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The effect of algorithmic trading on market liquidity: Evidence around earnings announcements on Borsa Italiana

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ABSTRACT

This paper examines the impact of algorithmic trading (AT) on market liquidity around periods of high information asymmetry when available liquidity is more valuable. We identify the implementation of proximity hosting services by Borsa Italiana, that are expected to increase AT, in order to examine the behaviour of liquidity around earnings announcements in pre- and post-AT periods. Consistent with previous research, we find that bid-ask spreads widen and market depth falls following earnings announcements in the pre-AT period. However, in the post-AT period, while we find a similar pattern in bid-ask spreads, we find no evidence of a significant fall in market depth. We also find firms that experience the largest increase in AT from pre- to post-AT periods, exhibit lower bid-ask spreads and greater depth following earnings announcements. We conclude that AT improves market liquidity by increasing the resiliency of markets around periods of high information asymmetry, specifically around earnings announcements.

1. Introduction

A small but growing body of literature examines the impact of algorithmic trading on liquidity. The seminal work of Hendershott et al. (2011) provides an empirical assessment of the effect of algorithmic trading (herein AT) on market liquidity. Using message traffic as a proxy for the quantity of AT, the authors provide evidence that the presence of AT in markets enhances liquidity. Brogaard (2010) extends the work of Hendershott et al. (2011) by examining a proprietary dataset that identifies the trading behaviour of twenty-six high-frequency traders on NASDAQ. Brogaard (2010) examines the cross-sectional determinants of the provision of liquidity by high-frequency traders and finds that high-frequency traders are more likely to set the inside quotes (i.e., provide liquidity) in larger stocks. More recently, Jarnecic and Snape (2014) examine the order submission strategies of traders and find that high-frequency traders provide liquidity at multiple prices in the order book and temper liquidity imbalances. This literature, therefore suggests that AT generally improves market liquidity.

In this paper, we extend previous literature examining the impact of AT on liquidity by examining liquidity provision during periods of high information asymmetry - specifically, around earnings releases. A considerable body of literature has examined the impact of earnings releases on liquidity including Morse and Ushman (1983); Lee et al. (1993) and Krinsky and Lee (1996). This literature generally finds that liquidity declines following earnings announcements. This decline in liquidity can be attributed to

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the greater adverse selection costs faced by liquidity providers around earnings announcements, who subsequently widen bid-ask spreads to compensate themselves for greater risk exposure and reduce depth in order to limit the amount of risk they face. We conjecture that because ATs can rapidly change quote or limit order prices as market conditions change, they are better able to manage the risks and reduce costs of adverse selection around earnings releases. Consequently, we hypothesize that liquidity around earnings announcements will improve in the presence of AT.

In order to test our hypothesis, we exploit a natural experiment that is likely to increase the amount of AT in markets. In 2009, Borsa Italiana introduced proximity hosting that enabled brokers to place their servers in the same room (i.e. in close proximity) as the exchange's trading server. This proximity hosting service reduced latency for ATs and was associated with a significant increase in message traffic through time, indicative of an increase in AT activity. We identify periods around the introduction in proximity hosting that clearly represent pre- and post-AT environments. We then examine liquidity around earnings announcements in the two periods to test the effect of AT on liquidity around earnings announcements.

Consistent with previous literature, we document a widening in bid-ask spreads and a decrease in depth at the time of, and following, earnings announcements in the pre-AT trading environment. We also find no evidence of a significant change in the behaviour of bid-ask spreads in the post-AT period. However, in the post-AT period, we provide strong evidence that depth is higher, following earnings announcements. We also provide evidence that bid-ask spreads are lower and depth higher following earnings announcements in the post-AT period for firms which experience the greatest increase in AT. This is consistent with the proposition that AT improves market liquidity around periods of high information asymmetry.

The remainder of this paper is structured as follows. The following section provides institutional detail including proximity hosting services for Borsa Italiana. Section 3 describes the data and method. Section 4 reports empirical results and Section 5 provides various robustness tests. The final section provides a conclusion.

2. Institutional Details

Since its integration into London Stock Exchange (LSE) Group, many services have been updated at Borsa Italiana to improve its electronic trading systems for market participants. On 10 November 2008, Borsa Italiana's equity market successfully migrated to TradElect: the LSE's trading system. Access sites were located in Milan and Turin, and hosted both the MDF/DDM Plus central system (the market data distribution system of Borsa Italiana) and CCG clearing system (the Clearing House system of Borsa Italiana).[1] All data centers were connected via high-capacity fiber-optic links (10 Gbps) providing a unique operating system. Borsa Italiana offered different connectivity options depending on customer needs: (1) virtual private network (VPN) connection via internet, (2) direct connection through dedicated lines installed at the firms or third-party locations (Bit Network) and (3) connection through an accredited service provider (Cervi, 2008).

In August 2009, the LSE Group launched its Exchange Hosting Service. Physically located at the LSE, the facility reduced latency and allowed participants to co-locate their servers as close as possible to the exchange's matching engine (Bailey, 2009; Harold, 2008). Hosting and co-location services in Borsa Italiana's main market (MTA) were available via data centers in Milan and London. However, due to their proximity to the LSE, London-based traders were provided a latency advantage[2] over the Italian-based traders (*The Trade*, 20 October 2011). Subsequently, on 25 June 2012, the LSE Group shifted the trading system used to trade Italian equities back to Milan (see *Financial Times*, 18 January 2012), coinciding with Borsa Italiana's adoption of the Millennium Exchange trading platform and the launch of its latest co-location service.

3. Data and Method

3.1. AT Activity on Borsa Italiana

Our analysis considers component securities of the FTSE MIB[3] Index as of April 2012 sourced from the Thomson Reuters Tick History (TRTH) database. The TRTH database managed and distributed by the Securities Industry Research Centre of Asia Pacific (SIRCA) also provides intraday trade and quote information time stamped to the nearest millisecond and order book information (price and volume) for up to ten price levels.

To investigate the effect of AT on liquidity around earnings announcements, we determine the change in AT via several proxies which are common in the literature to categorize our sample period into pre- and post-AT trading periods. Specifically, we examine: (1) message traffic, (2) the order-to-trade ratio (OTR) and (3) *Algo Trade* (Hendershott et al., 2011). Consistent with Boehmer et al. (2014) and Hendershott et al. (2011), we define message traffic as the sum of trades, new order submissions, modifications and order cancelations in the order book for each stock in the FTSE MIB on a given trading day.[4] In addition, for each stock in the

[1] On MDF/DDM Plus central system and CCG clearing system specifications see: London Stock Exchange (2014) and Cervi (2008).

[2] 24 ms latency advantages were sufficient to give the London traders a competitive advantage over long-term investors based in Italy; see *The Trade*, October 20, 2011.

[3] The FTSE MIB index consists of the most active, liquid and capitalized stocks of the Italian Equity Market (Frino et al., 2013).

[4] Messages are reflected in the TRTH database via new records at each timestamp.

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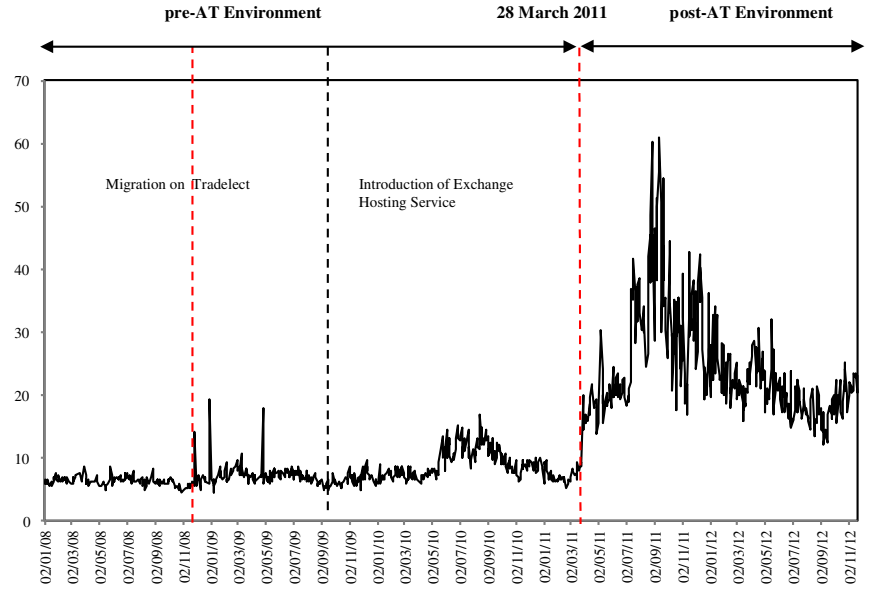
FTSE MIB, we estimate the order-to-trade ratio (OTR) for stock i on day t, as:

$$\mathrm{OTR}_{it} = \frac{Message\ \ Traffic_{it}}{Total\ \ Transactions_{it}} \tag{1}$$

we also standardize the OTR, as suggested by Hendershott et al. (2011) and calculate *Algo Trade*, defined as the negative of trading

(i) Order-to-trade ratio (OTR), (electronic messages/transactions) a proxy for algorithmic activity.



(ii) Algo Trade, (euro volume per electronic message -1), a proxy for algorithmic trading (100€)*

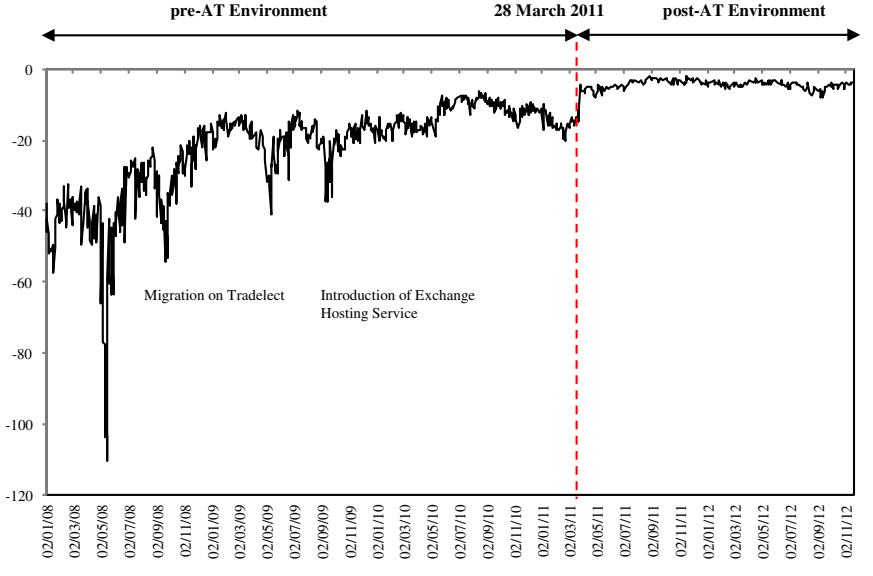


Fig. 1. Algorithmic trading measures. These figures depict algorithmic trading proxies on a daily basis and highlights system upgrades at Borsa Italiana.

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volume (in hundreds of euros) divided by message traffic:

$$AlgoTrade_{it} = \frac{-Euro\ \ Volume_{it}/100}{Message\ \ Traffic_{it}} \tag{2}$$

Fig. 1 shows the evolution of the *OTR* and *Algo Trade* from 2 January 2008 to 20 November 2012 for FTSE MIB stocks. Notwithstanding many of the technological developments implemented at Borsa Italiana, Fig. 1 identifies a systematic shift in AT post March 28, 2011. Our AT proxies do not appear to vary around the introduction of exchange hosting on August 2009 or around the introduction of the Millennium platform and co-location service on 25 June 2012.[5] This is likely to be driven by learning effects which imply that it may take some time for ATs to enter the market.

Consequently, we identify the period August 2, 2009 to March 27, 2011 as our pre-AT period and March 28, 2011 to November 20, 2012 as our post-AT period.

3.2. Earnings Announcement Sample and Estimated Parameters

We sample all earnings announcements of 35 FTSE MIB stocks that were listed on the Borsa Italiana from 2 August 2009 to 20 November, 2012.[6] A total of 469 announcements made by 35 stocks were collected from the News Service of Borsa Italiana. The data include information pertaining to the time and type of earnings announcement (quarterly, semi-annual, quarterly, or annual).[7] To examine AT behaviour around earnings announcements, we apply a series of standard filters to the population of earnings announcements. Table 1 summarizes the results of our sample selection process. We exclude earnings announcements outside of normal trading hours (from 9.00 a.m. to 5.25 p.m.) and those within the first hour and the last hour of normal trade to avoid intraday patterns associated with the market open and close. Our final sample of 241 announcements is split into 113 announcements (spread across 26 firms) during the pre-AT period and 128 announcements (spread across 24 firms) during the post-AT period.

We perform two sets of analysis to evaluate the effect of AT activity on liquidity around earnings announcements. First, we examine average daily differences in AT measures on earnings announcement days in pre- and post-AT periods. Second, we examine intraday AT activity and liquidity around the time of earnings announcements in pre- and post-AT periods. We proxy market liquidity as: (1) the *bid-ask spread* (in Euro) at the end of each minute (2) percentage bid-ask spreads at the end of each minute relative to the midquote and (3) *depth* (in shares) the total depth at the best bid and ask quotes. Intraday AT and liquidity measures are calculated for each 1-minute interval, over an event window which extends 15 min prior to and 30 min after each earnings announcement (time stamped to the nearest minute). Consistent with Gajewski (1999) we measure AT activity and liquidity for each 1-minute interval as the difference between the actual value and a pre-benchmark value. The pre-benchmark value is measured from 30 to 16 min prior to each earnings announcement and acts to standardize AT and liquidity measures for each earnings announcement. Specifically, we measure excess AT activity and liquidity as:

$$Excess_{dj} = \left(Actual_{dj} - \overline{\text{Benchmark}}_{\text{d}}\right) \tag{3}$$

where $Actual_{dj}$ is message traffic, bid-ask spread, percentage bid-ask spread or depth in minute interval j for announcement d, and $\overline{Benchmark}_{\text{d}}$ is the mean message traffic, bid-ask spread, percentage bid-ask spread or depth measured from interval −30 through −16 for announcement d.

4. Results

4.1. AT Activity on Earnings Announcement Days

We begin by examining the change in proxies for AT on earnings announcement days in pre- and post-AT periods. Table 2 reports summary statistics for all AT proxies including message traffic, messages per minute, OTR and Algo Trade. Table 2 reports that on earnings announcement days in the pre-AT period 28,744 messages are typically sent by traders. This increases to 90,784 in the post-AT period and the increase is significant at the 0.01 level of significance. Similar increases are reported for OTR, messages per minute and *Algo Trade* measures.

4.2. AT Activity and Liquidity Behaviour Around Earnings Announcements

Turning to our intraday analysis around earnings announcements, Fig. 2 plots the excess message traffic in pre-AT and post-AT periods. Before earnings announcements, standardized message traffic between the two periods is indistinguishable. Following the

[5] Brogaard et al. (2015) and Frino et al. (2014) report market liquidity for equity securities on the NASDAQ OMX Stockholm and futures products on the Australian Securities Exchange improved respectively, following co-location upgrades.

[6] We remove 5 stocks from our sample to ensure that we examine the same constituent stocks of the FTSE MIB throughout our sample period.

[7] The Board of Directors Committee approves the financial reports in the following periods: April–May (1st quarterly report), July–August (2nd quarterly or half yearly report), October–November (3rd quarterly report), and February–March (4th quarterly or annual report).

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Table 1
Earnings announcement sample and selection process.
This table summarizes the sample selection process used to identify the final sample of earnings announcements. The sample period extends 2 August 2009 to 20 November 2012 and includes 27 companies that are listed over the period and are included in the FTSE MIB Index.

Announcements sample	All periods	pre-AT Period	post-AT Period
Total of daytime and overnight announcements	469	218	251
Announcements outside trading hours	205	95	110
Announcements one hour after the opening time and one hour before the closing time	23	10	13
Final sample	241	113	128

Table 2
Algorithmic trading proxies.
This table reports the summary statistics for AT proxies in pre-AT and post-AT environments on Borsa Italiana. We perform a *t*-test to compare the daily mean of all AT activity proxies between post-AT and pre-AT periods. *, **, *** denote significance at the 10%, 5% and 1% levels, respectively.

	N	*Message Traffic*	*Messages per minute*	*Order to trade ratio*	*Algo Trade*
pre-AT	113	28,743.8	56.92	4.80	−25.90
post-AT	128	90,784.3	179.80	16.37	−6.17
Difference		62,040.5***	122.9***	11.58***	19.73***
t-stat.		7.62	7.62	12.68	8.09

earnings release a different picture arises, in the post-AT environment message traffic increases rapidly and then falls sharply, vis-à-vis message traffic in the pre-AT environment.

In terms of liquidity surrounding earnings releases, Figs. 3, 4 and 5, provide evidence consistent with Lee et al. (1993) that *excess bid-ask spreads* (quoted and percentage) widen and *excess depth* fall after earnings announcements during the pre-AT sample period. By contrast, a different trend is depicted in the post-AT environment, particularly for market depth.

Figs. 3 and 4 highlight a possible difference in *excess bid-ask* spreads (quoted and percentage) between the pre-AT and post-AT trading environments. Moreover, Fig. 5 clearly documents that *excess depth* does not decrease, in contrast to the pre-AT environment. Fig. 5 shows, before earnings releases *excess depth* in pre- and post-AT periods are similar. Following earnings releases, in the post-AT environment, *excess depth* does not decline, rather it remains resilient. These results provide preliminary evidence that depth around earnings releases improved following the increase in AT on Borsa Italiana.

Table 3 reports significance tests on the difference in liquidity measures between the pre- and post-AT sample periods for 1-minute intervals around earnings releases. The results in Panel A report a significant decrease in *excess bid-ask spreads* (quoted) in the first and third minute after the earnings release. However, Panel B reports no significant difference in *excess percentage bid-ask spreads* between the two trading periods. Panel C of Table 3 reports a positive change in *excess depth* (statistically significant at conventional levels of significance) for most of the post-announcement intervals examined.

In addition to univariate results reported above, we estimate the parameters of the following regression model to assess changes in liquidity surrounding earnings announcements in pre- and post-AT environments:

$$Liquidity_{jdi} = \alpha + \beta_1 D_{jdi}^{earnings} + \beta_2 D_{jdi}^{post-AT} + \beta_3 D_{jdi}^{earnings} D_{jdi}^{post-AT} + \delta_i FE_i + \varepsilon_{jdi} \quad (4)$$

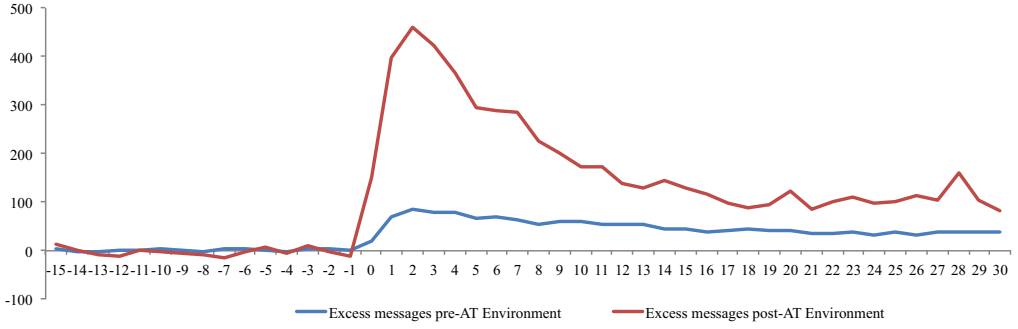

Fig. 2. Excess message traffic around earnings announcements in pre-AT and post-AT environments. This figure depicts mean *excess message* traffic for each 1-minute interval from −15 to +30 min around earnings announcements in pre-AT and post-AT environments. *Excess message* traffic is calculated as the difference between the actual value for each 1-minute interval and a benchmark value calculated as the mean from −30 to −16 min before the announcement time.

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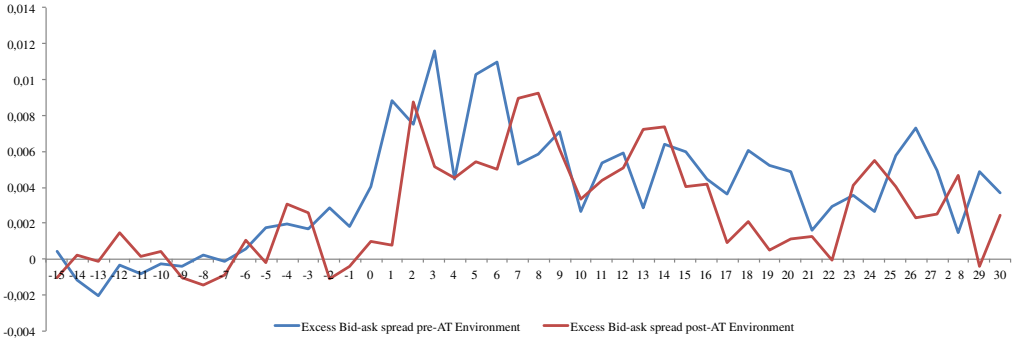

Fig. 3. Excess bid-ask spreads around the time of announcements in pre-AT and post-AT environments. This figure depicts mean *excess bid-ask spreads* for each 1-minute interval from −15 to +30 min around earnings announcements in pre-AT and post-AT environments. *Excess bid-ask spreads* is calculated as the difference between the actual value for each 1-minute interval and a benchmark value calculated as the mean from −30 to −16 min before the announcement time.

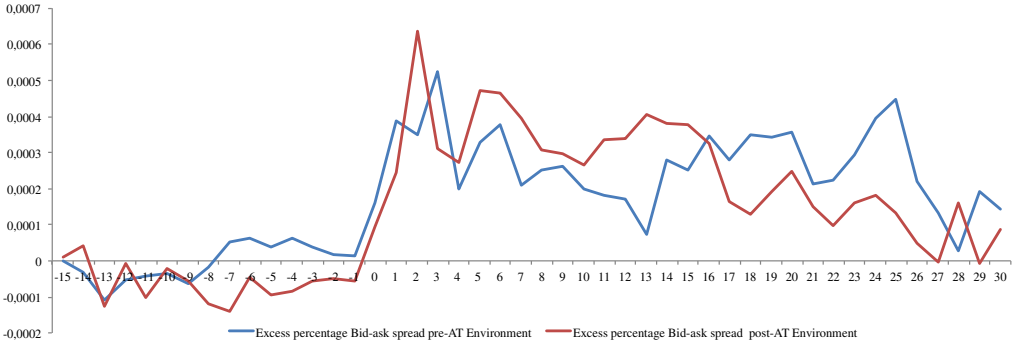

Fig. 4. Excess percentage bid-ask spreads around the time of announcements in pre-AT and post-AT environments. This figure depicts mean *excess percentage bid-ask spreads* for each 1-minute interval from −15 to +30 min around earnings announcements in pre-AT and post-AT environments. *Excess percentage bid-ask spreads* is calculated as the difference between the actual value for each 1-minute interval and a benchmark value calculated as the mean from −30 to −16 min before the announcement time.

where *Liquidity* is either *excess bid-ask spreads, excess percentage bid-ask spread* or *excess depth* for each 1-minute interval *j* from interval −15 to +30 min surrounding earnings announcement *d*. $D_{jdi}^{earnings}$, is a dummy variable which takes a value of one for intervals following the earnings announcements and zero otherwise. $D_{jdi}^{post-AT}$, is a dummy variable which takes a value of one for earnings announcements made in the post-AT period and zero otherwise. The coefficient on the interaction term β_3 captures the variation in liquidity measures following earnings announcements in a post-AT trading environment. FE_i, is a fixed effects term for firm *i*.

Parameter estimates for Eq. (4) reported in Table 4 document that *excess bid-ask spreads* (quoted and percent) increase significantly in the 30 min following an earnings release, while *excess depth* decreases significantly, consistent with aforementioned

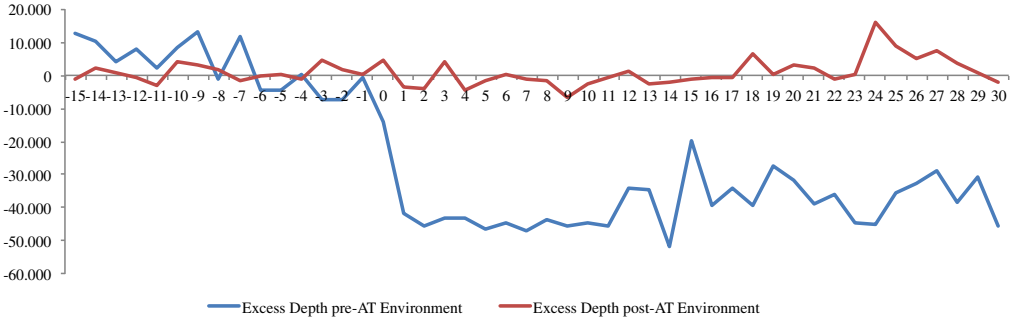

Fig. 5. Excess depth around the time of announcements in pre-AT and post-AT environments. This figure depicts mean *excess depth* for each 1-minute interval from −15 to +30 min around earnings announcements in pre-AT and post-AT environments. *Excess depth* is calculated as the difference between the actual value for each 1-minute interval and a benchmark value calculated as the mean from −30 to −16 min before the announcement time.

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Table 3
Change in liquidity from pre-AT to post-AT periods.
This table reports the results of a paired *t*-test for every 1-minute interval. We compare the mean *Excess Bid-Ask Spreads* in Panel A, *Excess Percentage Bid-Ask Spreads* in Panel B and *Excess Depth* in Panel C between post-AT (HAT) and pre-AT environments (LAT). *, **, *** denotes significance at the 10%, 5% and 1% level, respectively.

	Panel A			Panel B			Panel C		
	Excess bid-ask spreads			Excess percentage bid-ask spreads			Excess depth		
1 min interval	*HAT-LAT*		*t-stat*	*HAT-LAT*		*t-stat*	*HAT-LAT*		*t-stat*
−5	−0.00198		(0.97)	−0.00013		(1.46)	4,604.68		(−0.89)
−4	0.00115		(−0.40)	−0.00015		(1.48)	−1,514.55		(0.12)
−3	0.00094		(−0.38)	−0.00009		(0.88)	11,741.85		(−1.26)
−2	−0.00396		(1.41)	−0.00007		(0.65)	9,059.99		(−1.16)
−1	−0.00224		(0.94)	−0.00007		(0.65)	1,029.79		(−0.19)
0	−0.00300		(1.15)	−0.00007		(0.58)	18,704.83	*	(−1.64)
1	−0.00803	**	(2.04)	−0.00014		(0.99)	38,098.22		(−1.32)
2	0.00126		(−0.23)	0.00028		(−1.40)	41,652.84		(−1.42)
3	−0.00647	*	(1.63)	−0.00021		(1.42)	47,514.87	*	(−1.94)
4	0.00005		(−0.02)	0.00007		(−0.52)	38,727.74	*	(−1.70)
5	−0.00481		(1.00)	0.00014		(−0.87)	44,779.30		(−1.50)
6	−0.00595		(1.23)	0.00009		(−0.47)	44,982.30	**	(−1.95)
7	0.00370		(−0.86)	0.00019		(−1.21)	45,854.93	*	(−1.69)
8	0.00339		(−0.71)	0.00006		(−0.40)	41,745.82	*	(−1.69)
9	−0.00100		(0.25)	0.00004		(−0.25)	38,754.92		(−1.48)
10	0.00074		(−0.25)	0.00007		(−0.50)	42,026.97		(−1.63)
11	−0.00099		(0.32)	0.00015		(−1.30)	45,074.25	**	(−1.99)
12	−0.00089		(0.24)	0.00017		(−1.28)	35,548.50	**	(−2.18)
13	0.00437		(−1.32)	0.00033	**	(−2.20)	32,357.47	*	(−1.82)
14	0.00091		(−0.27)	0.00010		(−0.63)	49,716.60	*	(−1.91)
15	−0.00194		(0.55)	0.00012		(−0.86)	18,711.83		(−1.48)
16	−0.00025		(0.08)	−0.00002		(0.09)	38,791.40	*	(−1.83)
17	−0.00272		(1.07)	−0.00012		(0.55)	33,510.33	*	(−1.93)
18	−0.00391		(1.22)	−0.00022		(1.00)	46,065.63	**	(−2.14)
19	−0.00469		(1.63)	−0.00015		(0.68)	27,379.56	*	(−1.67)
20	−0.00373		(1.32)	−0.00011		(0.49)	35,135.83	*	(−1.69)
21	−0.00034		(0.13)	−0.00006		(0.29)	41,383.55	**	(−1.98)
22	−0.003001		(1.21)	−0.00013		(0.58)	34,771.72		(−1.56)
23	0.00057		(−0.24)	−0.00013		(0.60)	44,947.10	*	(−1.67)
24	0.00286		(−0.67)	−0.00021		(0.97)	61,385.72	**	(−2.11)
25	−0.00170		(0.51)	−0.00031		(1.41)	44,186.19	**	(−2.05)
26	−0.00497		(1.60)	−0.00017		(1.25)	37,781.43	***	(−2.58)
27	−0.00245		(0.77)	−0.00014		(1.04)	36,303.91	***	(−2.48)
28	0.00323		(−0.93)	0.00013		(−1.03)	42,151.73	*	(−1.77)
29	−0.00526	**	(2.20)	−0.00020		(1.47)	31,706.37		(−1.40)
30	−0.00129		(0.50)	−0.00006		(0.48)	43,068.92	*	(−1.85)

results. In relation to liquidity effects in a post-AT environment, *excess bid-ask spreads* and *depth* do not change significantly, although *excess percentage bid-ask spreads* overall are significantly lower at the 5% level of significance. The sign on the interaction term, our primary variable of interest, suggests that in the post-AT period following an earnings release *excess bid-ask spreads* and

Table 4
Changes in liquidity around earnings announcements in pre and post-AT environments.
This table reports coefficients estimates of regression analysis for changes in liquidity surrounding earnings announcements using data from 2009 to 2012. The specific model that we estimate over 10,534 observations is as follows:

$$Liquidity_{jdi} = \alpha + \beta_1 D_{jdi}^{earnings} + \beta_2 D_{jdi}^{post-AT} + \beta_3 D_{jdi}^{earnings} D_{jdi}^{post-AT} + \delta_i FE_i + \varepsilon_{jdi}$$

where Liquidity is either Excess bid-ask spreads (quoted or percent) and Excess depth for each minute interval *j* from −15 to +30 min for earnings announcement *d*. $D_{jdi}^{earnings}$, is a dummy variable which takes the value of one for intervals following the earnings announcements, and zero otherwise. $D_{jdi}^{post-AT}$, is a dummy variable which takes the value of one for earnings announcements made post March 28, 2011 and zero otherwise. The interaction terms β_3 captures the variation liquidity post earnings announcements in an AT trading environment. FE_i, is a fixed effects term for firm *i*. Robust standard errors for heteroskedasticity and autocorrelation are applied and *t*-stats reported. *, **, and *** denote significance at 10%, 5% and 1%, respectively.

Parameter	Excess bid-ask spread (quoted)		Excess percentage bid-ask spread (percent)		Excess depth (quoted)	
	Coefficient	*t-stat*	Coefficient	*t-stat*	Coefficient	*t-stat*
α	−0.0024	−2.10**	−0.0001	−2.35**	11,684.16	1.73*
$D_{jdi}^{earnings}$	0.0053	7.67***	0.0002	6.97***	−41,395.80	−10.00***
$D_{jdi}^{post-AT}$	−0.0010	−1.31	−0.0001	−2.01**	2,953.37	0.64
$D_{jdi}^{earnings} D_{jdi}^{post-AT}$	−0.0016	−1.07	0.0001	1.12	41,612.14	7.39***
Adj R squared	0.1483		0.0518		0.1468	

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Table 5
Changes in Liquidity around Earnings Announcements in pre and post-AT trading environments
This table reports coefficients estimates of regression analysis for changes in liquidity surrounding earnings announcements using data from 2009 to 2012. The specific model that we estimate over 3,634 observations as follows:
$Liquidity_{jdi} = \alpha + \beta_1 D_{jdi}^{earnings} + \beta_2 D_{jdi}^{post-AT} + \beta_3 D_i^{\Delta high-AT} D_{jdi}^{earnings} D_{jdi}^{post-AT} + \delta_i FE_i + \varepsilon_{jdi}$
where Liquidity is either Excess bid-ask spreads (quoted or percent) and Excess Depth for each minute interval j from −15 to +30 min for earnings announcement d. $D_{jdi}^{earnings}$, is a dummy variable which takes the value of one for intervals following the earnings announcements, and zero otherwise. $D_{jdi}^{post-AT}$, is a dummy variable which takes the value of one for earnings announcements made post March 28, 2011 and zero otherwise. The interaction terms β_3 captures the variation liquidity post earnings announcements for firms that experience the largest change in AT. $D_i^{\Delta high-AT}$ is dummy variable which takes the value of one for firms which experience the largest change is AT, and zero otherwise. FE_i, is a fixed effects term for firm i. Robust standard errors for heteroskedasticity and autocorrelation are applied and t-stats reported. *, **, and *** denote significance at 10%, 5% and 1%, respectively.

Parameter	Excess bid-ask spreads (quoted)		Excess percentage bid-ask spreads (percent)		Excess depth (quoted)	
	Coefficient	*t-stat*	Coefficient	*t-stat*	Coefficient	*t-stat*
α	−0.0008	−2.06*	−0.0001	−1.77*	5,179	1.70*
$D_{jdi}^{earnings}$	0.0011	4.15***	0.0002	4.47***	−7,039	−3.46***
$D_{jdi}^{post-AT}$	0.0003	0.90	0.0000	0.23	474	0.23
$D_i^{\Delta high-AT} D_{jdi}^{earnings} D_{jdi}^{post-AT}$	−0.0016	−3.71***	−0.0001	−1.98**	14,883	4.58***
Adj R squared	0.056		0.0498		0.0258	

excess percentage bid-ask spreads do not change significantly. In terms of *excess depth*, results in Table 4 confirm those reported in Table 3 - *excess depth* is significantly higher following earnings releases in a post-AT trading environment, suggesting that AT supports liquidity in markets during times of information asymmetry.

To further examine the effect of AT on liquidity surroundings earnings announcements, we perform an additional test for two sub-samples of securities with varying levels of change in AT activity. If AT does have an effect on liquidity, the changes in liquidity patterns should be most evident in the group of stocks experiencing the greatest change in levels of AT.[8] In order to identify groups of securities which experience the greatest (and smallest) change in AT, message traffic for each firm is calculated in the pre- and post-AT periods. Firms are ranked based on this change and then divided into quintiles. Data for firms in the top and bottom ranked quintiles are used to estimate the following model:

$$Liquidity_{jdi} = \alpha + \beta_1 D_{jdi}^{earnings} + \beta_2 D_{jdi}^{post-AT} + \beta_3 D_i^{\Delta high-AT} D_{jdi}^{earnings} D_{jdi}^{post-AT} + \delta_i FE_i + \varepsilon_{jdi} \quad (5)$$

where the coefficient on the interaction term β_3 captures the change in liquidity for firms that experience the greatest change in AT activity, vis-à-vis firms that experience the smallest change in AT activity. $D_i^{\Delta high-AT}$ is dummy variable which takes the value of one for firms which experience the greatest change in AT between the pre- and post-AT period, and zero otherwise. All other variables in Eq. (5) are defined as in Eq. (4).

Table 5 reports results similar to those in Table 4, specifically that following earnings announcements excess liquidity falls, and that in the post-AT trading environment excess liquidity is insignificantly different from the pre-AT environment. The coefficient on the variable of interest, coefficient β_3, confirms that the improvement in liquidity (around earnings releases) is most evident for firms which experience the greatest change in AT. Results in Table 5, suggest that *excess bid-ask spreads* (quoted and percent) are significantly lower and that *excess depth* is significantly higher around earnings releases for firms that experience the greatest increase in AT activity in the post-AT period.

5. Further Analysis and Robustness Tests

In this section, we report results of additional tests to probe our results and assess their robustness. Consistent with the literature that seeks to explain the determinants of liquidity (e.g. Chai et al., 2010; Demsetz, 1968), we examine intraday price volatility around earnings announcements. Fig. 6 plots the standard deviation of the midpoint returns in both the pre- and post-AT periods.[9] The results clearly demonstrate that *excess volatility* increases during both sample periods, following an earnings announcement. It also reports that the increase in volatility following earnings releases is greater in the post-AT environment. Given that spreads are positively related to volatility and depth is negatively related to volatility (Lee et al., 1993), the differences in the behaviour of liquidity following earnings announcements that we document in the post-AT period cannot be explained by volatility. Indeed the volatility differences following earnings announcements that we document create a bias against the findings we document and therefore only strengthen our conclusions.

We further split our sample on announcement dates by earnings surprises. Specifically, we calculate open to close returns and identify all firms with positive announcement-day returns as one group. The second group conversely includes all firms with

[8] We thank an anonymous referee for this suggestion.
[9] Excess volatility is estimated as difference between the actual value and a pre-benchmark value as described in the Eq. (3).
[10] Results available on request.

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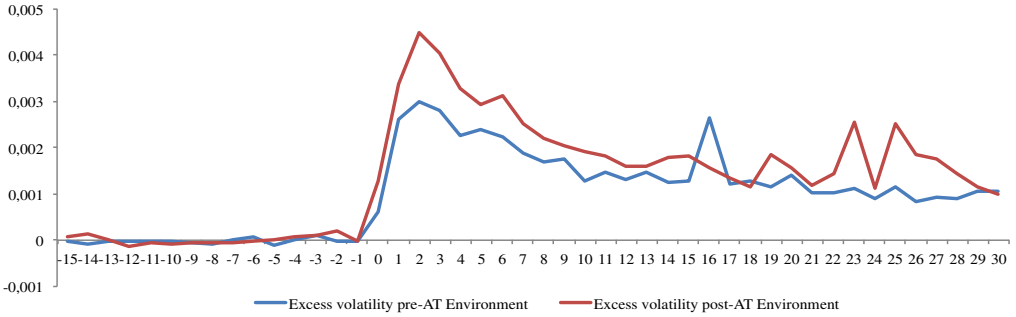

Fig. 6. Excess volatility around the time of announcements in pre-AT and post-AT Environments. This figure depicts mean *excess volatility* for each 1-minute interval from −15 to +30 min around earnings announcements in pre-AT and post-AT environments. *Excess volatility* is calculated as the difference between the actual value for each 1-minute interval and a benchmark value calculated as the mean from −30 to −16 min before the announcement time.

negative announcement-day price returns. These additional tests suggest that our results do not appear to be related to whether the news from the earnings release is positive or negative.[10]

6. Conclusion

This paper investigates liquidity patterns surrounding earnings announcements in pre- and post-AT periods on the Borsa Italiana. Borsa Italiana first introduced exchange-hosting services in August 2009; however, we find trading behaviour consistent with an increase in AT commenced in March 2011. The paper documents a deterioration in liquidity (spread widens and market depth drops) following earnings announcements in the pre-AT environment. In the post-AT environment, we find a similar pattern in bid-ask spreads, however we find that ATs support market depth following earnings announcements. Moreover, we find that firms which experience the largest increase in AT following the introduction of proximity hosting have lower bid ask spreads and higher depth following earnings announcements in the post-AT period.

Our study supports the hypothesis that AT and their increased activity in the market are associated with improvements in market liquidity, specifically its resiliency around the time of earnings announcements. Therefore, these results ultimately suggest that any regulatory action introduced to curtail this activity may have serious negative implications for liquidity and market participants.

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