disclosed to market participants and is based on a computational model that takes into account the historical volatility of the particular stock.

3.2 Data Set

For our empirical analysis, we rely on Thomson Reuters Tick History (TRTH) data comprising tick-by-tick order book and trade information of Xetra for all stocks in the German blue chip index (DAX30). Since there are only three changes in the constituents of the index during our observation period, we stick to the index composition as of September 1, 2015. This data set is completed with tick-by-tick order book and trade information of the three most prominent alternative venues Chi-X, Bats, and Turquoise. Additionally, we use quarterly fragmentation data regarding turnover in all DAX30 stocks from Fidessa (2016). For the following analysis, turnover is defined as the executed volume on each trading venue measured in euro.

We identify volatility interruptions by selecting all auctions which appeared in the period from January 2011 until the end of September 2015 outside the scheduled auction periods. The time range of almost five years comprises multiple periods of distress for European financial markets (e.g., the sovereign debt crisis between 2011 and 2012) as well as company-specific distress (e.g., the Volkswagen emission scandal in 2015). Therefore, we are able to analyze volume migration around volatility interruptions which are triggered by general market turmoil as well as volatility interruptions caused by price fluctuations due to company-specific events.

To avoid misclassifications, we only consider those auctions with a suitable duration and those which were not delayed opening auctions (e.g., due to technical problems) or earlier closing auctions (e.g., on Christmas or New Years Eve). Additionally, we verified the number of volatility interruptions as well as each start and endpoint with data provided by Deutsche Boerse. In summary, our data set contains the following information on a millisecond basis for every stock traded on the four analyzed venues: First, the data includes all executed trades with time stamps, price, and volume 15 minutes before the start and 15 minutes after the end of each interruption. Second, all order book snapshots consisting of ten levels on the bid and ask side of the order book are available for the same time periods.

To give an overview of the characteristics of our data set, we start by clarifying the number of considered volatility interruptions. Further, we present descriptive statistics such as turnover and market quality parameters during and around volatility interruptions.

Considering the whole observation period, we identified 3,048 volatility interruptions. Due to the fact that we consider a period of 30 minutes around the them (15 minutes before the start and 15 minutes after the end of a volatility interruption), we exclude those interruptions which started or ended within 15 minutes around the opening, intraday or closing auction. We further exclude volatility interruptions where the post-period overlapped the pre-period of the next interruption to prevent confounding effects. Moreover, we exclude 5 observations with obvious data errors or no trades on Xetra or on the three alternative venues in the 30 minutes period. This procedure results in 2,337 volatility interruptions in total (see Table 1). Table A1 in the appendix gives an overview of the number of interruptions triggered in each stock during the observation period as well as the direction in which they were triggered. The distributions of considered volatility interruptions over the trading day and the whole observation period are depicted in Figure A1 and Figure A6 in the appendix.

Total Number of Observed and Considered Volatility Interruptions	
Number of volatility interruptions on Xetra during our observation period from 01/01/2011 to 09/30/2015 and detailed information about the actual number used for our empirical analysis.	
Total number of volatility interruptions	3,048
- Start of volatility interruption close to opening auction	248
- Start or end of volatility interruption close to intraday auction	108
- End of volatility interruption close to closing auction	110
- Overlapping volatility interruptions	240
- Excluded volatility interruptions due to data issues	5
Number of considered volatility interruptions	**2,337**

Table 1: Number of observed and considered volatility interruptions.

3.3 Fragmentation and High-Frequency Trading

In the following empirical analysis, we analyze trading activity (turnover on each venue) and volatility with respect to a changing level of market fragmentation. To measure the degree of fragmentation, we rely on the Fidessa Fragmentation Index (Fidessa, 2016), which is the inverse of the Herfindahl-Hirschman Index (HHI):

$$HHI^{-1} = \frac{1}{\sum_{i=1}^{n} \alpha_i^2},$$

where α_i is the market share of trading venue i with respect to executed turnover in a certain stock or index and n is the total number of trading venues.

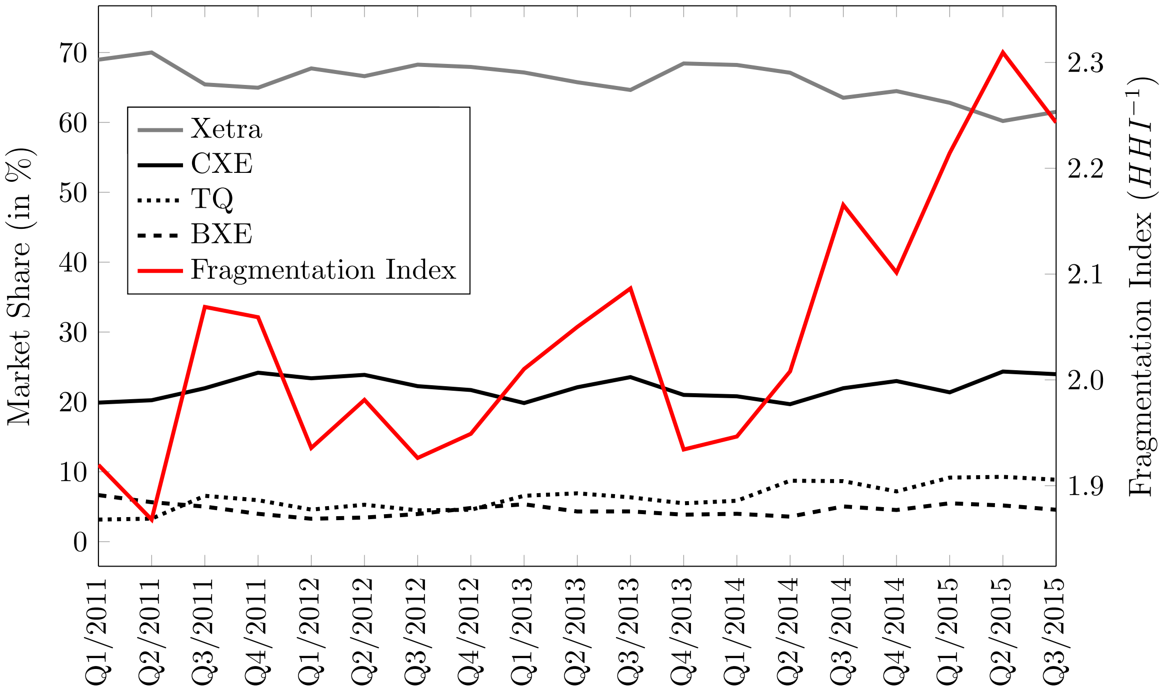


Figure 1: Market share and fragmentation of turnover in DAX30 instruments.

In Figure 1, we plot the market share of the four most relevant trading venues for DAX30 stocks as well as the Fragmentation Index. From the beginning of 2011 to the end of 2015, the market share of Xetra declined from 69% to 61.5%. During the same time, the market share of Chi-X increased from 19.9% to 24% and of Turquoise from 3.2% to 8.9%. The market share of Bats decreased slightly by 2.1 percentage points to a market share of 4.6% in Q3/2015. These changes are represented in the Fragmentation Index, which increased from 1.92 to 2.34 for DAX30 shares. The fragmentation of individual stocks, as reported in Table A2 in the appendix, exhibits a much wider range of fragmentation between 1.44 and 2.61 on a quarterly basis.

Besides differences in the level of market fragmentation in our observation period, also different levels of HFT activity might have an influence on possible volume and volatility spillovers to alternative venues during volatility interruptions on the main market. Similar to the increase in market fragmentation, HFT activity has gained substantial importance as well and accounts nowadays between 30% and 49% of the number of trades in European markets (European Securities and Markets Authority, 2014).

During continuous trading, HFT firms heavily engage in inter-market arbitrage and multi-market market making strategies (Hagströmer and Nordén, 2013; Menkveld, 2013). However, HFT activity tends to disappear during auctions because HFT firms are not able to pursue their strategies (e.g., profiting from the spread by providing liquidity in continuous trading) any longer and cannot manage their inventories instantly. Recent numbers show that HFT accounts for only 3% of the number of trades during auctions (European Securities and Markets Authority, 2014). Therefore, HFT activity is of special interest during volatility interruptions since the main market switches to a call auction (volatility interruption). Consequently, trading with immediate execution on the main market is not possible and price information of the dominant market is missing. Following the previous argumentation, it is uncertain how HFT firms change their behavior and whether they contribute to a possible volume migration during that time.

Since our data is not equipped with an additional HFT flag that indicates whether an orderbook activity or a trade is caused by an algorithm or a co-located machine, we rely on the order-to-trade-ratio (OTR) to approximate HFT activity. The OTR takes advantage of a typical trading behavior of HFT firms, i.e., submitting many orders to the exchange while executing only a small portion of them due to massive amounts of order deletions and modifications. Several academic studies use the OTR to measure HFT activity in order to investigate different effects of HFT on securities markets (Brogaard et al., 2015; Jørgensen et al., 2016; Malinova et al., 2016). Besides researchers, also regulators rely on the OTR as a measure for HFT and have passed acts that enforce trading venues to charge fees for traders with excessive OTRs (e.g., German High-Frequency Trading Act, 2013; Friederich and Payne, 2015). We quantify the level of HFT activity based on the OTR during a period of five (15) minutes around each volatility interruption i in our sample:

$$OTR_i = \frac{Orders_{i,pre} + Orders_{i,post}}{Trades_{i,pre} + Trades_{i,post}}.$$

$Orders_{i,pre}$ and $Orders_{i,post}$ represent the number of orders submitted to the main market Xetra during a during the 15 (respectively 5) minutes period before and after volatility interruption i. $Trades_{i,pre}$ and $Trades_{i,post}$ are the actual number of executed trades. Since we rely on order book snapshots, we indirectly obtain the number of order submissions and trades in each interval as shown by He et al. (2015). By comparing the number of orders on each limit to the previous order book situation, we compute the total number of orders that were submitted[3].

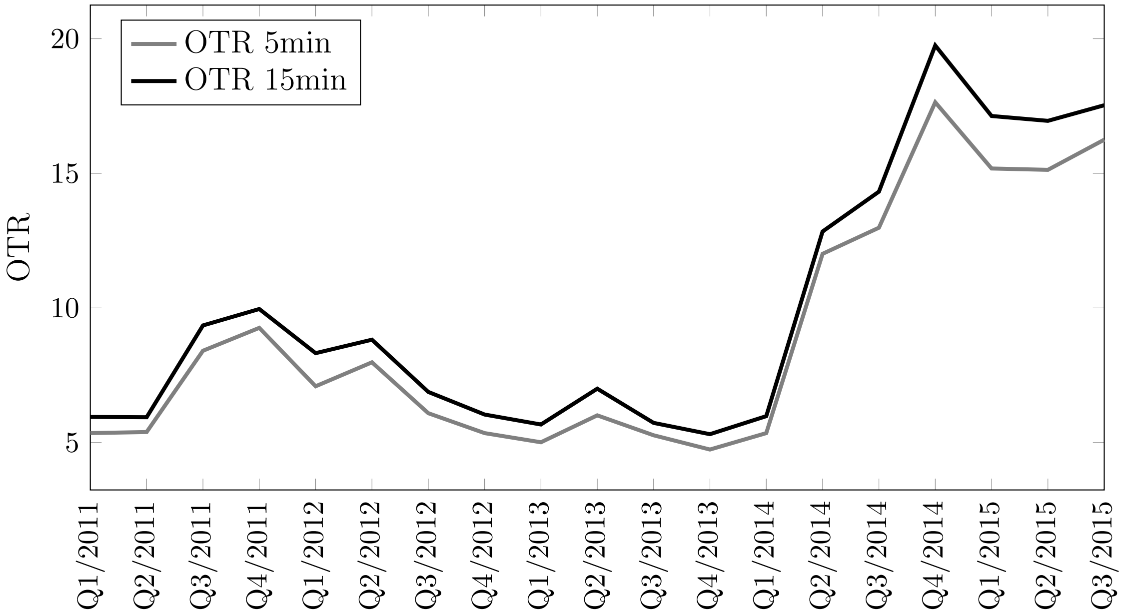


Figure 2: HFT activity measured by the OTR on Xetra five and 15 minutes around volatility interruptions.

Figure 2 shows the OTR on the main market for the five and 15 minutes aggregation periods. While Figure 1 highlights the actual development of fragmentation for each quarter, we are restricted to the OTR around the volatility interruption. This measure might deviate from the average quarterly OTR because the plotted OTR is inferred from periods with obvious higher volatility levels. Nevertheless, this measure is a better approximation of HFT activity around volatility interruptions than an OTR based on the whole trading period. Figure 2 should therefore not be referenced as the development of HFT activity in general. While the OTR is around 5 in the beginning of 2011, it increases to 17 at the end of 2015 so that our observation period covers different levels of HFT activity. The slight decline after Q2 2013 may be traced back to the German HFT Act, which came into force on May 15, 2013. The most prominent spike in Q4 2014 is yet subject to further investigations. Table A3 in the appendix provides an overview of the average OTR per stock.

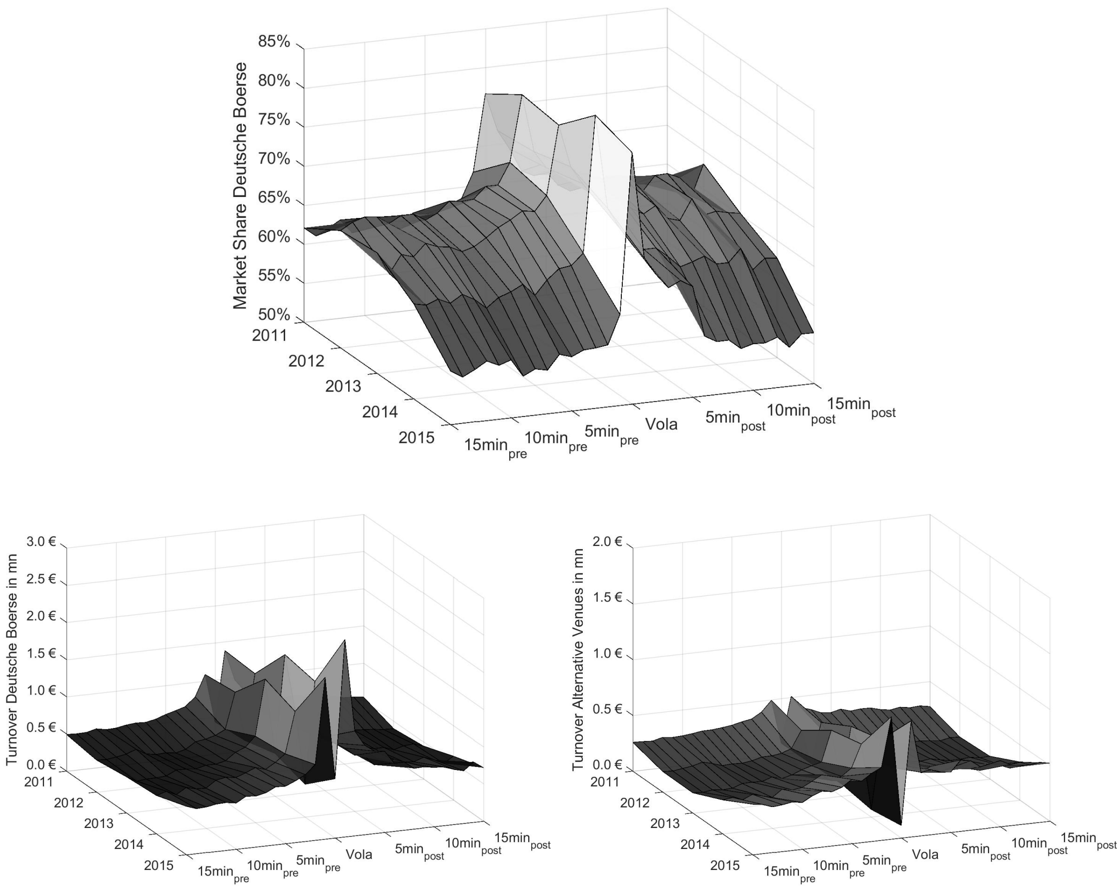
As we expect an increasing level of order flow fragmentation and an increasing HFT activity to be a significant and influencing factor impacting the change in

[3]With this procedure, we cannot observe market orders since they are immediately executed without an additional order book update between submission and execution. Consequently, the increase in the number of orders is not visible. Additionally, deletions and trades due to a new market order cannot be distinguished. However, market orders are used infrequently in general and especially rarely by HFT firms. Jarnecic and Snape (2014) find that HFT firms submit only 4.63% of their orders as market orders so that we capture almost the entire activity of HFT firms.

market shares around volatility interruptions, the following descriptive statistics and figures highlight the development of analyzed variables over time.

3.4 Volume Migration and Volatility Spillover to Alternative Venues

Theory suggests that volatility interruptions in fragmented markets can only be effective if they are coordinated among all venues where a certain stock is traded. Otherwise, trading volume will migrate to the alternative markets in case of an interruption on the main market thereby leading to a volatility spillover (Kyle, 1985; Subrahmanyam, 1994). The following descriptive analysis shows how turnover, market share, and volatility change on the different venues around a volatility interruption on the main market.



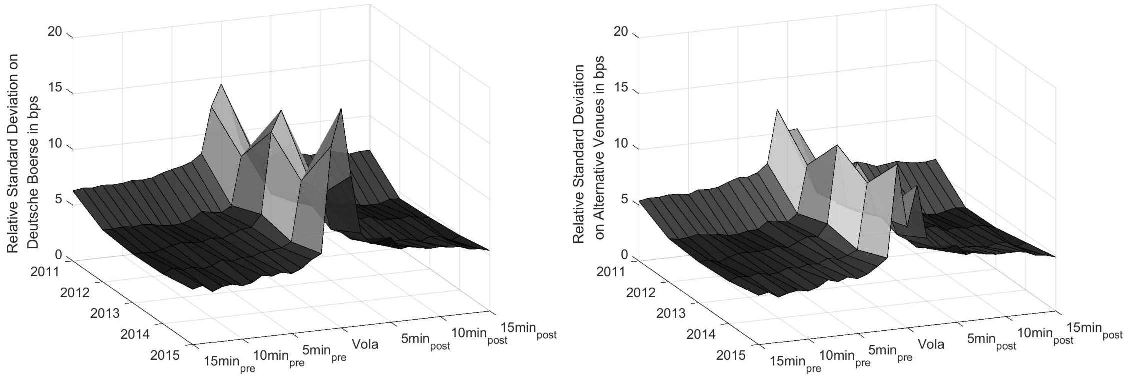
While each point during the pre- and the post-period represents a disjoint aggregation of one minute, the figures during the volatility interruption are not adjusted to a one minute period.

Figure 3: Market share and turnover of Xetra and alternative venues around volatility interruptions.

Figure 3 depicts the market share of total trading volume before, during, and after a volatility interruption. We also present the turnover on Xetra and the aggregated turnover on the three alternative venues. While turnover on Xetra slightly increased from 2011 to 2015 in the pre- and post-period, turnover on the three alternative venues increased significantly stronger by on average 77% in the pre- and post-period during the same time. Consequently, the market share of Xetra decreased from an average of 64% in 2011 to an average of 58% in 2015 during the pre- and post-period.

However, the situation during the volatility interruption differs substantially. While we observe a noticeable spike of trading volume shortly before the volatility interruption, trading activity during a volatility interruption is significantly reduced on the main market and even stronger on the alternative venues. Apart from the fact that the considered alternative venues were able to continuously increase their market share in general, trading activity during a volatility interruption shows a contrary pattern as the turnover on the alternative venues almost ceases completely. This is also supported by the two-dimensional figures showing the average trading volume and number of trades around volatility interruptions in the appendix (Figure A2 and A3). Consequently, the market share of Xetra increases on average to 79% during a volatility interruption and is even higher in 2014 and 2015 where the level of market fragmentation on a quarterly basis is higher. In contrast to the theoretical considerations of Kyle (1985) and Subrahmanyam (1994), this first analysis shows no support for volume migration from the main market to alternative venues during a volatility interruption on the main market. The changes in market share during an interruption are even more distinct with a more fragmented order flow because the trading activity on the alternative venues still almost ceases completely during an interruption on the main market. Nevertheless, the sharp increase in market share of the main market with respect to an increasing fragmentation and HFT activity is subject to a more profound analysis and will be investigated in more detail in section 4.

Together with volume migration, theory suggests that volatility will spill over to alternative venues as trading activity shifts to these smaller and less liquid venues. Figure 4 depicts the relative standard deviation for the main market and an aggregation for the alternative venues. Volatility in the pre- and post-period on the alternative venues shows a similar pattern as on the main venue. Shortly before the interruption, volatility spikes to a level which is on average two times higher than volatility one minute before. By considering the development over time, it can be inferred that volatility in 2011 is slightly higher compared to the remaining years. This effect may be traced back to the financial turmoil of the European sovereign debt crisis at that time.



While each point during the pre and the post period represents a disjoint aggregation of one minute, the data during the volatility interruption is not adjusted to a one minute period. The volatility during the volatility interruption on the main market represents volatility of indicative prices during the auction. To account for the size of the different venues, we average the relative standard deviation by a trade weighted aggregation.

Figure 4: Relative standard deviation around volatility interruptions.

Similar to trading volume, the situation during the volatility interruption differs substantially between main and alternative venues. While we observe the highest volatility during the volatility interruption itself on the main market (which is inferred from indicative prices), volatility on the alternative venues declines and spikes again when trading on the main market continues. This is also visible in the two-dimensional Figure A4 in the appendix. According to French and Roll (1986), calmer market conditions on the alternative venues (i.e., lowered volatility) can be explained with the significant reduction in trading volumes which we observe on the alternative venues during an interruption on the main market. Consequently, our descriptive analysis also shows no support for the volatility spillover hypotheses during a volatility interruption on the main market as volatility together with trading volume significantly declines on the alternative venues during the interruption and only reverts when continuous trading on the main market resumes.

3.5 Market Quality around Volatility Interruptions

For the analysis in subsequent section 4 and for reasons of robustness, we use two different aggregation periods around the volatility interruption: a window of 15 minutes before and after the volatility interruption and a second aggregation window of five minutes to capture short-term effects. Apart from the fact that we rely on the aggregate of the alternative venues in the regression analysis, we report the relevant variables separately for each market in the following table.

Table 2 describes important parameters for our regression setup. By aggregating a period of 15 minutes, we observe an average trading volume of 0.63mn euro per minute on the main market before the volatility interruption. This figure decreases by almost two thirds during the interruption and increases thereafter to an even higher level than before. On the alternative venues, the decline during the volatility interruption is even more significant with a decrease of 86% compared to the pre-period. After the interruption, turnover on the alternative venues is slightly higher as well. All these observation also hold for a shorter aggregation period of five minutes and when considering each alternative venue separately. The number of trades develops similarly to the trading volume as the number of trades on alternative venues is significantly lower during the volatility interruption than before or thereafter. On Xetra, we observe the auction trade at the end of the interruption that executes matching bid and ask orders at the uniform market clearing price.

Before the volatility interruption, the market share of Xetra is on average 66%. Even though the turnover during the auction declines, the market share of Xetra increases by 20% respectively 13 percentage points during the auction. After the interruption, the market share of the main market reverts but remains slightly higher at 68%. This observation is in line with Clapham and Zimmermann (2016), where the authors observe a significant decline of trading activity on alternative venues during mid-day auctions on Xetra.

In order to account for differences in the liquidity level, we rely on relative spreads and order book depth. The relative spread is calculated as the difference between the best bid and ask price divided by the midpoint. Order book depth is measured as the aggregate euro volume 10bps around the midpoint (Depth(10) as proposed by Degryse et al. (2015)). Both measures show that the main market Xetra is the most liquid market on average. After the volatility interruption, liquidity declines slightly. This observation also holds for the alternative venues. However, liquidity on alternative venues deteriorates strongly during the interruption on Xetra. At this time, the average relative spread on the alternative venues is more than three times higher than before the volatility interruption, reflecting a severe liquidity dry up. This also holds for order book depth which is lowered by 82% during the interruption. The development of liquidity on alternative venues around volatility interruptions is depicted in Figure A5 in the appendix. During the interruption, liquidity measures cannot be observed for the main market because only indicative prices and volumes are provided during the call auction.

Market Quality around Volatility Interruptions

This table provides market quality parameters 15min and 5min before, during, and after the volatility interruption. The parameters are calculated as the average over all observations separately for each market. Furthermore, we aggregate the values of the three alternative venues into a single measure. The aggregate figures are calculated as the sum of the individual venues' figures except for the relative standard deviation (trade-weighted mean) and the relative spread (minimum) to reflect a consolidated alternative venue. For better comparison of the different time intervals, number of trades, volume, and relative standard deviation are scaled down to one minute. Executed volume and order book depth are reported in euro millions. The percentage change is computed as the relative difference to the respective parameters 15min and 5min before the volatility interruption.

	Xetra		**Alt. Venues**		**CHI-X**		**Turquoise**		**BATS**	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
15min Before										
# Trades	36.09		50.66		32.00		10.23		8.43	
Volume [mn]	0.63		0.32		0.21		0.07		0.05	
Rel. Std. Dev. [bps]	9.35		9.09		9.15		8.97		8.97	
Market Share	0.66		0.34		0.22		0.07		0.05	
Rel. Spread [bps]	8.12		10.01		10.83		15.27		20.70	
Depth10 [mn]	0.43		0.29		0.16		0.07		0.05	
During Interruption										
# Trades	1.00		7.85	-84%	5.65	-82%	1.04	-90%	1.16	-86%
Volume [mn]	0.22	-64%	0.04	-86%	0.03	-84%	0.01	-92%	0.01	-88%
Rel. Std. Dev. [bps]	9.51	2%	5.78	-36%	6.27	-31%	2.54	-72%	2.85	-68%
Market Share	0.79	20%	0.21	-39%	0.15	-33%	0.03	-57%	0.03	-35%
Rel. Spread [bps]	na		40.97	309%	47.33	337%	79.62	421%	91.43	342%
Depth10 [mn]	na		0.05	-82%	0.03	-80%	0.01	-85%	0.01	-84%
15min After										
# Trades	41.93	16%	54.20	7%	34.26	7%	11.00	8%	8.94	6%
Volume [mn]	0.74	17%	0.35	9%	0.22	9%	0.07	10%	0.05	8%
Rel. Std. Dev. [bps]	7.18	-23%	6.90	-24%	6.93	-24%	6.85	-24%	6.80	-24%
Market Share	0.68	2%	0.32	-5%	0.21	-5%	0.07	-4%	0.05	-7%
Rel. Spread [bps]	8.63	6%	10.87	9%	12.07	11%	17.92	17%	21.99	6%
Depth10 [mn]	0.38	-11%	0.25	-13%	0.14	-13%	0.06	-13%	0.05	-13%
5min Before										
# Trades	45.68		61.67		38.17		12.89		10.62	
Volume [mn]	0.83		0.40		0.25		0.08		0.06	
Rel. Std. Dev. [bps]	10.42		9.75		9.38		9.78		9.65	
Market Share	0.67		0.33		0.21		0.07		0.05	
Rel. Spread [bps]	8.21		10.40		11.35		16.74		21.94	
Depth10 [mn]	0.42		0.27		0.16		0.07		0.05	
5min After										
# Trades	55.30	21%	63.77	3%	40.32	6%	12.79	-1%	10.66	0%
Volume [mn]	1.02	23%	0.42	5%	0.27	7%	0.08	1%	0.07	4%
Rel. Std. Dev. [bps]	8.55	-18%	8.09	-17%	8.18	-13%	7.93	-19%	7.80	-19%
Market Share	0.70	4%	0.30	-9%	0.20	-7%	0.06	-12%	0.04	-11%
Rel. Spread [bps]	9.03	10%	10.87	5%	13.05	15%	19.53	17%	24.49	12%
Depth10 [mn]	0.36	-16%	0.20	-29%	0.11	-28%	0.05	-30%	0.04	-29%

Table 2: Market quality on the analyzed venues around volatility interruptions.

4 Empirical Analysis

The descriptive analysis has shown that volume as well as volatility on alternative venues decline significantly during a volatility interruption on the main market. Traders seem to refrain from trading during that time to wait for the return of the price information of the main market which appears to be even stronger in a more fragmented market environment. In this section, we present our regression analysis highlighting whether and how the level of market fragmentation and HFT activity as well as other factors influence the shift of market shares during an active volatility interruption on the main market Xetra.

4.1 Research Approach

In order to examine shifts in market shares either due to volume migration from the main market Xetra to the alternative venues or due to a vanishing trading activity of the alternative markets, we analyze the difference in the inverse HHI between the trading period prior to and during the volatility interruption. This difference is captured in our dependent variable ΔHHI^{-1} for the five and 15 minutes interval:

$$\Delta HHI_i^{-1} = HHI_{i,Pre}^{-1} - HHI_{i,Vola}^{-1}.$$

To investigate the effects of market fragmentation and the level of HFT activity on volume migration and accompanying market shares, we run the following regression setup:

$$\begin{aligned}
\Delta HHI_i^{-1} \quad = \quad & \alpha + \beta_1 \cdot Fragmentation_i + \beta_2 \cdot OTR_i \\
& + \beta_3 \cdot Rel.\ Spread_AV_Vola_i + \beta_4 \cdot Depth(10)_AV_Vola_i \\
& + \beta_5 \cdot Turnover_Xetra_Pre_i + \beta_6 \cdot Turnover_AV_Pre_i \\
& + \beta_7 \cdot RSD_Xetra_Pre_i + \beta_8 \cdot RSD_AV_Pre_i \\
& + \beta_9 \cdot AucRSD_Xetra_i + \beta_{10} \cdot RSD_AV_Vola_i \\
& + \beta_{11} \cdot UpOrDown_i + \beta_{12} \cdot Stocks_in_Vola_i \\
& + \sum_{k=13}^{45} \beta_k \cdot Controls_i + \varepsilon_i
\end{aligned}$$

where i represents the respective volatility interruption. Normal distributed residuals are denoted as ε_i. Besides our main variables of interest $Fragmentation_i$ and OTR_i, which capture the influence of the level of market fragmentation and approximated HFT activity on shifts in market shares, we control for the general market environment of each volatility interruption. Therefore, we account for the liquidity level on the alternative venues in terms of relative spread ($Rel.\ Spread\_AV\_Vola_i$)

and order book depth ($Depth(10)\_AV\_Vola_i$) during an interruption on the main market. Furthermore, we consider the market activity prior to the interruption both on Xetra ($Turnover\_Xetra\_Pre_i$) and on alternative venues ($Turnover\_AV\_Pre_i$). Moreover, the general level of volatility measured by the relative standard deviation (RSD) of execution prices before ($RSD\_Xetra\_Pre_i$, $RSD\_AV\_Pre_i$) as well as during the volatility interruption ($AucRSD\_Xetra_i$, $RSD\_AV\_Vola_i$) is taken into account. For Xetra, we consider the relative standard deviation of indicative auction prices ($AucRSD\_Xetra_i$) to measure price variation during the volatility interruption. Additionally, we investigate whether differences can be observed when volatility interruptions are triggered in an upward or downward market movement. $UpOrDown_i$ is a dummy variable being one in case of an upward triggered interruption and zero otherwise. Furthermore, we analyze whether there are significant differences in market share shifts in case of market-wide events which are measured by the number of stocks that are hit by volatility interruptions on a specific day ($Stocks\_in\_Vola_i$). Year and stock specific controls are applied in all models.

We run this regression separately for a five and 15 minutes pre-period to account for short as well as for long-term effects. We perform the full model as well as a model without the independent variables describing the situation in which the volatility interruption was triggered (i.e., $UpOrDown_i$ and $Stocks\_in\_Vola_i$) to show the robustness of the results. This procedure results in four regression models in total. Heteroscedasticity-robust standard errors are applied in the pooled OLS regressions.

4.2 Results

The estimation results of the regression models are depicted in Table 3. As already shown in Figure 3, during the volatility interruption, the market share of the main market Xetra increases sharply and reaches on average 79%, i.e., a 20% higher level compared to the pre-period, although the alternative venues still offer the possibility to participate in continuous trading. Counter-intuitively, this phenomenon is even stronger for years which are characterized by a higher level of market fragmentation.

The results of our regression analysis support this finding. The fragmentation of turnover measured on a quarterly basis for each stock captured in the independent variable significantly influences the market share fragmentation during the volatility interruption. Specifically, the higher the level of $Fragmentation$, the higher are the shifts in market share (represented by a larger ΔHHI^{-1} which is the difference between the inverse HHI before and during the volatility interruption) in favor of the main market. This result suggests that traders either refrain from trading on the alternative venues during the volatility interruption or if they trade, they prefer to participate in the call auction of the volatility interruption on the main market. This observation is even more prevalent in case of higher fragmentation because market participants withdraw their trading activities with an absence of price signals of the main market. Consequently, this result provides no support for the hypothesis that volume tends to migrate from the main market to alternative venues during a volatility interruption.

Regarding the level of HFT activity measured by the OTR, the results indicate that the higher the HFT activity, the higher the difference between the fragmentation of turnover of the pre-period and the interruption-period, i.e., the more relevant the main market. This result might be caused by the fact that HFT firms regularly engage in multi-market market making and arbitrage trading which is constrained and more risky in the absence of the main market. Moreover, HFT firms regularly avoid trading during auctions as they cannot immediately rebalance their inventories. Consequently, the higher the proportion of turnover conducted by HFT firms, which regularly spreads over several venues, the higher the drop of fragmentation during the volatility interruption (i.e., an increase in ΔHHI^{-1}) as HFT firms reduce their trading activity. This result is significant and robust across all regression models.

Turning the view to the variables describing market quality around an active interruption on the main market, high relative spreads ($Rel.\ Spread\_AV\_Vola_i$) on the alternative venues indicating low liquidity lead to a higher market share of the main market within the auction of the volatility interruption which is described by an increase in ΔHHI^{-1}. This observation also holds for the second liquidity measure capturing order book depth. Lower order book depth on the alternative venues ($Depth(10)\_AV\_Vola_i$) is also associated with a decrease of fragmentation and less volume traded on alternative venues relative to the main market. This observation is reasonable as investors prevent trading on less liquid venues to avoid high implicit transaction costs (Harris, 2003).

Regarding general market activity, a high turnover on alternative venues prior to the volatility interruption ($Turnover\_AV\_Pre$) is associated with a decrease of fragmentation during the interruption (i.e., an increase in ΔHHI^{-1}). This is not surprising since turnover during the volatility interruption almost drys out on alternative venues and therefore the decrease is even more distinct if the turnover before the volatility interruption is on a comparatively high level. Regarding the pre-interruption turnover on Xetra ($Turnover\_Xetra\_Pre$), the explanation is the opposite. The higher the turnover on Xetra before the activation of the volatility interruption, the less fragmentation can decrease during the interruption.

We also take into account the general level of volatility before and during the interruption. The regression results suggest that the higher the pre-interruption relative standard deviation on alternative venues (RSD_AV_Pre), the more traders retreat from trading on alternative venues and rather engage in the call auction on Xetra. This might be the result of traders preferring to trade on the main market in

Regression Results: ΔHHI^{-1}

This table reports the results for comparing the level of fragmentation (measured by HHI^{-1}) before and during a volatility interruption. The endogenous variable is ΔHHI^{-1}. Exogenous variables are level of market fragmentation, approximated HFT activity, market quality variables, and volatility interruption variables. We apply robust standard error estimations (Newey West respectively White) to correct for potential heteroscedasticity and autocorrelation biases. Please note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Dependent Variable:	ΔHHI^{-1} 5min		ΔHHI^{-1} 15min	
	(1)	(2)	(3)	(4)
Constant	−0.391	−0.436	−0.428	−0.471
	t = −1.711*	t = −1.891*	t = −1.951*	t = −2.135**
Fragmentation	0.394	0.442	0.473	0.514
	t = 3.931***	t = 4.386***	t = 4.813***	t = 5.239***
OTR	0.007	0.008	0.003	0.004
	t = 2.626***	t = 2.986***	t = 1.496	t = 2.014**
Rel. Spread_AV_Vola	9.952	10.981	9.295	10.269
	t = 4.669***	t = 5.039***	t = 4.295***	t = 4.659***
Depth(10)_AV_Vola	−0.713	−0.815	−0.798	−0.898
	t = −3.440***	t = −3.825***	t = −3.923***	t = −4.300***
Turnover_Xetra_Pre	−0.042	−0.044	−0.023	−0.024
	t = −8.355***	t = −8.577***	t = −7.784***	t = −8.040***
Turnover_AV_Pre	0.104	0.107	0.049	0.050
	t = 8.191***	t = 8.230***	t = 7.998***	t = 8.067***
RSD_Xetra_Pre	−57.261	−56.339	−5.584	−4.323
	t = −3.195***	t = −3.134***	t = −0.324	t = −0.253
RSD_AV_Pre	61.273	64.492	11.219	13.280
	t = 3.246***	t = 3.401***	t = 0.621	t = 0.738
AucRSD_Xetra	12.983	13.354	8.151	8.528
	t = 2.446**	t = 2.439**	t = 1.595	t = 1.604
RSD_AV_Vola	−58.761	−58.138	−58.519	−57.776
	t = −5.866***	t = −5.822***	t = −6.129***	t = −6.062***
UpOrDown		0.020		0.029
		t = 0.814		t = 1.251
Stocks_in_Vola		−0.006		−0.006
		t = −3.632***		t = −3.690***
Controls:				
RIC	yes	yes	yes	yes
Year	yes	yes	yes	yes
Observations	2,336	2,336	2,337	2,337
R^2	0.227	0.232	0.235	0.241
Adjusted R^2	0.212	0.217	0.221	0.226
F Statistic	15.632***	15.353***	16.402***	16.136***
	(df = 43; 2292)	(df = 45; 2290)	(df = 43; 2293)	(df = 45; 2291)

Table 3: Results of the regression on ΔHHI^{-1}.

times of higher uncertainty. Therefore, fragmentation significantly decreases which is robust across all four regression models. Regarding the pre-interruption volatility on Xetra (RSD_Xetra_Pre), the results indicate that higher volatility leads to a lower turnover in the auction, i.e., a lower shift in market shares.

Regarding volatility during the interruption, the results again indicate that traders prefer the main market in times of higher uncertainty. Regarding the volatility as measured by indicative auction prices on Xetra ($AucRSD\_Xetra$), high volatility is associated with a drop to a low level of turnover fragmentation during the call auction. For volatility on the alternative venues (RSD_AV_Vola), the effect appears to be the opposite. However, due to the fact that RSD_AV_Vola is trade weighted and strongly correlated with the number of trades which again indicates a higher level of turnover, it is not surprising that a higher level of RSD_AV_Vola indicates a higher level of turnover on the alternative venues and therefore a less likely decrease of fragmentation.

In the full regression models (2) and (4), we additionally include variables describing the triggering situation of the volatility interruption in more detail. The insignificant coefficients concerning $UpOrDown$ show that the effect on market share distribution during the volatility interruption is independent from the direction of the market movement in which the volatility interruption was triggered. Moreover, the results show that the more stocks are affected by a volatility interruption, indicating that there is a market-wide event which increases volatility on the respective day, the lower is ΔHHI^{-1}. This suggests that more turnover is executed on alternative venues in case of an overall increase in volatility due to a market-wide event whose consequences are easier to assess than a suddenly triggered volatility interruption in an individual stock. As with the other measures regarding uncertainty (i.e., volatility measures), traders in this case rather rely on the main market or postpone their trading activity until the main market returns to continuous trading. Consequently, the results regarding the number of stocks affected by a volatility interruption ($Stocks\_in\_Vola$) support our hypothesis that traders prefer to trade on the main market in times of high uncertainty.

5 Discussion

In contrast to theoretical considerations of Kyle (1985) and Subrahmanyam (1994), we do not observe a volume migration to alternative venues when continuous trading is interrupted on the main market. Our data rather gives empirical evidence to the opposite. Even though trading volume during the volatility interruption is significantly reduced on the main market and on the alternative markets, the market share of the main market during that time significantly increases and is even amplified by the level of fragmentation. As long as market participants accept a market as the main and reference venue, an increasing fragmentation cannot be referenced as an additional motivation for coordination. Our descriptive results also show no empirical support for a volatility spillover to alternative venues in times of an interruption on the main market as theoretically shown by Kyle (1985) and Subrahmanyam (1994).

One possible explanation for this observations could be that liquidity providing strategies during periods of extreme price volatility are significantly reduced because implicit trading costs increase and make trading unattractive to market participants (see Goldstein and Kavajecz, 2004). A second explanation might be the withdrawal of HFT firms relying on arbitrage of inter-market price differences and multi-market market making strategies as these types of liquidity providers have no incentive to continue trading. Based on our approximation of HFT activity (OTR), we are able to show that higher market shares of the main market during volatility interruptions are even stronger in case of high HFT activity (around the specific market safeguard). While HFT firms ensure arbitrage-free markets during normal times, they seem to retreat from trading during a circuit breaker as the call auction of the volatility interruption offers no instant trading possibility on the main market. Due to the missing trading opportunity and price signal on the main market, HFT firms also retreat from trading on alternative venues and stop (inter-market) market making. On the one hand, this behavior is beneficial since it implicitly coordinates markets. On the other hand, liquidity, which is provided by HFT market makers to a large extent, is essential in times of high volatility and uncertainty. As depicted in Figure A5 in the appendix, liquidity almost dries up on the alternative venues during a volatility interruption on the main market. This low level of liquidity and associated high implicit transaction costs are also one of the reasons why traders refrain from trading on alternative venues during main market volatility interruptions.

Our regression results on shifts in market shares during volatility interruptions on Xetra also suggest that traders especially refrain from trading on alternative venues in times of high uncertainty. This applies to single-stocks being solely affected by a volatility interruption whose effect is harder to assess than the effect of a market-wide event. In general, market turmoil resulting from market-wide events such as ECB announcements is easier to predict than single-stock events. The observation that traders particularly cease trading on alternative venues in times of high uncertainty also holds for high volatility before and during the interruption. Similar to previous studies on circuit breakers, we do not find different effects for interruptions triggered in upward and downward market movements.

Consequently, our results suggest that a coordination of circuit breakers in the fragmented European market environment is not necessary since coordination is already achieved implicitly by traders' behavior. We have shown that turnover on alternative venues substantially decreases as traders refrain from trading on alternative venues until the price signal of the main markets returns with the end of the volatility interruption. This result is in line with the findings of Gomber et al. (2013) who investigated an isolated period of low fragmentation.

From an academic perspective, we contribute to the research on circuit breakers in fragmented securities markets. In contrast to theoretical considerations, our results provide no support for the hypothesis of volume migration and accompanying volatility spillover from the main market to alternative venues during a circuit breaker. Beyond that, we have shown that trading activity on alternative venues also ceases within an increasingly fragmented market environment and that the level of HFT activity is positively related to market share shifts towards the main venue during the circuit breaker.

Our results have important implications for regulators, venue operators, and market participants alike. On the one hand, they highlight the importance of the main market for the market system. Regulators therefore should pay particular attention to this market as it affects the entire system. Moreover, there is no need to coordinate circuit breakers as long as market participants agree on a single dominant market which has such a mechanism in place. However, once fragmentation increases even further, there might be a critical point when market participants no longer agree on one dominant venue. In this case, coordination might become necessary. For venue operators and market participants, our results are relevant as they highlight how trading behavior and activity changes during an active circuit breaker on the main market.

The analysis conducted in this study also has some limitations. On the one hand, we have only approximated the level of HFT activity based on the OTR. However, this measure is commonly used to describe HFT activity both from an academic as well as from a regulatory perspective. On the other hand, we have calculated the OTR based on order book data of the main venue around volatility interruptions. Besides potential biases in the OTR due to the selection of special and highly volatile market phases around volatility interruptions on Xetra, the OTR considered in our analysis is a more suitable approximation of HFT activity around volatility interruptions than an OTR based on the whole trading period. Additionally, we only analyze volume migration and accompanying volatility spillover during circuit breakers in the form of volatility interruptions in German blue chip stocks. In order to generalize the results for the European market, additional European indices with different main markets could be analyzed.

Future research could analyze instances in which the main market offers continuous trading while alternative markets have interrupted trading, e.g., due to technical difficulties or own circuit breaker mechanisms which alternative venues might implement after the introduction of MiFID II. It would be relevant to observe whether similar effects are visible if the main market has to trade in the absence of one or more alternative venues. Also, future research might include OTC markets in the analysis since a significant amount of total trading volume is conducted here (Gomber et al., 2015).

6 Conclusion

This paper provides new empirical insights concerning the discussion of circuit breaker coordination. We analyze volume migration, shifts in market shares, and volatility spillovers during circuit breakers in European fragmented securities markets. Therefore, we analyze 2,337 circuit breakers in the form of volatility interruptions which occurred between the start of Q1/2011 and the end of Q3/2015 in DAX30 securities on the main market Xetra, the electronic trading system of Deutsche Boerse, and on Chi-X, Bats, and Turquoise as alternative markets.

The descriptive part of this paper reveals two particular observations. First, during volatility interruptions, turnover is significantly reduced on the main market and turnover on the alternative venues almost drys out. Second, the market share of the main market increases sharply and reaches 79% on average during the volatility interruption. This represents a 20% higher market share compared to the period before the volatility interruption although the alternative venues still offer the possibility to participate in continuous trading.

We run different regression models to identify important factors influencing the shift of market shares during volatility interruptions on the main market. Based on the analysis and discussion, we are able to trace back the observed increasing importance of the main market during these times to two different phenomena: the level of market fragmentation and the level of HFT activity.

Counter-intuitively, a higher level of market fragmentation strengthens the shift of market share towards the main market and thereby its importance during volatility interruptions. In these situations, traders either refrain from trading on the alternative venues or, if they trade, they prefer to participate in the call auction on the main market. This observation is even more prevalent the more fragmented the market environment becomes because market participants seem to withdraw their trading activities if no price signal of the main market is available.

HFT firms rely on multi-market market making and arbitrage trading strategies, which are constrained and more risky in the absence of the main market. Moreover, they regularly avoid trading during auctions as they cannot immediately rebalance their inventories. Hence, the higher the HFT activity, the more trading is concentrated on the main market during the volatility interruption.

Consequently, our results provide empirical support against the hypothesis and often claimed concern that volume migrates from the main market to alternative venues during a circuit breaker on the main market. Contrary to theoretical models, a volatility spillover to alternative venues cannot be observed empirically. As long as one market is accepted as the main market, a coordination of circuit breakers among venues does not seem to be necessary, even against the background of increasing fragmentation in the European trading environment. Markets are implicitly coordinated due to traders' behavior since traders refrain from trading on alternative venues during a circuit breaker on the main market.

References

Battalio, Robert (1997). "Third Market Broker-Dealers: Cost Competitors or Cream Skimmers?" In: *Journal of Finance* 52.1, pp. 341–352.

Bennett, Paul and Li Wei (2006). "Market Structure, Fragmentation, and Market Quality." In: *Journal of Financial Markets* 9.1, pp. 49–78.

Boehmer, Beatrice and Ekkehart Boehmer (2003). "Trading your Neighbor's ETFs: Competition or Fragmentation?" In: *Journal of Banking & Finance* 27.9, pp. 1667–1703.

Brogaard, Jonathan, Björn Hagströmer, Lars Nordén, and Ryan Riordan (2015). "Trading Fast and Slow: Colocation and Liquidity." In: *Review of Financial Studies* 28.12, pp. 3407–3443.

Chakrabarty, Bidisha, Shane A. Corwin, and Marios A. Panayides (2011). "When a Halt is not a Halt: An Analysis of Off-NYSE Trading during NYSE Market Closures." In: *Journal of Financial Intermediation* 20.3, pp. 361–386.

Chou, Pin-Huang, Mei–Chen Lin, and Min–Teh Yu (2003). "The Effectiveness of Coordinating Price Limits across Futures and Spot Markets." In: *Journal of Futures Markets* 23.6, pp. 577–602.

Chowdhry, Bhagwan and Vikram Nanda (1991). "Multimarket Trading and Market Liquidity." In: *Review of Financial Studies* 4.3, pp. 483–511.

Clapham, Benjamin and Kai Zimmermann (2016). "Price Discovery and Convergence in Fragmented Securities Markets." In: *International Journal of Managerial Finance* 12.4, pp. 381–407.

Degryse, Hans (2009). "Competition between Financial Markets in Europe: What can be Expected from MiFID?" In: *Financial Markets and Portfolio Management* 23.1, pp. 93–103.

Degryse, Hans, Frank de Jong, and Vincent van Kervel (2015). "The Impact of Dark Trading and Visible Fragmentation on Market Quality." In: *Review of Finance* 19.4, pp. 1587–1622.

Economides, Nicholas (1996). "The Economics of Networks." In: *International Journal of Industrial Organization* 14, pp. 673–699.

European Parliament and Council (2004). *Markets in Financial Instruments Directive 2004/39/EC: MiFID I.*

— (2014). *Markets in Financial Instruments Directive 2014/65/EU: MiFID II.*

European Securities and Markets Authority (2014). *High-Frequency Trading Activity in EU Equity Markets.* URL: https://www.esma.europa.eu/sites/default/files/library/2015/11/esma20141_-_hft_activity_in_eu_equity_markets.pdf (visited on 11/30/2016).

Fabozzi, Frank J. and Christopher K. Ma (1988). "The OTC Market and NYSE Trading Halts." In: *The Financial Review* 23.4, pp. 427–437.

Fidessa (2016). *Fidessa Fragmentation Index: Making Sense of Global Fragmentation.* URL: http://fragmentation.fidessa.com/ (visited on 11/30/2016).
Foucault, Thierry and Albert J. Menkveld (2008). "Competition for Order Flow and Smart Order Routing Systems." In: *Journal of Finance* 63.1, pp. 119–158.
French, Kenneth R. and Richard Roll (1986). "Stock Return Variances." In: *Journal of Financial Economics* 17.1, pp. 5–26.
Friederich, Sylvain and Richard Payne (2015). "Order-to-Trade Ratios and Market Liquidity." In: *Journal of Banking & Finance* 50, pp. 214–223.
German High-Frequency Trading Act (2013). *Gesetz zur Vermeidung von Gefahren und Missbräuchen im Hochfrequenzhandel (Hochfrequenzhandelsgesetz).* URL: http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl113s1162.pdf#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl113s1162.pdf%27%5D__1480327147457 (visited on 11/30/2016).
Goldstein, Michael A. and Kenneth A. Kavajecz (2004). "Trading Strategies during Circuit Breakers and Extreme Market Movements." In: *Journal of Financial Markets* 7.3, pp. 301–333.
Gomber, Peter and Markus Gsell (2006). "Catching Up with Technology – The Impact of Regulatory Changes on ECNs/MTFs and the Trading Venue Landscape in Europe." In: *Competition and Regulation in Network Industries* 7.4, pp. 535–558.
Gomber, Peter, Martin Haferkorn, Marco Lutat, and Kai Zimmermann (2013). "The Effect of Single-Stock Circuit Breakers on the Quality of Fragmented Markets." In: *Enterprise Applications and Services in the Finance Industry.* Ed. by Fethi A. Rabhi and Peter Gomber. Vol. 135. Lecture Notes in Business Information Processing. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 71–87.
Gomber, Peter, Satchit Sagade, Erik Theissen, Moritz Christian Weber, and Christian Westheide (2015). "The State of Play in European Over-the-Counter Equities Trading." In: *Journal of Trading* 10.2, pp. 23–32.
— (2016). "Competition Between Equity Markets: A Review of the Consolidation Versus Fragmentation Debate." In: *Journal of Economic Surveys.*
Hagströmer, Björn and Lars Nordén (2013). "The Diversity of High-Frequency Traders." In: *Journal of Financial Markets* 16.4, pp. 741–770.
Harris, Larry (2003). *Trading and Exchanges: Market Microstructure for Practitioners.* Oxford and New York: Oxford University Press.
Harris, Lawrence E. (1993). "Consolidation, Fragmentation, Segmentation, and Regulation." In: *Financial Markets, Institutions & Instruments* 2.5, pp. 1–28.
He, Peng William, Elvis Jarnecic, and Yubo Liu (2015). "The Determinants of Alternative Trading Venue Market Share: Global Evidence from the Introduction of Chi-X." In: *Journal of Financial Markets* 22, pp. 27–49.

Hengelbrock, Jördis and Erik Theissen (2009). “Fourteen at One Blow: The Market Entry of Turquoise.” In: Working Paper.

Jarnecic, Elvis and Mark Snape (2014). “The Provision of Liquidity by High-Frequency Participants.” In: *Financial Review* 49.2, pp. 371–394.

Jørgensen, Kjell, Johannes Skjeltorp, and Arne Ødegaard (2016). “Throttling Hyperactive Robots - Order to Trade Ratios at the Oslo Stock Exchange.” In: *Working Paper*.

Kyle, Albert S. (1985). “Continuous Auctions and Insider Trading.” In: *Econometrica* 53.6, pp. 1315–1335.

Madhavan, Ananth (1995). “Consolidation, Fragmentation, and the Disclosure of Trading Information.” In: *Review of Financial Studies* 8.3, pp. 579–603.

Malinova, Katya, Andreas Park, and Ryan Riordan (2016). “Taxing High Frequency Market Making: Who Pays the Bill?” In: *Working Paper*.

Mendelson, Haim (1987). “Consolidation, Fragmentation, and Market Performance.” In: *Journal of Financial and Quantitative Analysis* 22.2, pp. 189–207.

Menkveld, Albert J. (2013). “High Frequency Trading and the New Market Makers.” In: *Journal of Financial Markets* 16.4, pp. 712–740.

Morris, Charles S. (1990). “Coordinating Circuit Breakers in Stock and Futures Markets.” In: *Economic Review* 75.1, pp. 35–48.

O’Hara, Maureen and Mao Ye (2011). “Is Market Fragmentation Harming Market Quality?” In: *Journal of Financial Economics* 100.3, pp. 459–474.

Pagano, Marco (1989). “Trading Volume and Asset Liquidity.” In: *Quarterly Journal of Economics* 104.2, pp. 255–274.

Parlour, Christine A. and Duane J. Seppi (2003). “Liquidity-Based Competition for Order Flow.” In: *Review of Financial Studies* 16.2, pp. 301–343.

Riordan, Ryan, Andreas Storkenmaier, and Martin Wagener (2011). “Do Multilateral Trading Facilities Contribute to Market Quality?” In: *Working Paper*.

Subrahmanyam, Avanidhar (1994). “Circuit Breakers and Market Volatility: A Theoretical Perspective.” In: *Journal of Finance* 49.1, pp. 237–254.

Appendix

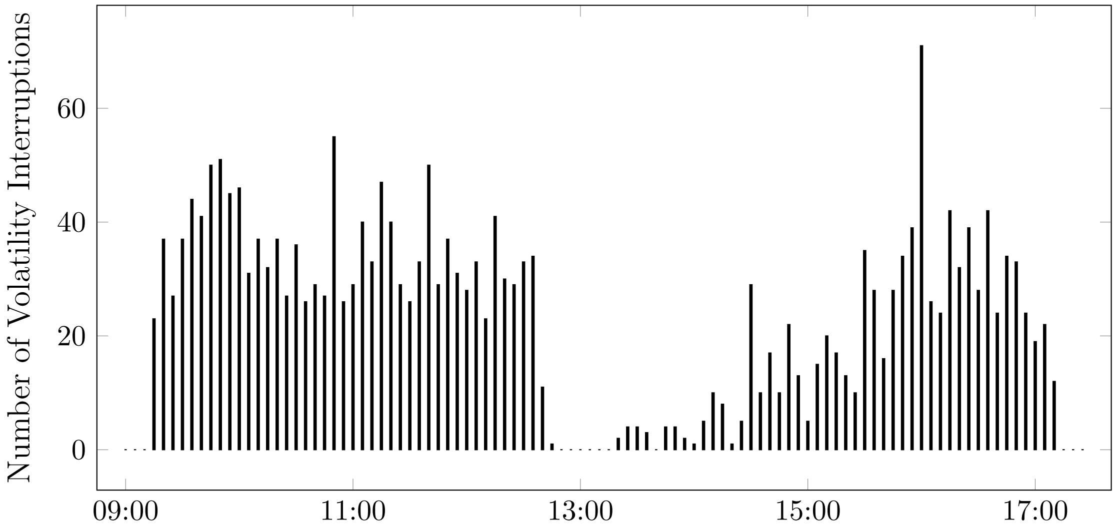


Figure A1: Occurence of volatility interruptions during the trading day in five minutes intervals (local time at Deutsche Boerse).

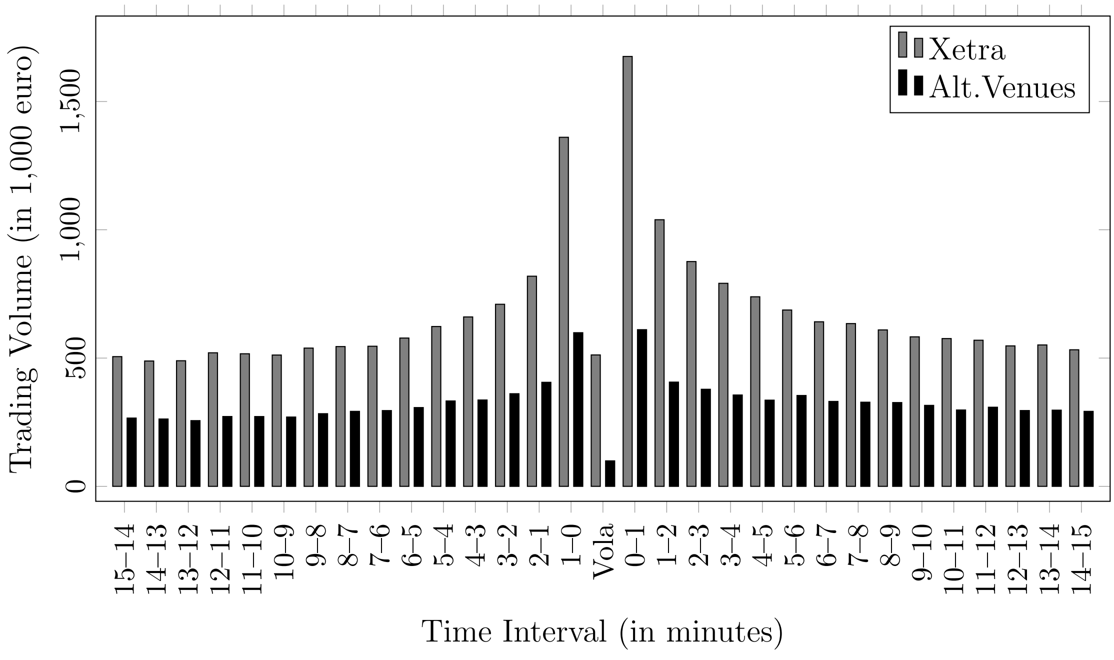


Figure A2: Trading volume in DAX30 instruments on Xetra and the alternative venues BXE, CXE, and TQ before, during, and after volatility interruptions.

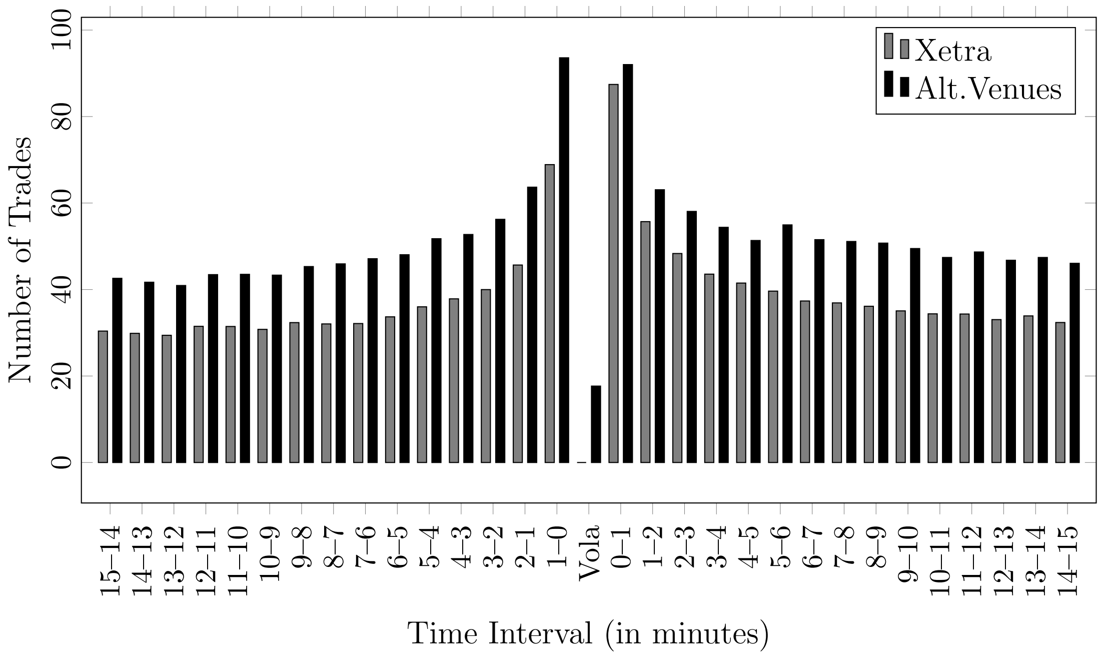


Figure A3: Number of trades in DAX30 instruments on Xetra and the alternative venues BXE, CXE, and TQ before, during, and after volatility interruptions on Xetra. On the main market, only one price determination takes place during the volatility interruption: the market clearing price at the end of interruption.

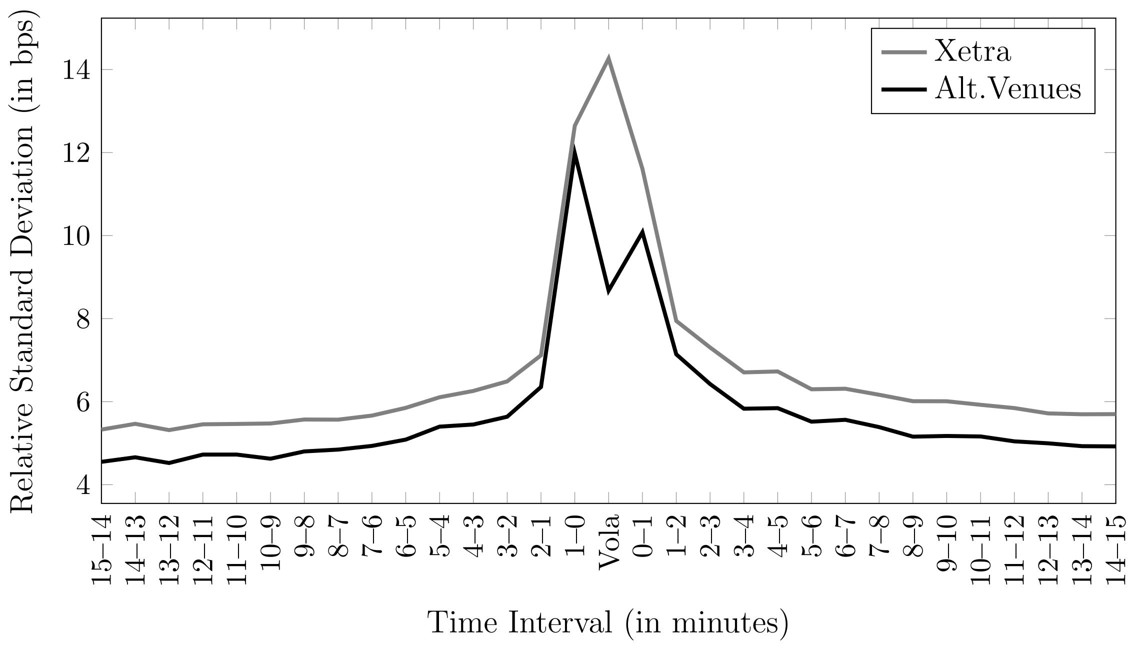


Figure A4: Volatility (relative standard deviation) of DAX30 instruments on Xetra and the alternative venues BXE, CXE, and TQ before, during, and after volatility interruptions on Xetra.

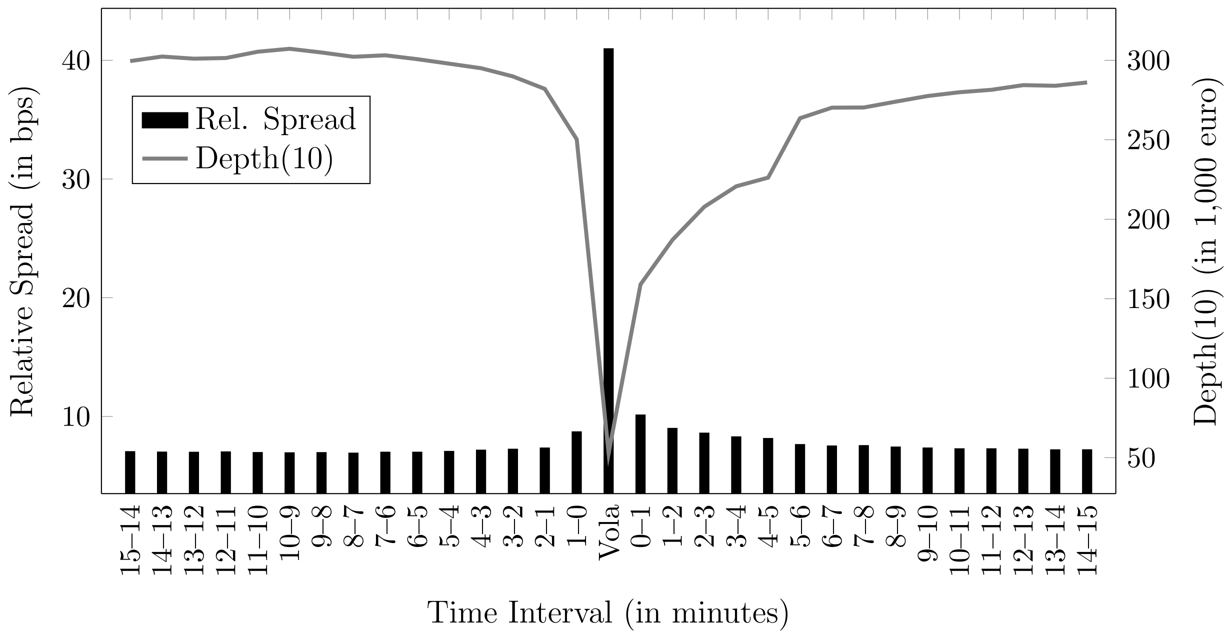


Figure A5: Liquidity measured by relative spread and Depth(10) aggregated across the alternative venues BXE, CXE, and TQ before, during, and after volatility interruptions on Xetra. In order to reflect a consolidated alternative venue, we sum up order book depth across all three venues and take the minimum relative spread for each observation. Both measures are then averaged over the 2,337 volatility interruptions in our sample.

Symbol	**Stock**	**No of Volas**	**Up**	**Down**
ADS	Adidas	48	23	25
ALV	Allianz	54	24	30
BAS	BASF	52	16	36
BAYN	Bayer	57	28	29
BEI	Beiersdorf	29	18	11
BMW	BMW	94	41	53
CBK	Commerzbank	281	111	170
CON	Continental	65	30	35
DAI	Daimler	90	30	60
DBK	Deutsche Bank	52	25	27
DB1	Deutsche Boerse	149	70	79
DPW	Deutsche Post	38	15	23
DTE	Deutsche Telekom	39	19	20
EOAN	E.ON	86	41	45
FME	Fresenius Medical Care	32	13	19
FRE	Fresenius	41	21	20
HEI	HeidelbergCement	107	47	60
HEN3	Henkel VZ	27	13	14
IFX	Infineon	114	48	66
LHA	Lufthansa	137	64	73
LIN	Linde	37	14	23
LXS	Lanxess	87	36	51
MRK	Merck	36	17	19
MUV2	Munich Re	32	11	21
RWE	RWE	108	53	55
SAP	SAP	28	11	17
SDF	K+S	139	62	77
SIE	Siemens	37	9	28
TKA	Thyssenkrupp	128	56	72
VOW3	Volkswagen VZ	113	42	71
Mean		**78**	**34**	**44**
Median		**56**	**27**	**33**
Min (HEN3)		**27**	**13**	**14**
Max (CBK)		**281**	**111**	**170**

Table A1: Number of volatility interruptions per stock. In total, 2,337 volatility interruptions are included in the analysis. Thereof, 1,008 (43%) are triggered in an upward market movement, 1,329 (57%) in a downward market movement.

Symbol	Stock	Fragmentation of Turnover (inv. HHI)				
		Mean	**Median**	**Min**	**Max**	**Std. Dev.**
ADS	Adidas	2.13	2.12	1.87	2.32	0.11
ALV	Allianz	1.95	1.95	1.68	2.36	0.19
BAS	BASF	1.97	2.00	1.73	2.15	0.13
BAYN	Bayer	2.06	2.04	1.85	2.29	0.12
BEI	Beiersdorf	2.18	2.21	1.86	2.31	0.12
BMW	BMW	2.05	2.06	1.82	2.35	0.14
CBK	Commerzbank	1.72	1.70	1.44	2.07	0.19
CON	Continental	2.34	2.34	2.17	2.48	0.10
DAI	Daimler	1.97	1.94	1.76	2.36	0.17
DBK	Deutsche Bank	1.96	1.92	1.79	2.17	0.12
DB1	Deutsche Boerse	2.07	2.04	1.58	2.50	0.24
DPW	Deutsche Post	2.15	2.16	1.96	2.27	0.10
DTE	Deutsche Telekom	2.09	2.06	1.82	2.48	0.16
EOAN	E.ON	1.92	1.89	1.67	2.19	0.14
FME	Fresenius Medical Care	2.27	2.28	2.04	2.61	0.14
FRE	Fresenius	2.16	2.22	1.67	2.46	0.18
HEI	HeidelbergCement	2.22	2.21	2.00	2.43	0.11
HEN3	Henkel VZ	2.16	2.16	1.88	2.35	0.13
IFX	Infineon	2.04	2.06	1.71	2.29	0.14
LHA	Lufthansa	2.02	2.02	1.80	2.23	0.13
LIN	Linde	2.19	2.14	1.93	2.57	0.18
LXS	Lanxess	2.14	2.15	1.85	2.50	0.18
MRK	Merck	2.15	2.16	1.85	2.42	0.16
MUV2	Munich Re	2.02	2.03	1.76	2.35	0.16
RWE	RWE	1.92	1.86	1.76	2.20	0.16
SAP	SAP	2.24	2.22	1.98	2.48	0.13
SDF	K+S	1.87	1.86	1.56	2.31	0.19
SIE	Siemens	2.07	2.08	1.88	2.30	0.12
TKA	Thyssenkrupp	1.97	1.99	1.66	2.18	0.14
VOW3	Volkswagen VZ	1.97	2.00	1.67	2.28	0.20
Mean		**2.07**	**2.06**	**1.80**	**2.34**	**0.15**
Median		**2.06**	**2.06**	**1.81**	**2.34**	**0.14**
Min (CBK)		**1.72**	**1.70**	**1.44**	**2.07**	**0.19**
Max (CON)		**2.34**	**2.34**	**2.17**	**2.48**	**0.10**

Table A2: Turnover fragmentation (measured by the inverse HHI) per stock within the DAX30 index per quarter.

Symbol	OTR (Proxy for HFT activity) Mean		Median		Min		Max	
	OTR-5	**OTR-15**	**OTR-5**	**OTR-15**	**OTR-5**	**OTR-15**	**OTR-5**	**OTR-15**
ADS	8.47	9.59	7.62	8.90	3.42	3.74	17.12	19.84
ALV	6.82	8.01	6.10	6.59	2.69	3.12	17.40	26.85
BAS	7.73	8.65	6.69	6.98	2.35	2.84	21.09	24.30
BAYN	8.63	10.02	7.59	8.79	2.23	2.21	20.83	22.82
BEI	9.38	10.28	7.09	7.70	3.90	4.43	27.90	34.48
BMW	8.88	10.06	7.35	8.50	1.85	2.91	30.41	31.23
CBK	6.03	6.57	4.11	4.49	1.57	1.86	29.73	30.96
CON	12.23	13.69	9.00	10.10	3.74	4.97	41.78	40.07
DAI	7.36	8.60	6.54	7.37	1.80	1.94	20.06	25.46
DBK	7.19	8.21	5.41	6.47	2.05	2.48	28.90	31.12
DB1	17.21	19.80	10.27	12.25	3.09	3.10	68.25	89.50
DPW	10.33	11.83	8.79	9.73	3.23	3.85	29.94	30.33
DTE	10.99	12.70	9.02	10.90	1.62	2.20	25.82	28.95
EOAN	9.12	9.71	7.63	8.45	1.62	1.79	45.99	38.46
FME	14.05	15.24	10.52	11.48	3.87	4.68	43.75	38.66
FRE	12.15	12.41	12.42	12.11	3.05	3.32	32.54	27.38
HEI	13.18	13.88	9.97	11.61	2.64	3.69	44.57	52.79
HEN3	10.05	12.12	9.08	10.98	2.80	4.05	23.37	24.29
IFX	8.90	9.98	7.39	8.45	2.04	2.46	33.98	40.51
LHA	9.88	10.90	8.73	10.13	2.94	3.02	24.58	28.88
LIN	11.04	12.11	9.60	11.62	3.33	4.20	35.90	31.60
LXS	10.45	11.18	7.61	7.75	2.35	2.72	50.58	42.55
MRK	12.80	14.63	11.96	11.17	2.93	3.73	30.26	37.87
MUV2	12.39	14.10	10.77	12.97	2.67	3.60	32.34	30.64
RWE	10.14	11.08	8.71	10.41	1.84	2.38	27.76	29.06
SAP	8.64	10.25	7.66	9.45	1.99	2.64	19.22	29.26
SDF	8.36	9.12	6.44	7.47	1.86	2.13	28.74	30.31
SIE	6.35	7.29	5.49	6.42	2.09	2.69	15.13	18.75
TKA	8.77	9.79	6.92	7.93	2.01	2.25	29.59	30.73
VOW3	7.37	7.99	6.17	6.94	1.84	1.91	29.20	28.55
Mean	**9.83**	**10.99**	**8.09**	**9.14**	**2.41**	**3.03**	**30.89**	**33.21**
Median	**9.25**	**10.26**	**7.62**	**8.85**	**2.29**	**2.87**	**29.39**	**30.49**
Min (CBK)	**6.03**	**6.57**	**4.11**	**4.49**	**1.57**	**1.86**	**29.73**	**30.96**
Max (DB1)	**17.21**	**19.80**	**10.27**	**12.25**	**3.09**	**3.10**	**68.25**	**89.50**

Table A3: HFT activity on Xetra in every DAX30 stock approximated by the OTR based on five and 15 minutes around the volatility interruptions.

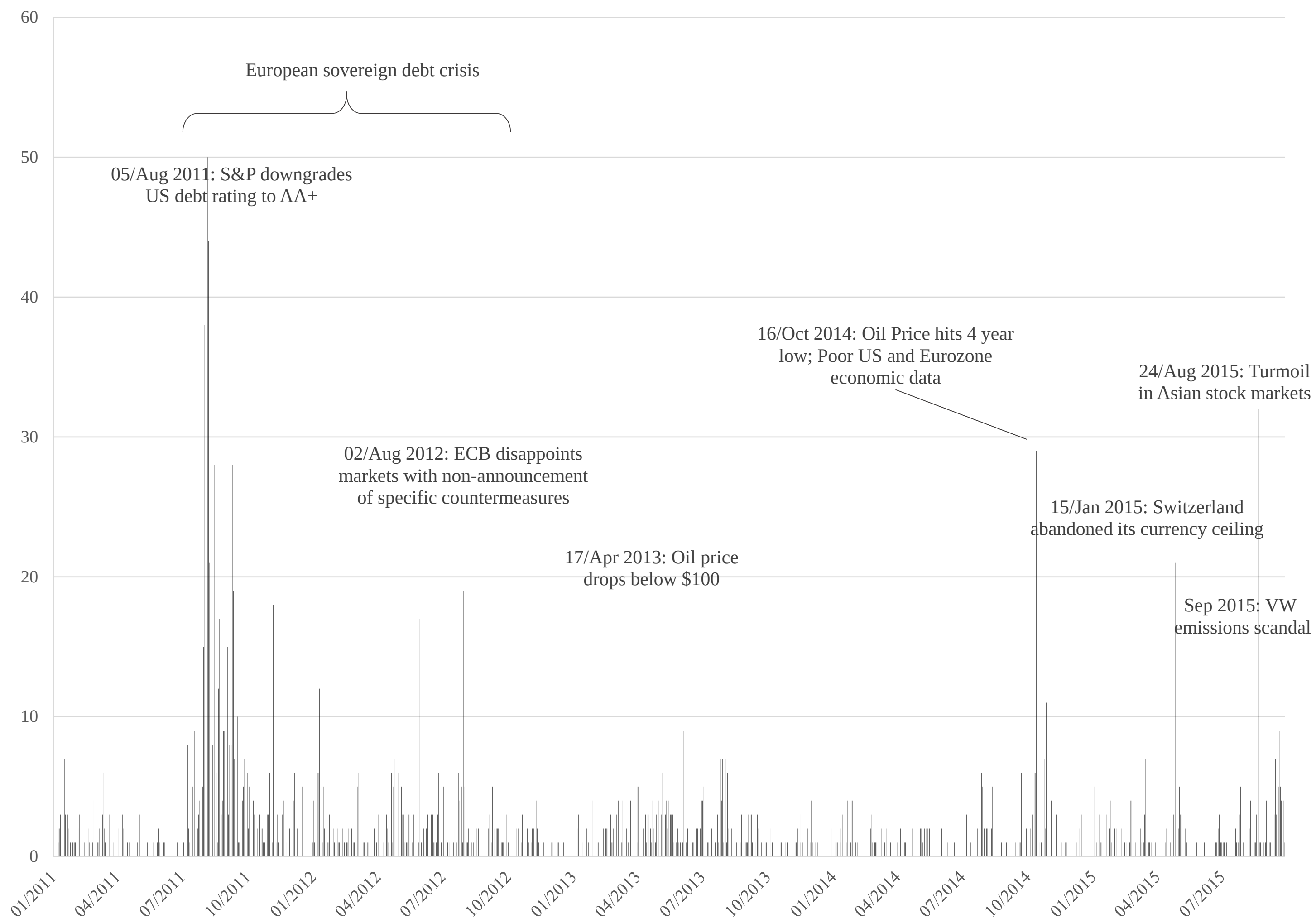


Figure A6: Occurrence of volatility interruptions during the observation period from January 2011 to September 2015.

House of Finance
Working Paper Series

Recent Issues

No. 195	Benjamin Clapham, Peter Gomber, Martin Haferkorn, Sven Panz	Managing Excess Volatility: Design and Effectiveness of Circuit Breakers
No. 194	Baptiste Massenot	A Business Cycle Model with Neuroeconomic Foundations
No. 193	Mario Bellia, Roberto Panzica, Loriana Pelizzon, Tuomas Peltonen	The Demand for Central Clearing: To Clear or Not to Clear, That is the Question
No. 192	Vincenzo Pezone	The Real Effects of Judicial Enforcement: Evidence from Italy
No. 191	Julia Hirsch, Uwe Walz	Financial constraints, newly founded firms and the financial crisis
No. 190	Vanya Horneff, Raimond Maurer, Olivia S. Mitchell	How Persistent Low Expected Returns Alter Optimal Life Cycle Saving, Investment, and Retirement Behavior
No. 189	Carlo Wix	The Long-Run Real Effects of Banking Crises: Firm-Level Investment Dynamics and the Role of Wage Rigidity
No. 188	Michael Donadelli, Patrick Grüning, Marcus Jüppner, Renatas Kizys	Global Temperature, R&D Expenditure, and Growth
No. 187	Baptiste Massenot, Yuri Pettinicchi	Can Firms see into the Future? Survey evidence from Germany
No. 186	Nicole Branger, Paulo Rodrigues, Christian Schlag	Level and Slope of Volatility Smiles in Long-Run Risk Models
No. 185	Patrick Grüning	Heterogeneity in the Internationalization of R&D: Implications for Anomalies in Finance and Macroeconomics
No. 184	Tobias Tröger	Remarks on the German Regulation of Crowdfunding
No. 183	Joost Driessen, Theo E. Nijman, Zorka Simon	The Missing Piece of the Puzzle: Liquidity Premiums in Inflation-Indexed Markets
No. 182	Mario Bellia, Loriana Pelizzon, Marti G. Subrahmanyam, Jun Uno, Darya Yuferova	Coming Early to the Party