The Impact of High-Frequency Trading on Modern Securities Markets – An Analysis Based on a Technical Interruption

Benjamin Clapham, Martin Haferkorn, Kai Zimmermann

Appendix (available online via http://link.springer.com)

Appendix

Table 5 Constituents of the DAX30 and the CAC40 stock index during our observation period, which are analyzed in this study.

DAX30		CAC40	
RIC	Company Name	RIC	Company Name
ADSGn.DE	Adidas AG	ACCP.PA	Accor SA
ALVG.DE	Allianz SE	AIR.PA*	Airbus SE
BASFn.DE	BASF SE	AIRP.PA*	Air Liquide SA
BAYGn.DE	Bayer AG	ATOS.PA*	Atos SE
BEIG.DE	Beiersdorf AG	AXAF.PA*	AXA SA
BMWG.DE	Bayerische Motoren Werke AG	BNPP.PA*	BNP Paribas SA
CBKG.DE	Commerzbank AG	BOUY.PA*	Bouygues SA
CONG.DE	Continental AG	CAGR.PA	Credit Agricole SA
DAIGn.DE	Daimler AG	CAPP.PA*	Capgemini SE
DB1Gn.DE	Deutsche Börse AG	CARR.PA*	Carrefour SA
DBKGn.DE	Deutsche Bank AG	DANO.PA	Danone SA
DPWGn.DE	Deutsche Post AG	ENGIE.PA*	Engie SA
DTEGn.DE	Deutsche Telekom AG	ESSI.PA*	Essilor International SA
EONGn.DE	E.ON SE	EXHO.PA*	Sodexo SA
FMEG.DE	Fresenius Medical Care AG & Co KGaA	FTI.PA*	TechnipFMC PLC
FREG.DE	Fresenius SE & Co KGaA	LEGD.PA	Legrand SA
HEIG.DE	HeidelbergCement AG	LHN.PA	Lafargeholcim Ltd
HNKG_p.DE	Henkel AG & Co KgaA (pref.)	LVMH.PA*	LVMH SE
IFXGn.DE	Infineon Technologies AG	MICP.PA*	Michelin SCA
LHAG.DE	Deutsche Lufthansa AG	MT.AS*	ArcelorMittal SA
LING.DE	Linde AG	ORAN.PA*	Orange SA
MRCG.DE	Merck KGaA	OREP.PA*	L'Oreal SA
MUVGn.DE	Münchener Rückversicherungs AG	PERP.PA*	Pernod Ricard SA
PSMGn.DE	Prosieben Media	PEUP.PA*	Peugeot SA
RWEG.DE	RWE AG	PRTP.PA*	Kering SA
SAPG.DE	SAP SE	PUBP.PA	Publicis Groupe SA
SIEGn.DE	Siemens AG	RENA.PA*	Renault SA
TKAG.DE	Thyssenkrupp AG	SAF.PA*	Safran SA
VNAn.DE	Vonovia SE	SASY.PA*	Sanofi SA
VOWG_p.DE	Volkswagen AG (pref.)	SCHN.PA*	Schneider Electric SE
		SGEF.PA*	Vinci SA
		SGOB.PA	Compagnie de Saint Gobain SA
		SOGN.PA*	Societe Generale SA
		SOLB.BR	Solvay SA
		STM.PA*	STMicroelectronics NV
		TOTF.PA*	Total SA
		UNBP.AS*	Unibail Rodamco SE
		VIE.PA*	Veolia Environnement SA
		VIV.PA	Vivendi SA
		VLOF.PA	Valeo SA

Note: RIC represents the Reuters Intrument Code; (pref.) indicates preference shares; * denotes that the respective CAC40 stock is included in the matched pairs sample

Table 6 Descriptive statistics for the DAX30 stocks traded on Xetra. This table provides descriptive statistics for the 30 stocks of the treatment group during our observation period of the first hour of trading on the event day as well as on four non-event days. Market quality and trading activity variables are aggregated into one-minute intervals so that the descriptive statistics are based on 8,990 observations. L1-Volume, Depth(10), and trading volume are reported in 1,000 euro. Trade price and midpoint standard deviation are denoted in bps. Control variables are calculated on a daily basis and are, thus, based on 150 observations. Market capitalization and daily trading volume are reported in 1,000,000 euro.

Variable	Mean	Median	Std. Dev.	Min	Max
Market Quality					
Spread	5.07	4.58	2.58	1.30	27.45
L1-Volume	98.20	52.14	113.73	4.29	1,456.99
Depth(10)	768.15	603.97	586.55	0.00	4,800.66
Order Imbalance	0.23	0.20	0.13	0.00	0.98
S.D. Price	2.12	1.82	2.06	0.00	55.04
S.D. Midpoint	2.13	1.75	1.77	0.00	50.84
Trading Activity					
Trades	10.78	7.00	12.03	0.00	237.00
Volume	177.59	88.13	275.88	0.00	7,217.68
Quotes	112.25	90.00	91.72	0.00	1,282.00
Submissions	174.25	145.00	130.49	0.00	1,802.00
Control Variables					
Market Cap	42,299	29,829	30,307	6,510	117,261
Closing Price	84.02	84.81	59.84	9.21	215.55
Daily Volume	83.85	71.48	47.04	15.65	242.57
High-to-Low	1.01	1.01	0.01	1.00	1.04

Table 7 Descriptive statistics for the CAC40 stocks traded on Euronext Paris. This table provides descriptive statistics for the 40 stocks of the control group during our observation period of the first hour of trading on the event day as well as on four non-event days. Market quality and trading activity variables are aggregated into one-minute intervals so that the descriptive statistics are based on 12,000 observations (11,820 for Depth(10), order imbalance, and number of submissions). L1-Volume, Depth(10), and trading volume are reported in 1,000 euro. Trade price and midpoint standard deviation are denoted in bps. Control variables are calculated on a daily basis and are, thus, based on 200 observations. Market capitalization and daily trading volume are reported in 1,000,000 euro.

Variable	Mean	Median	Std. Dev.	Min	Max
Market Quality					
Spread	4.91	4.46	2.44	1.14	27.40
L1-Volume	81.57	64.78	56.57	8.12	1,112.25
Depth(10)	644.47	542.62	424.50	2.73	2,698.77
Order Imbalance	0.20	0.17	0.11	0.02	0.85
S.D. Price	1.79	1.53	1.85	0.00	33.91
S.D. Midpoint	2.07	1.74	1.68	0.00	24.94
Trading Activity					
Trades	17.55	11.00	23.23	0.00	458.00
Volume	129.75	61.61	223.73	0.00	4,297.17
Quotes	153.18	125.00	118.52	0.00	1,260.00
Submissions	185.63	149.00	168.17	0.00	3,742.00
Control Variables					
Market Cap	37,263	27,572	29,161	10,503	121,905
Closing Price	79.72	66.50	65.77	13.78	313.85
Daily Volume	68.76	53.92	60.17	6.11	494.39
High-to-Low	1.01	1.01	0.01	1.00	1.04

Table 8 Regression results explaining changes in liquidity and volatility due to the interruption of HFT based on the matched pairs sub-sample (equally sized treatment and control group). *Spread*, *S.D. Price*, and *S.D. Midpoint* are in bps, *L1-Volume* and *Depth*(10) are in 1,000 euro. *Event* is dummy variable being one for the trading day on which HFT was interrupted, *DAX* is a dummy variable being one if a stock is a constituent of the DAX30, and *Day* represents the different observation days.

	Spread	L1-Volume	Depth(10)	Order Imb.	S.D. Price	S.D. Mid
Event	−0.085	−7.290	−26.858	−0.001	−0.232	−0.243
	(−0.741)	(−1.844*)	(−1.783*)	(−0.093)	(−2.230**)	(−2.383**)
Day	−0.007	−2.586	−32.033	−0.001	0.031	0.044
	(−0.243)	(−2.331**)	(−4.161***)	(−0.406)	(1.202)	(1.796*)
DiD	1.043	−9.487	−204.724	0.067	0.339	0.168
(Event · DAX)	(6.003***)	(−1.339)	(−4.393***)	(6.106***)	(2.265**)	(1.207)
Time Trend	0.036	−2.382	−20.110	0.002	−0.065	−0.052
(Day · DAX)	(0.797)	(−1.081)	(−1.821*)	(0.601)	(−1.853*)	(−1.595)
Controls	yes	yes	yes	yes	yes	yes
Observations	17,990	17,990	17,870	17,870	17,990	17,990
R^2	0.556	0.096	0.467	0.298	0.184	0.176
Adjusted R^2	0.553	0.090	0.463	0.293	0.178	0.170
F Statistic	334.133***	28.456***	232.167***	112.581***	60.075***	57.055***
Note:				t-statistics in parentheses; *p<0.1; **p<0.05; ***p<0.01		

Table 9 Regression results explaining changes in trading activity due to the interruption of HFT based on the matched pairs sub-sample (equally sized treatment and control group). *Trades*, *Quotes*, and *Submissions* are in number of occurrences, *Volume* is in 1,000 euro. *Event* is dummy variable being one for the trading day on which HFT was interrupted, *DAX* is a dummy variable being one if a stock is a constituent of the DAX30, and *Day* represents the different observation days.

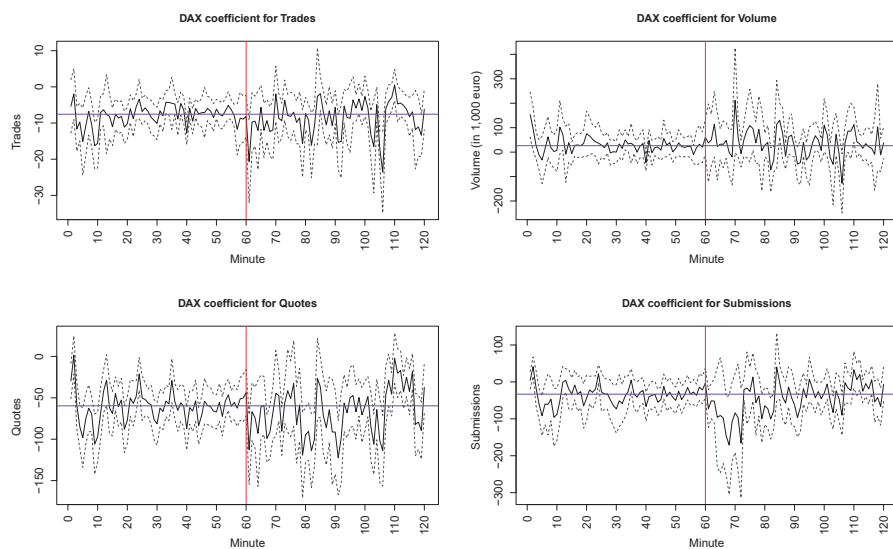|	Trades	Volume	Quotes	Submissions
Event	−1.811	−19.037	−40.064	−50.763
	(−1.198)	(−1.250)	(−6.262***)	(−6.345***)
Day	0.977	7.785	−0.764	2.730
	(1.862*)	(1.588)	(−0.297)	(0.448)
DiD	−0.869	6.873	−3.520	−5.094
(Event · DAX)	(−0.563)	(0.375)	(−0.519)	(−0.542)
Time Trend	−1.486	−17.040	−6.058	−9.128
(Day · DAX)	(−2.395**)	(−2.374**)	(−1.995**)	(−1.344)
Controls	yes	yes	yes	yes
Observations	17,990	17,990	17,990	17,870
R^2	0.074	0.051	0.141	0.131
Adjusted R^2	0.068	0.044	0.135	0.125
F Statistic	21.680***	14.412***	43.815***	39.889***
Note:		t-statistics in parentheses; *p<0.1; **p<0.05; ***p<0.01		

Table 10 Effect size of changes in market quality net of changes in trading activity based on the matched pairs sub-sample. *Non-Event Value* provides market quality and trading activity measures for DAX30 stocks on non-event days (these numbers are identical for the full and the matched sample since only the control stocks change). *DiD-Coefficient* reports the β_1-coefficient from Equation (7). *Percentage Change* is calculated by comparing the DiD-coefficient with the corresponding non-event value. *Net Effect* provides the percentage change for each market quality measure net of the change in trading activity measured by the number of trades and quotes. Coefficients printed in bold are significant at the 10%-level.

|	Trades	Volume	Quotes	Submissions		
Non-Event Value	11.06	177.24	117.86	181.49		
DiD-Coefficient	-0.87	6.87	-3.52	-5.09		
Percentage Change	-7.86%	3.88%	-2.99%	-2.81%		
	Spread	L1-Volume	Depth(10)	Order Imb.	S.D. Price	S.D. Mid
Non-Event Value	4.90	101.00	813.85	0.21	2.06	2.12
DiD-Coefficient	**1.04**	-9.49	**-204.72**	**0.07**	**0.34**	0.17
Percentage Change	21.28%	-9.39%	-25.15%	31.63%	16.48%	7.94%
Net Effect (Trades)	13.42%	-1.53%	-17.29%	23.77%	8.62%	0.08%
Net Effect (Quotes)	18.29%	-6.40%	-22.16%	28.64%	13.49%	4.95%

Table 11 Results of the DiD-analysis with matched stocks based on Equation (7) when dividing the sample into thirds according to market capitalization of the stocks. For brevity and better comparison, this table only reports the DiD-coefficient $Event \cdot DAX$ of each regression model. Panel A reports the results for changes in liquidity and volatility due to the interruption of HFT and Panel B reports those for changes in trading activity. *Spread*, *S.D. Price*, and *S.D. Midpoint* are in bps, *L1-Volume*, *Depth*(10), and *Volume* are in 1,000 euro, *Trades*, *Quotes*, and *Submissions* are in number of occurrences.

Panel A

	Spread	L1-Volume	Depth(10)	Order Imb.	S.D. Price	S.D. Mid
Largest Third	0.553	−12.447	−212.249	0.070	0.175	0.001
(Event · DAX)	(4.181***)	(−0.919)	(−1.783*)	(4.192***)	(1.053)	(0.011)
Medium Third	1.217	−15.194	−270.987	0.090	0.577	0.463
(Event · DAX)	(4.805***)	(−2.013**)	(−6.269***)	(6.169***)	(2.588***)	(2.296**)
Smallest Third	1.340	7.419	−82.614	0.051	0.100	−0.114
(Event · DAX)	(3.167***)	(0.585)	(−2.964***)	(2.100**)	(0.364)	(−0.448)

Panel B

	Trades	Volume	Quotes	Submissions
Largest Third	−1.236	1.913	−7.902	−14.496
(Event · DAX)	(−0.331)	(0.044)	(−0.649)	(−1.144)
Medium Third	−0.483	20.527	−9.932	−3.206
(Event · DAX)	(−0.203)	(0.908)	(−0.963)	(−0.171)
Smallest Third	−2.058	−5.892	−4.357	−24.375
(Event · DAX)	(−1.105)	(−0.268)	(−0.435)	(−2.066**)

Note:	t-statistics in parentheses; *p<0.1; **p<0.05; ***p<0.01

This figure illustrates the β_1-coefficient from Equation (6), i.e., the minute-wise cross-sectional differences between treatment (DAX30) and control group (CAC40), for each minute of the first hour of trading on non-event days (minutes 1 to 60) and the event day (minutes 61 to 120) separated by the red line. Dependent variables are $Trades$, $Volume$, $Quotes$, and $Submissions$. The purple line represents the median coefficient for non-event days and the dotted lines represent the upper and lower bounds of the 95%-confidence interval.

Fig. 2 Changes in trading activity due to the interruption of HFT (minute-wise regressions).
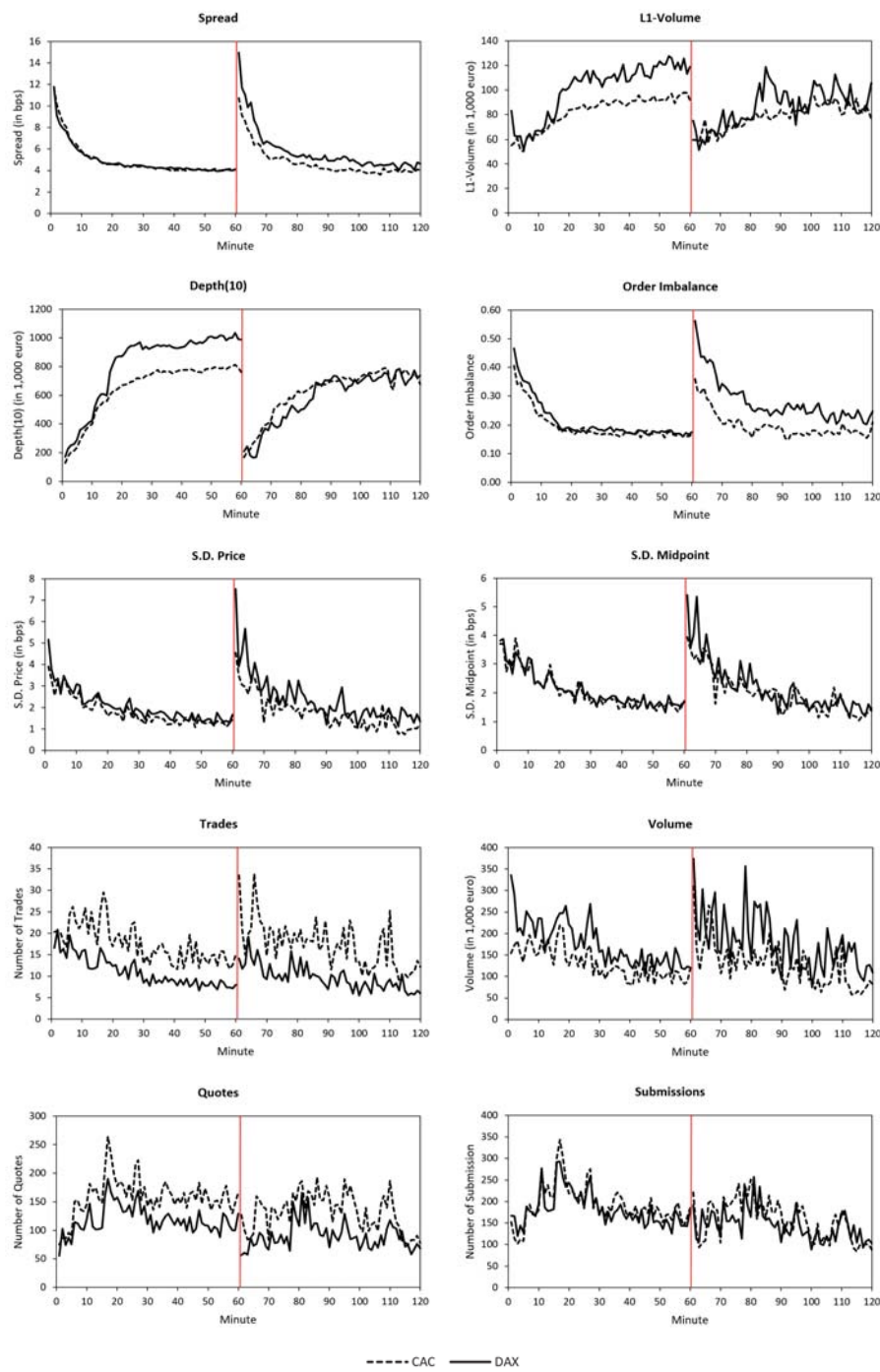
This figure plots the analyzed market quality and trading activity measures for DAX30 and CAC40 stocks averaged for each minute of the first hour of trading on non-event days (minutes 1 to 60) and the event day (minutes 61 to 120) separated by the red line.

Fig. 3 Market quality and trading activity during the first hour of trading on non-event days and the event day.