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A. Can Inci
Bryant University

Deniz Ozenbas
Montclair State University, ozenbasd@montclair.edu

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Intraday volatility and the implementation of a closing call auction at Borsa Istanbul☆

A. Can Inci [a], Deniz Ozenbas [b,*]

[a] College of Business, Bryant University, United States
[b] Feliciano School of Business, Montclair State University, United States

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ABSTRACT

The implementation of a closing call auction on market quality and volatility is examined at Borsa Istanbul in Turkey. Using 5- and 15-minute intervals, we document the accentuated volatility after the open and before the close during the morning and afternoon sessions. We show that the implementation of a closing call decreases volatility accentuation just prior to the market close, and increases market quality. We also document the evolution of intraday volatility patterns at Borsa Istanbul using the longest to date high frequency dataset available, and show that volatility has been increasing over time, especially at the close.

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1. Introduction

Global trade and international investments have seen continual growth over recent decades owing to a reduction of frictions on capital flows across borders, a higher level of integration across markets, and the ease with which information can be accessed around the world. Investors have increased their allocations of funds to international markets, especially to emerging country financial markets.

In this global framework, trading activity in both developed and emerging country equity markets have become more susceptible to international news and events, and volatilities have increased. Recent studies such as Jawadi et al. (2015) find evidence of volatility spillovers from the U.S. to European markets and vice versa, supporting this contagion hypothesis. Nishimura et al. (2015) study return/volatility spillovers from China to Japan using high frequency data and report that China's large impact on Japanese stocks has become stronger in recent years, as the Chinese economy has gained importance. Singh et al. (2013) investigate how U.S. macroeconomic surprises affect stock markets in developed and emerging markets, and suggest that the degree of bilateral trade connectedness matters.

Overly accentuated volatility in stock markets is not a desirable characteristic as it may indicate periods of inefficiency, difficulties in price discovery, and potential disadvantages to some market participants. Consequently, stock exchange regulators try

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* Corresponding author.
E-mail addresses: ainci@bryant.edu (A.C. Inci), ozenbasd@mail.montclair.edu (D. Ozenbas).

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to develop ways to reduce volatility accentuation. One such mechanism is implementing opening, closing and/or intraday call auction mechanisms. According to Schwartz and Davis (2010), a call auction batches buy and sell orders together for simultaneous execution in a multilateral trade, at a single price, at a single point in time. As a result, the call auction determines a fair execution price that maximizes the number of shares traded based on these orders. Most developed country exchanges open and close their trading days with call auctions.[1] These auctions aim to alleviate the frantic trading behavior right after the open and before the close of trading. Thus, the volatility smile (the observed accentuated volatility pattern at the market open and close), which is a common characteristic of many stock exchanges, is expected to diminish with the help of these auction mechanisms.

This issue is particularly important for the exchanges of emerging markets, such as Borsa Istanbul (BIST). The large and open Turkish economy is a good representative of an emerging economy where a significant portion of the participants are non-domestic, and international news and economic events have a significant impact. In fact, Lagoarde-Segot and Lucey (2007) show that Israel and Turkey are the most promising markets in the Middle East and North Africa in terms of global capital market integration.

When Borsa Istanbul closes for the day, European equity markets are still trading and the U.S. markets recently opened due to time zone differences. We expect a significant impact of this in the Turkish stock market, manifested particularly as accentuated volatility around closing time. In fact, due to this and other related concerns, Borsa Istanbul implemented on March 1, 2012 a (closing) call auction that takes place soon after the closing of continuous trading for the day.

Borsa Istanbul is a pioneer among emerging markets in implementing a closing call auction. Emerging markets typically have lower stock market liquidity compared to developed country markets. Regulators worry that the implementation of a call auction would steal liquidity away from continuous trading, and hence exacerbate liquidity problems. Consequently, the success of BIST in implementing the closing call has important implications for other emerging markets as well. Additionally, BIST is distinctive as it employs two consecutive trading sessions during the day; the most current trading hours are an initial session between 9:35 am and 12:30 pm and a second session between 2:15 pm and 5:30 pm. Its two market openings and two closings per day gives us the opportunity to compare and contrast volatility patterns during both sessions, in addition to the impact of the closing call on volatility accentuation.

In this study, we examine several different issues about intraday volatility at Borsa Istanbul. First, using the longest-to-date high frequency data, we address the intraday volatility patterns at Borsa Istanbul. Second, we document the dynamic evolution of this pattern, and determine whether volatility has changed with time. Third, we examine whether the implementation of the closing auction by the exchange has been successful in reducing intraday volatility, especially near the close.

We find that the volatility pattern is different between the morning and the afternoon sessions. There is a volatility smirk during the morning session, i.e. there is accentuated volatility when the market opens but not prior to the midday close. On the other hand, we find a volatility smile in the afternoon session. There is accentuated volatility both when the market reopens and then again before the market closes for the day. This finding is consistent with academic literature, such as Ozenbas et al. (2010), that shows that the causes of volatility accentuation at the open and the close are different from one another. At the open, volatility is driven by the difficulty of translating new information into prices following an extended period of non-trading. At the close, it is mainly driven by traders who wish to complete their position transactions in an attempt to avoid possible adverse price fluctuations overnight. Since a call auction provides traders an additional chance to complete their orders before the overnight period, it should have a significant impact on reducing volatility. On the other hand, since there is no extended period of non-trading following the morning session, there is also no volatility accentuation at the mid-day close at Borsa Istanbul.

We find that the implementation of a closing call had a positive impact on reducing intraday volatility as we expected. A comparison of closing volatility before and after the implementation indicates a clear reduction in volatility accentuation. The conclusions are statistically significant and robust to several volatility measurements. Additionally, we show that overall intraday volatility at BIST has increased substantially between 1998 and 2014, which we expected due to globalization and the further integration of Turkish economy with world markets.

The rest of the paper is organized as follows. Section 1.1 provides an overview of related literature review. Section 2 describes the institutional details at Borsa Istanbul. Section 3 presents the data and empirical framework. Section 4 presents the discussion and interpretation of the empirical results. Section 5 presents robustness checks. Conclusion follows in Section 6.

1.1. Literature review

Intraday volatility patterns in equity markets have been investigated extensively, especially for developed countries, as such patterns provide information about the efficiency of equity markets. Stoll (2000) shows that arbitrary price fluctuations and short-term volatility lead to illiquidity, inefficiency, and ultimately the discouragement of investors from participating in financial markets. Hasbrouck and Schwartz (1988) and Bessembinder and Rath (2008) both find evidence of a link between accentuated volatility and heightened transaction costs.

Ozenbas et al. (2002) contrast intraday volatility patterns across several European and U.S. equities markets, and document the effect of a variety of rule changes implemented in these markets. Kissell (2014) compares the performance of different intraday volatility models applied to the U.S. stock exchanges. Ozenbas et al. (2010) and Hussain (2009) examine the quality of price discovery and find that large capitalization stocks lead smaller-cap stocks to their new equilibrium values in the U.S. and U.K. stock

[1] Some exchanges, such as Deutsche Borse, also use or have used in the past) intra-day call auctions as well.

markets. Earlier studies that document and explain intraday volatility patterns in various equity markets include Admati and Pfleiderer (1988), Foster and Viswanathan (1990) and Wood et al. (1985).[2]

Additionally, a separate time-series oriented literature that has started with the AutoRegressive Conditional Heteroskedasticity (ARCH) model of Engle (1982) has modeled intraday volatility directly, focusing on volatility that changes through time (volatility periodicity). For example, Andersen and Bollerslev (1997, 1998) discuss in detail how the volatility changes throughout the day (intraday periodicity) impact volatility estimates using a Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) framework.[3]

Accentuated opening volatility mainly indicates the difficulty market participants have in translating information accumulated overnight into trading prices, whereas accentuated volatility before the closing mainly indicates difficulty traders face when trying to complete their trades before the extended non-trading period overnight. The opening and closing procedures play a critical role in facilitating price discovery. Many exchanges including Nasdaq, New York Stock Exchange, London Stock Exchange and the Deutsche Börse use opening and closing call auctions to generate liquidity and to execute orders at one price. Several studies such as Barclay et al. (2008), Chang et al. (2008), and Schwartz and Davis (2010) show that the quality of continuous trading improves due to the implementation of call auctions.[4] Other research that investigates the use of call auctions at European exchanges includes Reboredo (2012) who studies Bolsa de Madrid.

While developed country equity markets have been investigated extensively there has been relatively limited research on intraday patterns at emerging country equity markets in general. Some such studies include Choe and Shin (1993), Tian and Guo (2007) and Tissaoui (2012) who study the Korean Stock Exchange, the Shanghai Stock Exchange, and the Tunisian Stock Exchange respectively. Bildik (2001) and Inci (2012) both survey the intraday return and volatility behavior at the Borsa Istanbul (and its predecessor Istanbul Stock Exchange) using different sample periods. Our paper is different from previous work; we examine the evolution of intraday volatility at BIST using the longest to date high frequency data, and also analyze the impact of the closing call auction implementation on intraday volatility accentuation, especially near the market close. As mentioned before, call auctions are not as common in emerging markets as they are in developed markets. Borsa Istanbul is a pioneer, and the success of a call auction implementation at an emerging market has important implications for other similar markets.

2. Trading hours and opening/closing procedures at the BIST

There are various instruments traded at Borsa Istanbul (BIST), such as ordinary shares (most of the intraday volume), ETFs, preferred shares, rights issues, and American Depositary Receipts (ADRs). There is no foreign ownership restriction, and foreign ownership has been between 60–70% of the float over the last decade. There are approximately 300 stocks traded at the BIST; however, the focus of this study is the 100 most actively traded stocks at the exchange.

Borsa Istanbul has two consecutive trading sessions, separated by a midday trading break. The trading hours have changed slightly over the last three decades. Currently the morning session starts at 9:35 am and concludes at 12:30 pm, and the afternoon session starts at 2:15 pm and concludes at 5:30 pm. The morning and the afternoon sessions both open with a call auction. The exchange has instituted the opening call in 2001.

The closing call auction has been introduced on March 1, 2012, and has four phases:

(1) Order transfer phase (3 min, 5:30–5:33 pm): All unmatched orders excluding quotation orders are transferred to be included in the closing session.
(2) Order collection phase (3 min, 5:33–5:36 pm): New orders are entered into the trading mechanism.
(3) Price determination and closing session transactions phase (2 min, 5:36–5:38 pm): The closing price is determined.
(4) Trades at the closing price/single price phase (2 min, 5:38–5:40 pm): New orders may be entered only for the securities traded in the closing session. These orders are traded in accordance with priority rules if matched with a pending order.

3. Data and methodology

The sample period is from January 5, 1998 through December 31, 2014 and includes tick by tick price data during the day for every trading day.[5] The 100 most liquid of the approximately 300 stocks are used for the investigation.[6] We use measurement intervals of 5 and 15 min.

[2] Other related studies include Schwartz and Francioni (2004), Madhavan et al. (1997), Ozenbas (2006), and Nguyen and Phengpis (2009).

[3] We discuss and employ the Andersen and Bollerslev (1997, 1998) methodology in Section 5 for robustness checks. Additionally, throughout the study we compare volatility patterns during the same period of the trading day to each other, for example the first 5-minute segment of the day across the days in the study period. This is again due to well-established patterns in intraday volatility.

[4] Call auctions have also received criticism. Hillion and Suominen (2004) develop a theoretical model to examine the relationship between closing price manipulation and the impact of a call auction. According to Camilleri and Green (2009), potential order imbalances may lead to even lower liquidity during the call auction. While call auction procedures certainly need to be designed carefully to avoid any manipulation or other adverse effects, call auctions are routinely utilized in the majority of developed country stock exchanges.

[5] Research involving intraday frequency data tends to use shorter sample periods due to the high volume of the data. For example, Belhaj et al. (2015) use an intraday data sample from October 2011 through September 2012, Tissaoui (2012) uses intraday data covering the period October 2008 to June 2009 and Bildik (2001) uses a limited sample period from 1996 through 1998. In this paper, the sample period is much longer than previous studies, and covers most of the policy changes in the microstructure of Borsa Istanbul. The proprietary data are not readily available and were provided by BIST.

[6] We also perform robustness checks using the most active 30 stocks.

We use several alternative metrics to calculate returns as presented below. Each metric refers to the periodic return per measurement interval (5 or 15 min) per trading day:

$$\text{Return}: \text{RET} = \left(Price_{end} - Price_{beg}\right)/Price_{beg} \tag{1}$$

$$\text{Log Return}: \text{LOG} = \log\left(Price_{end} \Big/ Price_{beg}\right) \tag{2}$$

$$\text{Absolute Price Difference}: \text{ABS} = \left|Price_{end} - Price_{beg}\right| \tag{3}$$

$$\text{Normalized Absolute Price Difference}: \text{NABS} = \left|\left(Price_{end} - Price_{beg}\right)/Price_{beg}\right| \tag{4}$$

$$\text{Difference between the High and the Low}: \text{MAXMIN} = \left(Price_{high} - Price_{low}\right) \tag{5}$$

$$\text{Normalized Maxmin}: \text{NMAXMIN} = \left(Price_{high} - Price_{low}\right)/\left((Price_{high} + Price_{low}\right)/2) \tag{6}$$

We then compute and report the standard deviations of these variables for each intra-day trading period separately (i.e. the first 5-minute segment of each day, second 5-minute segment of each day, etc.) during our sample days.

Previous studies have reported evolving patterns in stock markets over time. We split the entire sample into two equal parts to examine the dynamic evolution of volatility patterns over time: the early sample is from January 5, 1998 to July 1, 2006 and the recent sample is from July 1, 2006 to December 31, 2014. We also split the entire sampling period into three equal parts for robustness: the early sub-sample is from January 5, 1998 through May 1, 2003; the middle sub-sample is from May 1, 2003 through September 1, 2009; and the recent sub-sample is from September 1, 2009 to December 31, 2014. We contrast these early and recent sub-sample periods for any volatility pattern changes over the decades. Finally, we also examine volatility patterns before, during, and after the financial crisis period of 2007–2008.

We explore the presence of accentuated volatility during the opening and closing of the market in the morning and the afternoon sessions separately. The differences in intraday volatilities are presented with point estimates, statistical tests, and graphical plots.

The closing call auction was implemented on March 1, 2012. We use a 5-year sub-sample around the implementation date in order to measure its impact on intraday volatility. We focus especially on the last trading interval (5, 15 and 30 min) before the

Table 1
5-Minute intraday volatilities.
The sample period is from January 5, 1998 through December 31, 2014. Each variable represents a different return measurement: ABS is the absolute value of the difference between the final and the beginning price; LOG is the logarithmic return; RET is regular return; NABS is ABS divided by the ending price; MAXMIN is the difference between maximum and minimum values; and NMAXMIN is MAXMIN divided by the average of the final and beginning prices. We report the standard deviation of these variables, expressed in basis points.

5-Minute intervals	ABS	LOG	RET	NABS	MAXMIN	NMAXMIN
All	65.98	34.93	34.90	28.48	75.18	31.74
1st 5 min	133.15	85.81	85.50	68.75	138.05	71.53
2nd 5 min	71.58	42.26	42.58	33.56	79.73	36.58
3rd 5 min	68.93	36.52	36.50	28.62	76.01	30.18
4th 5 min	62.15	34.41	34.41	25.52	69.08	28.22
Mid-morning 5 min	43.24	21.97	21.95	16.38	53.68	20.55
4th to last 5 min bef. break	38.98	21.48	21.44	16.51	49.95	20.57
3rd to last 5 min bef. break	36.43	20.28	20.26	15.09	47.19	19.32
2nd to last 5 min bef. break	35.95	20.69	20.67	15.46	47.52	19.71
Last 5 min before break	38.29	22.23	22.23	16.57	50.37	20.41
1st 5 min after break	84.50	45.91	45.75	38.10	89.44	40.78
2nd 5 min after break	59.16	29.81	29.81	23.28	69.12	27.41
3rd 5 min after break	53.13	29.63	29.60	22.50	61.93	25.96
4th 5 min after break	60.05	28.30	28.30	21.72	66.97	25.78
Mid-afternoon 5 min	54.68	24.56	24.56	18.64	65.50	22.09
4th to last 5 min bef. close	56.75	25.00	24.99	18.02	66.57	21.01
3rd to last 5 min bef. close	54.53	24.97	24.95	18.09	64.99	21.33
2nd to last 5 min bef. close	51.83	24.22	24.22	16.97	63.12	21.20
Last 5 min before close	61.71	27.75	27.78	19.90	74.36	23.84

market closes for the day. We conjecture subsiding closing volatility following the implementation of the closing call auction. We find clear evidence supporting this conjecture.

4. Results and discussion

4.1. Intraday patterns

We first present the general patterns of intraday volatility at Borsa Istanbul using different volatility metrics. In Table 1 we present our findings using 5-min measurement intervals. We focus on the opening 20 min, a 5-minute interval at the middle of the session, and the last 20 min before the market closes for both the morning and afternoon sessions. In line with academic literature, our 1998–2014 sample reveals that highest volatilities are during the 5 min when the stock market opens in the morning, followed by the 5 min when the market reopens for the afternoon session and, finally, by the 5-minute volatility just before the market closes. We repeat the above analysis with 15-minute and 30-minute time intervals to check for robustness. The conclusions from Table 1 are firmly supported.[7]

Visual representations of the results in Table 1 are presented in Fig. 1. Fig. 1 is based on 5-minute return volatilities.[8] We can clearly observe the L-shaped pattern in the morning session and a 'muted' U-shape in the afternoon session.

Volatility changes over time. Reduction of trade barriers across borders and increasing relevance of international news and events have made emerging equity markets more susceptible to non-domestic developments, and thus, generally more volatile. To investigate the evolution of intraday volatility at Borsa Istanbul, we split our 1998–2014 sample into two sub-samples as Early and Recent; and also into three sub-samples as Early, Middle, and Recent. For brevity, we report a subset of the volatility measures in Table 2. Panel A reports the results for 5-minute intervals, while Panel B reports the results for 15-minute intervals. We consistently observe an increasing volatility pattern from the early sub-samples to the recent sub-samples in every panel. Panel C of Table 2 centers on the financial crisis of 2007–2008. The Turkish economy and its equity market were not as negatively impacted by the crisis as developed markets, however, the contagion effects of the crisis are evident in heightened volatility values in Panel D. Pre-crisis volatility measures are consistently lower than those during the crisis and post-crisis periods.

4.2. Implementation of the call auction

We next focus on the implementation of the closing call auction by Borsa Istanbul on March 1, 2012, and its impact on intraday volatility. We examine a 5-year sub-sample around the closing call auction, and compare the volatility pattern during the period before (May 1, 2009 to March 1, 2012) to the period after the implementation of the closing call (March 2, 2012 to December 31, 2014). Our main interest is finding out whether the closing call auction has led to a decrease in intraday volatility right before the market closes, and whether this decrease is statistically significant. We conjecture that the existence of a closing call auction should alleviate the intense pressure to trade before the market closes for the day as the closing call auction provides another opportunity to trade. Additionally, some market participants may decide to skip the period leading to the market close and choose to trade only during the closing call, taking advantage of its superior price discovery based on matching the highest number of buys and sells possible. Ultimately uncertainty, and hence volatility, before the closing of the market should decline with the introduction of the closing call auction.

In order to test our conjecture we follow a battery of tests. First, we calculate the closing period volatility separately before and after the implementation of the call auction, and test whether there is an economically and statistically significant change in it.[9] This tells us whether or not the implementation of the call was successful in lowering the volatility accentuation right before the market closes. These results are presented in Table 3. Second, we test how the closing period volatility changed in comparison to intra-day mid-session volatility. Towards this goal we calculate variance ratios where the numerator is the 5-minute closing period variance and the denominator is 1) mid-session 5-minute variance during the morning session and 2) mid-session 5-minute variance during the afternoon session.

$$\mathrm{VR} \equiv \frac{Var[r_t(close)]}{Var(r_t(mid))} \tag{7}$$

The formula provided above follows the methodology described in Hasbrouck and Schwartz (1988) and Campbell et al. (1997). A decline in the variance ratio following the implementation of the call auction would tell us that the closing period became less volatile compared to mid-session, hence showing the success of the call auction in decreasing closing period volatility accentuation compared to the rest of the day. These results are presented in Table 4 and Fig. 2.

Finally, in Section 5, we report additional robustness tests using the Two-Scales Realized Volatility model of Aït-Sahalia et al. (2011) and the GARCH model used in Andersen and Bollerslev (1998).

Table 3 reports the point estimates of the closing interval volatilities before and after the implementation of the closing call auction mechanism. Volatilities are consistently lower after the closing call auction according to all (5-, 15- and 30-min)

[7] 15-minute and 30-minute results are available upon request.
[8] Intraday volatility graphs for 15 and 30-minute intervals are very similar to 5-minute graphs and therefore not included for brevity.
[9] We use the regular return (RET), Eq. (1), from Section 3 to calculate volatilities.

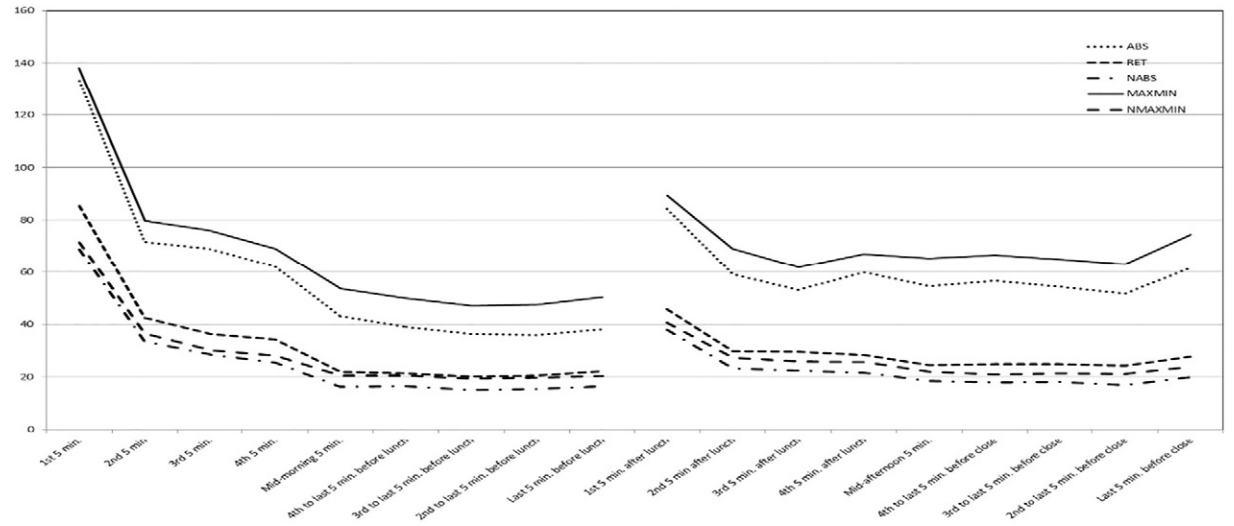

Fig. 1. 5-Minute trading period volatility. ABS is the absolute value of the difference between the final and the beginning price; LOG is the logarithmic return; RET is regular return; NABS is ABS divided by the ending price; MAXMIN is the difference between maximum and minimum values; and NMAXMIN is MAXMIN divided by the average of the final and beginning prices. The standard deviation of these variables, expressed in basis points, is on the vertical axis and the intraday time interval is on the horizontal axis.

measurement intervals. All the results, except the ones that are not in bold, confirm that intraday volatility has decreased after the implementation of the closing call auction at 1% statistical significance level.

In Table 3 we investigated how closing period volatility changed after the implementation of the closing call. In Table 4 and Fig. 2 we use variance ratios to examine how the closing period volatility compares to mid-session volatility both before and after the implementation of the call. If the ratio of closing period variance to mid-session period variance declines (i.e. if the variance ratio declines), it would provide further evidence that closing volatility accentuation declined due to the closing auction mechanism. We calculate the closing period-to-mid-session variance ratio for both the morning and the afternoon mid-

Table 2
Evolving intraday volatility.
ABS is the absolute value of the difference between the final and the beginning price; MAXMIN is the difference between maximum and minimum values. We report the standard deviation of these variables, expressed in basis points. Panel A is based on 5-minute periods and Panel B is based on 15-minute periods. The sample period is from January 5, 1998 through December 31, 2014, Early half sample is from January 5, 1998 through July 1, 2006 and Recent half sample is from July 1, 2006 through December 31, 2014. Finally, the entire sample is split into three parts: First (January 5, 1998 through May 1, 2003), Second (May 1, 2003 through September 1, 2009), and Third (September 1, 2009 through December 31, 2014). Panel C presents the results for three sub-samples: before, during, and after the financial crisis of 2007–2008.

Panel A. 5m	ABS	MAXMIN
Entire sample	65.98	75.18
Early	52.35	58.73
Recent	73.13	76.99
First	41.25	49.07
Second	68.42	72.41
Third	75.01	77.75
Panel B. 15m	ABS	MAXMIN
Entire sample	93.41	113.28
Early	67.16	81.30
Recent	106.99	114.25
First	56.68	71.20
Second	90.41	101.77
Third	112.08	120.09
Panel C. 5m	ABS	MAXMIN
Pre-crisis	53.86	59.88
Crisis	72.82	69.75
Post-crisis	73.13	76.24
15m	ABS	MAXMIN
Pre-crisis	68.69	82.33
Crisis	103.91	103.21
Post-crisis	109.34	118.17

Table 3
End-of-day volatilities before and after closing call auction.
Each variable represents a different return measurement: ABS is the absolute value of the difference between the final and the beginning price; LOG is the logarithmic return; RET is regular return; NABS is ABS divided by the ending price; MAXMIN is the difference between maximum and minimum values; and NMAXMIN is MAXMIN divided by the average of the final and beginning prices. We calculate the volatility of these variables. Closing period volatilities are reported before and after the implementation of the closing call auction mechanism.

Closing time volatilities					
ABS	Before	After	LOG	Before	After
5mRet	**85.94**	**57.59**	5mRet	**22.36**	**12.00**
15mRet	**124.76**	**111.33**	15mRet	**35.08**	**22.73**
30mRet	175.07	200.87	30mRet	**49.80**	**39.01**
RET	Before	After	NABS	Before	After
5mRet	**22.40**	**12.00**	5mRet	**16.10**	**7.82**
15mRet	**35.08**	**22.73**	15mRet	**23.92**	**15.04**
30mRet	**49.70**	**38.99**	30mRet	**34.12**	**26.98**
MAXMIN	Before	After	NMAXMIN	Before	After
5mRet	**79.69**	**60.43**	5mRet	**15.30**	**7.89**
15mRet	120.66	118.31	15mRet	**24.30**	**15.49**
30mRet	177.69	196.74	30mRet	**36.15**	**25.82**

Results that are at least at 5% statistical significance are denoted in bold.

sessions. We use 5-minute (Panel A) and 15-minute (Panel B) period returns to compute the variance ratios reported in Table 4. Most variance ratios in the table are larger than one prior to the implementation of the closing call, reflecting the accentuated closing volatility we reported earlier in Section 4.1. We find that the variance ratios decline consistently after the implementation of the closing call auction mechanism. While the ratio continues to be above one for some variance ratios, it is less than one for others. This shows there is no particular accentuation at the close compared to the rest of the day, and provides further support for the effectiveness of the closing call. We report our findings visually in Fig. 2 using the 5-minute period results reported in Panel A of Table 4.[10] The first two variance ratios use mid-morning volatilities, while the last two variance ratios use mid-afternoon volatilities as the denominator. The graph shows that the variance ratio (i.e. closing period variance) diminishes in comparison to both mid-morning session and mid-afternoon session variances following the call auction implementation.

5. Robustness checks

In Section 4 we document the statistically significant reduction in intraday volatility after the implementation of the closing auction by Borsa Istanbul. However, it is established in academic literature that intraday volatility analysis can be biased due to volatility periodicity as we discussed in Section 2. To make sure our results are not confounded by this, we perform two robustness checks. First, we utilize the Two Scales Realized Volatility model by Aït-Sahalia et al. (2011) in Section 5.1, and second, in Section 5.2, we perform the GARCH methodology application to high frequency data described in Andersen and Bollerslev (1997, 1998).

5.1. Two-scales realized volatility

Aït-Sahalia et al. (2011) argue that market microstructure noise becomes a dominant consideration for the volatility estimation of asset prices sampled at high frequencies. The authors show that combining two time scales works in diminishing this problem when the noise exhibits time series dependence, and propose the modeling approach Two Scales Realized Volatility (TSRV).[11]

The model is for volatility estimation using ultra-high frequency datasets, where time increments in the data are measured in seconds rather than minutes or hours. Our intraday data are perfect for this model. As shown in Aït-Sahalia et al. (2011) the TSRV model is robust to data collection, cleaning procedures, and outliers. We apply their model with a focus on the closing period volatility, and statistically determine whether there is indeed a reduction after the closing call auction implementation as we have documented in Section 4.

Estimation of volatility using Aït-Sahalia et al. (2011) TSRV model involves the evaluation of quadratic variation at two different frequencies, averaging the results over the entire sample period, and taking a suitable linear combination of the result at the two frequencies. These steps provide a consistent and asymptotically unbiased estimator. The rationale behind the TSRV estimator is to partition the intraday frequency data into 5-min grids. Volatility estimates are obtained from series created by starting from the first observation, then by starting from the second observation, etc. Finally the average of these volatility estimates is computed. This subsampling and averaging together gives rise to the TSRV.

[10] Figures using 15 minute results are similar to 5 minute results, and not included for brevity.
[11] Aït-Sahalia et al. (2011) also examine a multi-stage realized volatility model but they have not reported substantial benefits beyond TSRV.

Table 4
Variance ratios before and after closing call auction.
Each variable represents a different return measurement: ABS is the absolute value of the difference between the final and the beginning price; LOG is the logarithmic return; RET is regular return; NABS is ABS divided by the ending price; MAXMIN is the difference between maximum and minimum values; and NMAXMIN is MAXMIN divided by the average of the final and beginning prices. We calculate the variance of these variables. Variance ratios use the closing period variance in the numerator and either mid-morning or mid-afternoon variance in the denominator. 5-minute (Panel A) and 15-minute (Panel B) period returns are used for variance measurements. The variance ratios before and after the implementation of the closing Call Auction Mechanism (CAM) are reported. ***, **, and * represent the statistical difference of the numerator (closing variance) with respect to the denominator (mid-morning or mid-afternoon variance) at 1%, 5%, or 10% level.

	Mid-morning		Mid-afternoon	
	Before CAM	After CAM	Before CAM	After CAM
Panel A. 5-minute period returns				
ABS	1.73***	0.97	1.36***	0.91**
LOG	1.62***	1.09**	1.25***	1.01
RET	1.62***	1.09**	1.25***	1.01
NABS	1.75***	0.98	1.25***	0.91**
MAXMIN	1.45***	1.00	1.20***	0.93*
NMAXMIN	1.47***	0.99	1.08**	0.90***
Panel B. 15-minute period returns				
ABS	1.45***	1.30***	1.26***	0.95
LOG	1.49***	1.31***	1.25***	1.05
RET	1.49***	1.31***	1.25***	1.04
NABS	1.51***	1.32***	1.23***	0.95
MAXMIN	1.37***	1.26***	1.19***	0.96
NMAXMIN	1.43***	1.24***	1.16***	0.92**

Aït-Sahalia et al. (2011) recommend that the sampling frequency of the time series data to range from 5 min to 30 min. We focus on 5 minute price changes in our data.

The results are presented in Table 5. All the volatility metrics calculated following the TSRV model consistently indicate that the implementation of the closing auction has been successful. Volatility subsides, and this finding is statistically significant. We see concrete evidence of it whether we focus on the top 100 stocks (Panel A) or the top 30 stocks (Panel B) at Borsa Istanbul. In each panel, we present two sets of before-and-after subsamples on which the volatility measures are based. In the first set, the 5-year period around the date of the closing auction implementation is simply split into two around the event date. In the second set, the 5-year period is split into three and the earliest subsample and the most recent subsample are used to see the impact of the closing auction implementation. By extracting out the middle sub-sample, we focus on the stabilized impact of the policy implementation. The F-test of the equality of the volatilities and the associated *p*-values indicate the statistically significant reduction in volatility in most of the comparisons (results that are at least at 5% statistical significance are denoted in bold).

5.2. Intraday volatility modeling - GARCH

Numerous studies in academic literature use Autoregressive Conditional Heteroscedasticity (ARCH) and Generalized Autoregressive Conditional Heteroscedasticity (GARCH), originally developed by Engle (1982) and Bollerslev (1986) respectively,

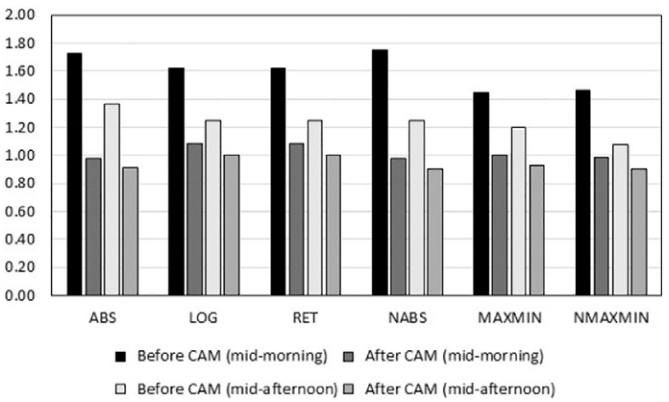

Fig. 2. Variance ratios from 5-minute period returns before and after the implementation of the closing auction mechanism (CAM). Each variable represents a different return measurement: ABS is the absolute value of the difference between the final and the beginning price; LOG is the logarithmic return; RET is regular return; NABS is ABS divided by the ending price; MAXMIN is the difference between maximum and minimum values; and NMAXMIN is MAXMIN divided by the average of the final and beginning prices. The two bars on the left (right) for each return metric represent the variance ratios before and after the implementation of the closing call for the morning (afternoon) sessions.

Table 5
Two-scales realized volatilities before and after closing call auction.
Panel A presents volatilities based on the most active 100 stocks at Borsa Istanbul, while Panel B is based on the top 30 most active stocks at the exchange. First set of volatilities in each panel are the volatilities before the start of the closing auction from May 1, 2009 to March 2, 2012 and after the start of the closing auction from March 2, 2012 to December 31, 2014. In the second set of volatilities in each panel the 5 year period around the implementation of the closing auction is split into three subsamples. The subsample immediately around the policy implementation date is extracted out with 'Before' representing May 1, 2009 to March 10, 2011 and 'After' representing February 20, 2013 to December 31, 2014. Each volatility metric is computed following the two-scales realized volatility method of Aït-Sahalia et al. (2011). After each volatility metric the F-statistic and the *p*-value for the equality of volatilities before and after the policy implementation are reported. ABS is the absolute value of the difference between the final and the beginning price; LOG is the logarithmic return; RET is regular return; NABS is ABS divided by the ending price; MAXMIN is the difference between maximum and minimum values; and NMAXMIN is MAXMIN divided by the average of the final and beginning prices. Volatilities are calculated based on these return metrics.

	ABS	F-val (*p*-val)	LOG	F-val (*p*-val)	RET	F-val (*p*-val)	NABS	F-val (*p*-val)	MAXMIN	F-val (*p*-val)	NMAXMIN	F-val (*p*-val)
Panel A	Top 100 stocks											
Before	**68.02**	1.09	**19.23**	2.16	**19.25**	2.16	**12.74**	2.09	67.87	1.04	**13.17**	2.27
After	**65.01**	(0.009)	**13.10**	(0.000)	**13.10**	(0.000)	**8.80**	(0.000)	65.45	(0.113)	**8.75**	(0.000)
Before	**70.28**	1.16	**19.46**	1.95	**19.47**	1.95	**12.51**	1.79	65.31	1.07	**12.25**	2.04
After	**65.22**	(0.000)	**13.93**	(0.000)	**13.93**	(0.000)	**9.34**	(0.000)	63.05	(0.075)	**8.58**	(0.000)
Panel B	Top 30 Stocks											
Before	96.69	1.06	**21.72**	1.97	**21.74**	1.96	**14.22**	1.7	**98.14**	1.08	**14.87**	2.17
After	94.18	(0.092)	**15.48**	(0.000)	**15.51**	(0.000)	**10.92**	(0.000)	**94.53**	(0.027)	**10.09**	(0.000)
Before	**96.86**	1.08	**22.07**	1.99	**22.07**	1.99	**14.08**	1.83	**94.82**	1.09	**13.90**	2.09
After	**93.15**	(0.049)	**15.63**	(0.000)	**15.63**	(0.000)	**10.41**	(0.000)	**90.74**	(0.033)	**9.63**	(0.000)

Results that are at least at 5% statistical significance are denoted in bold.

and other related models to explain and predict intraday volatility dynamics in financial market asset returns. Andersen and Bollerslev (1997, 1998) explain in detail the application of GARCH methodology to intraday, high frequency equity market data. To check for the robustness of our findings described in Section 4, we also adapt this approach into our analysis. We examine intraday volatility before and after the implementation of the closing call auction, and investigate further whether our previous conclusion of reduced closing period volatility holds according to this modeling approach as well.

We focus on the 5-min period before the close of the market,[12] and calculate the returns both through log differences (LOG) and also regular return (RET) calculations that were described in Section 4. The formal definition of GARCH(1, 1) model, following Andersen and Bollerslev (1997, 1998), to estimate variance of returns is:

$$r_t = \sigma_t e_t \tag{8}$$

and

$$\sigma_t^{\,2} = \Phi + \alpha[\sigma_{t-1} e_{t-1}]^2 + \beta \sigma_{t-1}^{\,2} \tag{9}$$

where e_t is independent and identically distributed with mean zero and variance one, $\sigma_t 2$ is the conditional variance of the returns based on the information up through time $t - 1$. Estimated volatility, $\hat{S}$, is the square root of the conditional variance estimation $\sigma_t 2$. This is the intraday volatility based on the GARCH(1, 1) model for the 5-min before the close of the market for the trading day.

We compare the estimated volatilities before and after the implementation of the closing auction mechanism. We consider two sets of sub-samples for the volatility comparison. In the first set, we split the 5-year period around the March 2, 2012 implementation date into two parts: May 1, 2009 through March 2, 2012 as the 'Early' sub-sample and March 2, 2012 through December 31, 2014 as the 'Recent' sub-sample. In the second set, we split the 5-year period around the March 2, 2012 implementation date into three parts and focus on the earliest sub-sample from May 1, 2009 through March 10, 2011 ('Early') and the most recent sub-sample from February 20, 2013 through December 31, 2014 ('Recent').

Table 6 presents the results of the analysis. Panel A presents the GARCH(1, 1) model estimates, along with the standard errors of those estimates. Panel B presents the estimated volatility results in basis points before and after the implementation of the closing call auction. Whether we focus on the standard versus the log returns; or whether we look at two sub-samples or the earliest and most recent of the three sub-samples, we can clearly detect in Panel B that intraday volatility diminishes before the close of the market after the implementation of the closing auction. The statistical verification of the reduction in volatility is provided in Panel C. The differences in the volatility values and the standard errors of the differences (all in basis points) along with the *t*-statistics of the difference (based on the Satterthwaite method) indicate that the reduction in intraday volatility in the final 5-min of the trading day is statistically significant at 1 % level according to the GARCH(1, 1) estimations for all alternative evaluations.

[12] We employed the GARCH(1, 1) model for 15-minute and 30-minute periods before the close of the market as well, and obtained similar conclusions. These analyses and the results are not reported here for brevity but are available upon request.

Table 6
GARCH(1, 1) 5-minute intraday volatility estimates.
Intraday Volatility analyses conducted using the GARCH(1, 1) model are presented in the table. The 5-year sample period around the implementation of the closing call auction is split in two ways: In the 2 sub-sample split, May 1, 2009 through March 2, 2012 and March 2, 2012 through December 31, 2014 are the 'early' and 'recent' sub-samples. In the 3-sub-sample split, May 1, 2009 through March 10, 2011 and February 20, 2013 through December 31, 2014 are the 'early' and 'recent' sub-samples. LOG is the logarithmic return; RET is regular return. Panel A presents the GARCH(1, 1) model estimates and the standard errors. Panel B presents the 5-minute volatility estimations from the GARCH(1, 1) model along with standard deviations (in basis points) before and after the implementation of closing auction. Panel C provides the statistical significance of the volatility comparisons before and after the closing auction.

	2 Sub-samples				3 Sub-samples			
	LOG		RET		LOG		RET	
	Early	Recent	Early	Recent	Early	Recent	Early	Recent
Panel A. GARCH(1, 1) model estimates								
Φ (10E-7)	18.443	4.7155	18.457	4.7166	21.966	5.1412	21.987	5.1409
(std.err)	(1.3845)	(0.2594)	(1.3862)	(0.2592)	(1.9569)	(0.4046)	(1.9588)	(0.4044)
α	0.4760	0.6113	0.4761	0.6114	0.3921	0.5910	0.3918	0.5910
(std.err)	(0.0422)	(0.0432)	(0.0423)	(0.0432)	(0.0436)	(0.0506)	(0.0436)	(0.0506)
β	0.0384	0.1171	0.0386	0.1170	0.0232	0.1475	0.0234	0.1475
(std.err)	(0.0444)	(0.0286)	(0.0444)	(0.0286)	(0.0622)	(0.0380)	(0.0622)	(0.0379)
Panel B. Estimated volatility ($\hat{S}$) from GARCH(1, 1) – all in basis points (bp):								
$\hat{S}$	18.339	11.826	18.349	11.826	18.76	12.611	18.767	12.611
std.dev($\hat{S}$)	6.222	5.696	6.232	5.697	5.002	5.982	4.999	5.983
Panel C. Equality of $\hat{S}$ early vs. recent:								
$\Delta(\hat{S})$ (bp)	6.51		6.52		6.15		6.16	
std.err (bp)	0.14		0.14		0.16		0.16	
t-Statistic:	45.56		45.58		38.15		38.20	

Overall, our robustness analyses following both the TSRV methodology of Aït-Sahalia et al. (2011) and the GARCH(1, 1) model based on Andersen and Bollerslev (1998) confirm our earlier results in Section 4. The implementation of the closing call auction has been successful in reducing intraday volatility before the close of the BIST Exchange for the trading day.

6. Conclusion

A closing call auction can be an important tool for reducing intraday volatility and enhancing market efficiency and price discovery, especially in emerging country equity markets that typically have lower liquidity and higher volatility compared to their developed country peers. In this paper, we examine both the intra-day volatility patterns and the implementation of a closing call auction in an important emerging country stock market: Turkey's Borsa Istanbul.

Borsa Istanbul employs two consecutive trading sessions during the day, and as a large and significant emerging market, the trading patterns there are significantly impacted by global developments. Using the longest high frequency time series data available to date, we verify that intraday volatility in the Turkish stock exchange exhibits a 'smirk' in the morning session and a 'smile' in the afternoon session. During the morning session there is volatility accentuation at the open but there is no volatility accentuation at the close, hence we call it a smirk. In the afternoon session, there is volatility accentuation both at the open and the close, hence the smile. This finding is consistent with academic literature that shows that the reasons behind opening and closing period volatilities are different. Volatility at the open is mainly driven by price discovery errors that arise when accumulated information is being translated into prices following an extended period of non-trading. On the other hand, volatility at the close is mainly driven by traders rushing to complete their orders before an extended period of non-trading such as an overnight period. The risk of carrying an incomplete position overnight is particularly significant in Turkey since, due to time zone differences, trading continues in European and North American exchanges for several hours after the market closes in Turkey.

We examine the evolution of intraday volatility over the 1998–2014 period, and verify that volatility accentuation becomes more pronounced in the second half of our sample period. The regulatory framework in Turkey that reduced restrictions and supported full integration with global economy has also led to the increased impact of global news and events on Borsa Istanbul. This is manifest in higher levels of accentuated volatility, especially during the afternoon trading session when there is more overlap with developed country markets. We argue that this trend was what mobilized the exchange to implement a closing call auction in March 2012. Opening and closing call auctions, while widely used in developed country markets such as NASDAQ, NYSE, London Stock Exchange, and Deutsche Börse, are relatively less common tools for developing country markets. We show that the implementation of the call auction was a success at Borsa Istanbul. Using a detailed examination that centers around the 5-year period around this rule change, we find that intraday volatility near the close has significantly declined following the implementation of the closing call.

The presence of a closing call auction reduces volatility accentuation and increases market efficiency. As the confidence of market participants are boosted up, both domestic and international capital flows into the equity market would increase. The success of the closing auction mechanism at Borsa Istanbul can be a guide for other emerging stock exchanges for the promotion of an attractive and efficient investment environment. There are also some initiatives in developed country equity markets, such as the London Stock Exchange, to add intraday call auction sessions to supplement continuous trading. The results of this paper

are encouraging for these initiatives as well, as we provide further proof that call auctions can be useful in different trading environments. The findings of the paper are also important for risk management policies. Strategies looking for reduced volatility and better price discovery thrive with the closing call auction mechanism, while counter strategies become less profitable.

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