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# The influence of call auction algorithm rules on market efficiency ☆

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**Abstract**

This paper analyzes the impact of call auction design on the efficiency of auction prices. On 18 March 2002, the Australian Stock Exchange introduced a new matching algorithm and began to disseminate indicative auction prices and indicative surplus volumes. The results indicate that these changes significantly enhanced call auction price efficiency, especially in active stocks at the open. The efficiency gains are greatest when call auction prices are set after considering order imbalances and market pressure. Consistent with previous research, the results also indicate significant noise in pre-open prices. As the market open approaches, this noise diminishes and price discovery occurs.


*JEL classification:* G14

*Keywords:* Call auction; Price efficiency; Matching algorithm; Auction design

## 1. Introduction

The single price batch auction, widely referred to in the literature as a call auction, is a trading mechanism that has increased in popularity in recent years. Markets around the world have incorporated, or are planning to incorporate, this trading mechanism into their

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market design.[1] A number of factors contributed to this increase in call auction use. First, at the market open, a call auction may facilitate order entry, reduce volatility and enhance price discovery after a significant non-trading period (Economides and Schwartz, 1995). Second, at the market close, there is significant demand to trade at closing prices (Cushing and Madhavan, 2000). This concentration of demand at the close may impose significant stress on a trading mechanism. Madhavan (1992) argues that, at these times of market stress, a call auction is able to determine prices more efficiently than a continuous auction.

Where already adopted, evidence indicates that call auctions attract a substantial proportion of daily trading activity. Madhavan and Panchapagesan (2000) find trading at the open on the New York Stock Exchange (NYSE) accounts for around 10 percent of average daily trade value. Biais et al. (1999) find trading at the open on the Paris Bourse also accounts for approximately 10 percent of average daily trade value.

The Australian Stock Exchange (ASX) was one of the first markets to introduce a closing call auction in 1997. Since its introduction, the design of the ASX call auction has undergone a number of changes—the most recent of which occurred on 18 March 2002. This change was motivated by excessive volatility experienced at the close of the market on quarter-end days. On these days, a number of factors combine to create excess demand and high price volatility. These factors include trading by passive index funds that wish to replicate index returns, index arbitrage activity, overseas institutional investors, and the use of performance benchmarking techniques based on closing prices.

The ASX call auction design had a number of limitations that contributed to excessive quarter-end and month-end volatility, including the level of transparency and the design of the matching algorithm. These limitations were addressed through a number of significant changes to call auction design. These changes were introduced on 18 March 2002 and apply at all times a call auction is held. Specifically, transparency in the call auction was increased through the dissemination of an indicative auction price (IAP) and a surplus volume (SV) indication. The matching algorithm used to determine the auction price was also altered. This study examines the impact of the 18 March 2002 changes to ASX call auction design on price efficiency.

While there are a number of papers examining the difference between price efficiency in continuous and call markets, there are no published papers that have empirically examined the impact of a change in call auction design on price efficiency.[2] This lack of empirical research is addressed by examining a natural experiment offered by the change in call auction design on the ASX. The results presented here demonstrate that call auction design is important and influences price efficiency. The results are instructive for market regulators and exchanges considering the introduction of, or changes to, call auctions.

The paper is structured as follows: Section 2 reviews the relevant literature, Section 3 discusses ASX institutional detail, and Sections 4 and 5 present the hypotheses and data. Sections 6 to 9 report the results, and Section 10 concludes.

[1]The London Stock Exchange introduced a fully automated opening call auction in 1997 and a closing call auction in 2000. The Toronto Stock Exchange introduced a closing call auction in 2004 and the NASDAQ introduced an opening and closing call auction in 2004.

[2]Papers that examine price efficiency in the call and continuous auction are examined in Section 2. Other relevant papers include Muscarella and Piwowar (2001) and Lauterbach (2001).

## 2. Review of literature

A growing volume of academic literature examines the call auction mechanism and its impact on price efficiency. While this literature typically compares a call auction mechanism to a continuous auction, it says little about call auction design. Pagano and Schwartz (2003) suggest that a call auction mechanism may reduce trading costs and enhance price discovery. These trading costs include bid ask spreads, market impact costs and costs of adverse selection. A reduction in trading costs is achieved through the temporal consolidation of order flow and execution of orders at a single price (e.g., Domowitz and Madhavan, 2001; Economides and Schwartz, 1995). In addition, Madhavan (1992) provides justification for the use of a call auction, rather than a continuous auction, at times of market stress. Madhavan (1992) also demonstrates that a call auction mechanism can operate where a continuous auction fails, that is, where information asymmetry is excessive and price volatility is high. Hillion and Suominen (2004) develop a theoretical model which demonstrates that it is more difficult to manipulate the closing price when a call auction is used. However, a number of factors may impair the effectiveness of a call auction. These include insufficient order flow and significant order imbalances. Madhavan and Panchapagesan (2000) suggest these factors result in high trading costs and prices that are unrepresentative of a stock's true value. This implies that call auction design is important. A call auction design which is unable to attract sufficient order flow and/or is unable to consider order imbalances may have a direct impact on call auction price efficiency.

The matching algorithm and the level of transparency are two important design features in a call auction that may influence price efficiency. McCormick (2001) analyzes the algorithm used on the Arizona Stock Exchange. He concludes that volume maximization may not be appropriate as only around five percent of orders entered in the pre-open execute. This process frustrates traders and causes the failure of the call auction to discover meaningful prices (McCormick, 2001). Transparency in call auction design is discussed in a number of studies (e.g., Economides and Schwartz, 1995; Pagano and Röell, 1996). Domowitz and Madhavan (2001) discuss the impact of transparency on call auction price efficiency. They argue that inadequate transparency in a call auction may attract informed traders. This may reduce liquidity and increase price volatility. However, they also argue that excessive transparency may reduce call auction efficiency as traders fear that placing orders will reveal their information. This suggests a balance needs to be achieved that provides enough transparency to encourage liquidity while protecting traders who fear their orders may be exploited.

Strategic trading in the call auction has been the subject of much analysis. Biais et al. (1999) examine the pre-open period on the Paris Bourse. They suggest that noise in indicative call auction prices may be due to strategic trading as call auction design on the Paris Bourse permits investors to enter, cancel and amend orders at any time throughout the pre-open period without penalty.

Economic theory examining strategic trading in the call auction provides further insights. Medrano and Vives (2001) suggest informed traders may trade strategically over the pre-open period as they have an incentive to keep the information in prices low. Rustichini et al. (1994) examine a call auction mechanism in a theoretical setting and suggest traders misrepresent their true supply/demand to influence prices in their favor.

Therefore, strategic trading behavior may add noise to the price discovery process and reduce pre-open price efficiency.

The literature suggests that call auction design is important but says little about any optimal design or the impact of a change in call auction design. This analysis extends the literature by empirically examining the impact of a change in call auction design on price efficiency.

## 3. Institutional details

The ASX operates a fully automated order-driven trading system, known as the *Stock Exchange Automated Trading System (SEATS)*. Limit and market orders are executed in a continuous auction between 10:00 and 16:00 on the basis of price then time priority.

A call auction is used to open and close the market each day. The opening call auction occurs in five batches of stocks between 10:00 and 10:09. Each batch opens randomly up to $\pm 15$ seconds from its designated opening time. The closing call auction occurs randomly between 16:05 and 16:06, except on quarter-end days and other month-end days where it occurs randomly between 16:10 and 16:11. Each call auction is preceded by a pre-open period during which time orders may be entered, amended and cancelled without restriction. The morning pre-open operates between 7:00 and the random open, while the afternoon pre-open period (pre-close) operates between 16:00 and the random close. Undisclosed orders are available where all or part of the order volume may be hidden from the market. The hidden part of the order must always have a value greater than 200,000 Australian dollars (AUD) or the order volume will be disclosed to the market. The hidden part of the order is always executed before the disclosed portion, and price then time priority applies. No official market-makers/liquidity providers operate on the ASX at any time.

The ASX introduced a number of preliminary changes to the design of the closing call auction prior to 18 March 2002, to reduce volatility on quarter-end days. These included prohibiting the entry, and restricting the amendment of, undisclosed orders in the pre-close from 25 June 2001, extending the pre-close period to fifteen minutes on the last day of the March and June quarters 2001, abandoning the closing call auction on 28 September 2001, and indefinitely extending the pre-close from five to ten minutes on all month-end days from 30 November 2001. The most significant action aimed at reducing volatility on quarter-end days was a decision made by the Sydney Futures Exchange (SFE), in consultation with the ASX, on 28 September 2001, to decouple SPI 200™ Futures Contract settlement prices from closing prices (a temporary SPI 200™ Futures Contract settlement price arrangement was in place for 28 September 2001). Since 31 December 2001 the SPI 200™ Futures Contract settlement price is based on a Special Opening Quotation calculated using opening call auction prices. This change should reduce index arbitrage activity at the close, and as a result, reduce closing price volatility.

The final changes to ASX call auction design were introduced on 18 March 2002. These changes address two limitations identified in ASX call auction design: the matching algorithm and the level of pre-trade transparency. Although trading on quarter-end days drove these changes, they apply at all times a call auction is held.

The previous algorithm determined a single weighted average price based on the price and volume of the last two orders matched in the order book. This algorithm had a number of limitations. Many orders failed to execute even though they were entered at prices better than the call auction price set, and the auction price could be manipulated. Furthermore, traders had an incentive to enter orders at unrepresentative prices, which ensured execution as orders are matched in price then time priority. In addition, the weighted average price calculation would ensure a trade price better than the unrepresentative price.

While transparency of the order book during the pre-open and pre-close period remained high, it was limited by the presence of undisclosed orders. Undisclosed order restrictions, introduced in the pre-close on 25 June 2001, increased pre-close transparency. However, as undisclosed orders could still be carried forward into the pre-close from the continuous trading session, traders were still unable to determine closing prices with certainty.

The new call auction eliminates many of the limitations of the previous call auction design. It reduces the impact of unrepresentative orders and the problem of unfilled interest at prices better than the auction price. This is achieved through a relatively simple price-setting process that follows four principles. Principle 1 maximizes trading volume. If there is more than one price where trading volume is maximized, the algorithm then considers Principle 2. Principle 2 considers the range of prices where trading volume is maximized and selects the price within this range at which order imbalances are minimized. If there is more than one price where order imbalances are minimized, the algorithm then considers Principle 3. If all of the prices that exhibit the minimum order imbalance attract buy (sell) surplus volume, Principle 3 sets the highest (lowest) of these prices as the opening price. If both buy and sell surplus volumes are present at these prices, then Principle 4 is considered. Principle 4 sets an auction price based on a reference price. The reference price is the previous closing price (or the last traded price of the day for the closing call auction). The two prices where buy and sell pressure change are selected and are compared to the reference price. If the reference price is at or above the higher of these two prices then the highest price is the auction price; if the reference price is at or below the lower of these two prices then the lowest price is the auction price. If the reference price lies between these two prices then the reference price is the auction price. Detailed examples of the price setting process, based on the new and old algorithms, are presented in Appendix A.

The implementation of the new algorithm also allowed for a change in the level of pre-trade transparency. After 18 March 2002 the ASX began to disseminate an IAP and SV indication in real time throughout the pre-open and pre-close period. Hence, traders know the indicative opening price at any time with certainty, are no longer restricted by the presence of undisclosed orders, and are able to identify any order imbalance present at that price.

## 4. Hypotheses

Intuitively, one would expect increases in pre-trade transparency to allow information to be impounded into prices more quickly, therefore enhancing price discovery and liquidity (e.g., Flood et al., 1999). However, the existing literature on the relationship between pre-trade transparency, liquidity and price discovery is far from conclusive.

In an experimental markets framework, Flood et al. (1999) find that increased transparency reduces search costs, therefore reducing uncertainty and enhancing liquidity. As a result, dealers will use less aggressive price adjustments, therefore slowing price discovery. In contrast, Bloomfield and O'Hara (1999) report that increased transparency heightens informational efficiency, giving rise to more rapid price discovery. Furthermore, in a natural experiment examining a change in the level of order book disclosure on the

Toronto Stock Exchange (TSX), Madhavan et al. (2001) find that increased transparency has a detrimental effect on liquidity.

The difference in these results may be driven in part by the characteristics of the stocks being traded and the traders trading them. Informed traders will prefer to trade in an opaque market where they can retain their informational advantage, while uninformed traders will prefer to trade in a highly transparent market. In addition, the impact of a change in transparency is likely to have a bigger impact on stocks with larger information asymmetries. Nathan (1996) and Brennan and Subrahmanyam (1996) suggest that less active stocks exhibit higher information asymmetries. For this reason active stocks and less active stocks are considered separately.

### *4.1. Active stocks*

The new matching algorithm should contribute to enhanced call auction price efficiency in active stocks at both the open and close. This is achieved through the new algorithm's capacity to set a price that both maximizes volume and minimizes supply and demand imbalances. A matching algorithm that maximizes trading volume should reduce the price impact of any single order as the call auction price is set where the majority of orders will trade. In addition, the propensity of traders in active stocks to engage in gaming behavior over the pre-open increases the importance of an algorithm design that is able to reduce the impact of large and unrepresentative orders. With the previous algorithm, a large order entered in the order book at an unrepresentative price had the capacity to move the call auction price significantly, increasing adverse selection costs.[3] An algorithm that considers supply and demand imbalances should also enhance price efficiency by allowing prices to adjust in the direction of these imbalances. This was not possible with the previous matching algorithm.[4] As a result, the design of the new matching algorithm should enhance price efficiency.

Madhavan (1992) argues that increased transparency will increase the visibility of noise. At the open, unrestricted order entry, amendment and cancellation, may increase information asymmetry after a significant non-trading period. This combined with possible strategic trading in active stocks may create noise in pre-open prices. Increased transparency may reveal this noise and this may discourage traders from entering informative orders. However, strategic traders risk trading near the random opening and should withdraw as the open approaches. As a result, noise should diminish near the open as informative orders intended to trade in the opening call auction dominate order entry and facilitate price discovery.

A significant increase in interest at the close is expected in active stocks. Many traders, particularly passive index fund traders, attempt to trade in the closing auction to achieve the closing price (Cushing and Madhavan, 2000). In addition, there is less motivation for strategic trading following a period of significant price discovery. As a result, the

[3]The ASX has detected a number of instances where large orders have influenced call auction prices. ASX Participant Circular, No. 568/02, "Disciplinary Matters," documents trading at the closing call auction on 29 June 2001. This day is excluded from the sample. On this quarter-end day, large orders were entered at unrepresentative prices across a number of stocks in the All Ordinaries Index. These orders significantly increased closing call auction prices and increased the closing value of the S&P/ASX 200 Index by 45.7 points or 1.3 percent.

[4]Appendix A provides an example of how the new algorithm, after considering order imbalances, determines a price substantially different from the price determined by the previous algorithm.

motivation for trading and the characteristics of traders at the closing call auction are different from the open. Enhanced transparency should be valued by these uninformed traders (transparency is high at the close due to both the IAP and SV indication and the restrictions on undisclosed orders), and they will be more willing to trade at the close as a result. This should translate into more efficient call auction prices as the new matching algorithm maximizes trade volumes and considers supply and demand imbalances.

**Hypothesis 1:** The change in call auction design will increase price efficiency in active stocks at the opening and closing call auction.

### *4.2. Less active stocks*

Previous research indicates that call auctions may reduce trading costs (e.g., Domowitz and Madhavan, 2001; Economides and Schwartz, 1995). These trading costs are higher in less active stocks. Therefore, the benefits of call auction trading should be especially apparent in less active stocks. Consistent with this research, many large world exchanges, such as Euronext, trade less active market segments only by call auctions.

However, problems with the previous ASX call auction design, as explained in Section 3, may negatively impact call auction trading in less active stocks. For example, a large order may be entered at an unrepresentative price to gain execution priority. This may have a significant impact on the call auction price, as there may be insufficient liquidity in the order book to offset the impact of this large order. The ability of large orders to impact call auction prices may also increase the probability of successful call auction price manipulation. The new call auction algorithm may assist in reducing these problems by setting a price that maximizes trade volume. If one price does not exhibit maximum trade volume, the algorithm then considers order imbalances and market pressure. This should reduce the impact of a large order on the call auction price.

Pagano and Roëll (1996) argue that the higher the level of pre-trade transparency, the easier it is to detect informed traders and their strategies, and the less successful informed traders are at taking advantage of uninformed traders. Therefore, increased transparency should enhance order flow in stocks where the likelihood of trading with an informed trader is high (i.e., less active stocks). Increased order flow, in turn, may further assist in reducing the impact of a large order on call auction prices.

As a result, the new call auction algorithm and increased transparency should significantly enhance order volumes and price efficiency in less active stocks at both the open and close. Therefore, Hypothesis 2 states:

**Hypothesis 2:** The change in call auction design will increase price efficiency in less active stocks at the opening and closing call auction.

## 5. Data

The data used in this study is obtained from the *SEATS* database maintained by the *Securities Industry Research Centre of Asia-Pacific (SIRCA)*. Intra-day data is obtained from 18 March 2000 to 18 March 2001 (pre-event) and from 18 March 2002 to 18 March

2003 (post-event). This provides a sample period covering 500 trading days or 250 trading days pre-event and 250 trading days post-event. The period between 18 March 2001 and 18 March 2002 is excluded from the sample to mitigate the impact of confounding factors such as the change in SPI 200$^{\mathrm{TM}}$ Futures Contract settlement prices.

The new execution algorithm was introduced on 18 March 2002[5]. Data is obtained for all stocks which traded in the All Ordinaries Index over the entire sample period. This results in a sample of 155 stocks. As stated, more active and less active stocks are considered separately. Therefore the data is partitioned into stocks included in the S&P/ASX 200 Index (S&P/ASX 200), 105 stocks, and those excluded (ASX 201-500), 50 stocks.[6] The S&P/ASX 200 is recognized as the investable benchmark in the Australian equity market.

Order flow is examined in one-minute intervals over a fifteen minute period prior to the opening call auction. To account for the random opening time each interval is measured from the actual opening time back fifteen minutes. The pre-open period from 7:00 to 9:45 is excluded from the analysis. Order amendment and cancellation activity over this time result in minimal changes in order book volumes and excessive noise in pre-open prices. However, as the open approaches, traders place orders intended to trade in the call auction and price discovery occurs. Therefore, only the final fifteen minutes of the pre-open period is examined. Order flow is also examined over one-second intervals prior to the designated opening time to analyze the impact of the random opening on price discovery. For the pre-close period, order flow is examined over one-minute intervals.

Details of all individual orders placed on *SEATS* over the sample period are obtained. Each order record includes details of the price and volume and is time stamped to the nearest second. IAP and SV indications are calculated over the pre-open and pre-close periods.

In an examination of the S&P 500 Index, Stoll and Whaley (1990) find unusual trading activity, including abnormally high trading volumes, on futures expiration days. The SPI 200$^{\mathrm{TM}}$ Futures Contract expires on quarter-end days. Consistent with Stoll and Whaley (1990), unusually high order flow, trading volume and volatility are observed on these days and other month-end days. Therefore, all quarter-end and month-end days are considered separately due to unusual trading activity on these days.

## 6. Call auction use, order flow and execution

### 6.1. Opening call auction

Table 1 presents descriptive statistics on call auction trading in S&P/ASX 200 stocks (active stocks) and ASX 201-500 (less active) stocks at the open. Call auction trading at the open is first examined in active stocks on non-quarter-end and other non-month-end days. Table 1, Panel A indicates that there is a call auction trade on 89.2 percent of post-event

[5]The IAP and SV indication were available to the market from 20 March 2002. Therefore 18 and 19 March 2002 are excluded from the sample.

[6]Stocks are included in the S&P/ASX 200 group on those days they traded in the S&P/ASX 200 over the sample period and in the ASX 201-500 group on those days they traded outside the S&P/ASX 200. The data is reconfigured to include only those stocks that traded in the S&P/ASX 200 for the entire sample period, and only those stocks that traded outside the S&P/ASX 200 over the entire sample period. The results are consistent with those presented.

Table 1
Opening call auction descriptive statistics

Table 1 presents non-quarter-end days (other month-end days are also excluded) and quarter-end days (all other month-end days are included) separately. Panel A presents the percentage of sample days with an opening call trade before and after the change in the opening algorithm. Column 1(2) presents call auction frequency for the pre-event (post-event) period for non-quarter-end days. Column 3 presents the difference between columns 1 and 2, and column 4 presents a *t* statistic to test for the change in the pre and post-event values. Panel A, columns 5–8, present similar statistics for quarter-end days. Column 9, Diff. change, presents the difference between columns 3 and 7. Panel B presents the total volume of orders entered over the last 15 minutes of the pre-open, divided by the total volume of orders entered over the day. Panel B also presents total traded volume for the opening call, divided by total daily trade volume (excluding the call volume). Column 1(2) presents relative order entry and relative trade volume for the pre-event (post-event) period for non-quarter-end days. Column 3 presents the difference between columns 1 and 2, and column 4 presents a *t* statistic to test for the change in the pre and post-event values. Panel B, columns 5–8, present similar statistics for quarter-end days. Column 9, Diff. change, presents the difference between columns 3 and 7. Analysis is performed separately for the S&P/ASX 200 and the ASX 201-500.

| Call frequency | Non-quarter-end days (%) | | | | Quarter-end days (%) | | | | (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Pre-event | Post-event | Change | *t*-stat. | Pre-event | Post-event | Change | *t*-stat. | Diff. change |
| *Panel A: Call auction frequency* | | | | | | | | | |
| S&P/ASX 200 | 81.7 | 89.2 | 7.5 | 3.34** | 80.8 | 84.4 | 3.6 | 1.36 | 3.9 |
| ASX 201-500 | 64.8 | 61.5 | −3.3 | −0.69 | 65.7 | 54.2 | −11.5 | −2.08* | 8.2 |
| *Panel B: Relative order entry (volume) and relative trade volume over pre-open* | | | | | | | | | |
| Relative order entry | | | | | | | | | |
| S&P/ASX 200 | 2.2 | 2.4 | 0.2 | 6.72** | 1.9 | 9.2 | 7.3 | 21.04** | −7.1 |
| ASX 201-500 | 3.1 | 3.5 | 0.4 | 2.85** | 3.0 | 3.6 | 0.6 | 0.77 | −0.2 |
| Relative trade volume | | | | | | | | | |
| S&P/ASX 200 | 3.7 | 3.4 | −0.3 | −5.59** | 3.2 | 13.0 | 9.8 | 17.36** | −10.1 |
| ASX 201-500 | 10.7 | 14.5 | 3.8 | 10.39** | 10.4 | 13.1 | 2.7 | 1.58 | 1.1 |

*Significant at the 0.05 level.
**Significant at the 0.01 level.

days at the open compared to only 81.7 percent of pre-event days at the open. This represents a statistically significant increase post-event (at the 0.05 level) in the frequency of call auction trading.

Table 1, Panel B indicates there is a small improvement, post-event, in pre-open order entry on non-quarter-end/non-month-end days. Order entry is measured using the total volume of orders entered during the pre-open period divided by the total volume of orders entered over the whole day. Panel B also indicates a small but significant decline in trade volumes at the opening call auction on non-quarter-end/non-month-end days from 3.7 to 3.4 percent.[7]

[7]As pre-open (and pre-close) order flow and call auction trade volumes have trended upwards over the sample period, relative metrics are calculated to remove the effect of general market movements. That is, all pre-open totals and trade volumes are divided by daily totals.

In contrast to active stocks, Table 1, Panel A indicates lower call auction trade frequency in less active stocks on non-quarter-end/non-month-end days, with a call auction trade on 61.5 percent of post-event sample days at the open. There is no significant change in the frequency of call auctions from the pre to the post-event periods. However, when call auctions are held in less active stocks on non-quarter-end/non-month-end days, this trading mechanism accounts for a significant proportion of daily trade volume. In addition, trade volumes increased significantly, from 10.7 percent pre-event to 14.5 percent post-event at the open. Table 1, Panel B also indicates a small but significant increase in pre-open order entry for less active stocks on non-quarter-end/non-month-end days.

Table 1 also presents similar results for quarter-end and other month-end days. For active stocks at the open, Panel A indicates no significant change in call auction frequency. However, Panel B indicates a significant increase in order entry over the pre-open, from 1.9 percent pre-event to 9.2 percent post-event, and a significant increase in trading at the call auction, from 3.2 percent pre-event to 13.0 percent post-event. The change in the SPI 200$^{TM}$ Futures Contract settlement price calculation is likely to be responsible for this result. Changing the settlement price calculation from closing to opening prices on quarter-end days appears to have substantially increased interest at the open on these days. Consistent with this explanation, there is little corresponding increase in order entry or trade volumes in stocks not included in the S&P/ASX 200.

The final column in Table 1 compares the non-quarter-end days pre and post-event and the quarter-end and other month-end days pre and post-event. Differences are evident between these two groups of days. Specifically, the change in call frequency is higher on non-quarter-end days, while consistent with the preceding analysis, the change in order entry and trade volumes is significantly higher on quarter-end and other month-end days in active stocks.

### 6.2. *Closing call auction*

Table 2 presents descriptive statistics on call auction trading in S&P/ASX 200 stocks (active stocks) and ASX 201-500 (less active) stocks at the close. Call auction trading at the close is first examined in active stocks for non-quarter-end/other non-month-end days. Table 2, Panel A indicates that there is a statistically significant increase in call auction trade from 70.2 percent of pre-event days at the close to 87.7 percent of post-event days at the close. Table 2, Panel B indicates a significant increase in both pre-close order entry and trade volumes on non-quarter-end/non-month-end days.

In contrast to active stocks at the close, Table 2, Panel A indicates lower call auction trade frequency in less active stocks on non-quarter-end/non-month-end days, with a call auction trade on 38.8 percent of post-event sample days. There is no significant change in the frequency of call auctions from the pre to the post-event periods. In addition, relatively little order entry is observed over the pre-close, around 1.2 percent, even though trade volumes are substantial. This disparity suggests that traders are amending existing orders that did not execute during the continuous trading session, rather than entering new orders, to trade at the close.

Table 2 then presents similar results for quarter-end and other month-end days. In active stocks, a significant increase in order entry is evident over the pre-close, from 5.5 percent pre-event to 9.5 percent post-event, and a significant increase is evident in trading at the

Table 2
closing call auction descriptive statistics

Table 2 presents non-quarter-end days (other month-end days are also excluded) and quarter-end days (all other month-end days are included) separately. Panel A presents the percentage of sample days with a closing call trade before and after the change in the closing algorithm. Column 1(2) presents call auction frequency for the pre-event (post-event) period for non-quarter-end days. Column 3 presents the difference between columns 1 and 2, and column 4 presents a $t$ statistic to test for the change in the pre and post-event values. Panel A, columns 5–8, present similar statistics for quarter-end days. Column 9, Diff. change, presents the difference between columns 3 and 7. Panel B presents the total volume of orders entered over the pre-close, divided by the total volume of orders entered over the day. Panel B also presents total traded volume for the closing call, divided by total daily trade volume (excluding the call volume). Column 1(2) presents relative order entry and relative trade volume for the pre-event (post-event) period for non-quarter-end days. Column 3 presents the difference between columns 1 and 2, and column 4 presents a $t$ statistic to test for the change in the pre and post-event values. Panel B, columns 5–8, present similar statistics for quarter-end days. Column 9, Diff. change, presents the difference between columns 3 and 7. Analysis is performed separately for the S&P/ASX 200 and the ASX 201-500

| Call frequency | Non-quarter-end days (%) | | | | Quarter-end days (%)m | | | | (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Pre-event | Post-event | Change | $t$-stat. | Pre-event | Post-event | Change | $t$-stat. | Diff. change |
| *Panel A: Call auction frequency* | | | | | | | | | |
| S&P/ASX 200 | 70.2 | 87.7 | 17.5 | 7.92** | 72.9 | 90.7 | 17.8 | 7.81** | −0.3 |
| ASX 201-500 | 40.0 | 38.8 | −1.2 | −0.23 | 45.0 | 54.0 | 9.0 | 1.72 | −10.2 |
| *Panel B: Relative order entry (volume) and relative trade volume* | | | | | | | | | |
| Relative order entry | | | | | | | | | |
| S&P/ASX 200 | 2.2 | 5.5 | 3.3 | 76.88** | 5.5 | 9.5 | 4.0 | 12.78** | −0.7 |
| ASX 201-500 | 1.3 | 1.2 | −0.1 | −1.36 | 3.1 | 5.1 | 2.0 | 2.38* | −2.1 |
| Relative trade volume | | | | | | | | | |
| S&P/ASX 200 | 4.4 | 5.4 | 1.0 | 16.62** | 7.8 | 10.6 | 2.8 | 7.22** | −1.8 |
| ASX 201-500 | 7.5 | 9.8 | 2.3 | 5.58** | 13.9 | 16.6 | 2.7 | 1.54 | −0.4 |

*Significant at the 0.05 level.
**Significant at the 0.01 level.

closing call auction, from 7.8 percent pre-event to 10.6 percent post-event, despite the decoupling of the SPI 200$^{TM}$ Futures Contract settlement price calculation from closing prices. A corresponding increase in call auction frequency at the close is also evident in Table 2, Panel A. Demand to trade active stocks at the close on quarter-end and other month-end days remains strong, driven by a range of factors including trading by fund managers whose performance is based on closing prices, passive/index fund rebalancing and trading by overseas investors. Post-event, increased transparency and reduced arbitrage activity at the close may also increase demand to receive closing prices. In contrast, stocks outside the S&P/ASX 200, the less active stocks, exhibit a small but statistically significant increase in order flow over the pre-close on quarter-end and other month-end days. However, no significant change in trade volumes or call auction frequency is evident.

The final column in Table 2 compares the non-quarter-end days pre and post-event and the quarter-end and other month-end days pre and post-event. Differences are evident between these two groups of days. Specifically, the change in call frequency, order entry and trade volumes are greatest on quarter-end and other month-end days across stocks.

## 7. Variance ratios

Past literature has frequently utilized variance ratios to test for the impact of a call auction mechanism on return volatility (e.g., Amihud and Mendelson, 1987, 1991; Amihud et al., 1990). Open-to-same day 11:00 returns and close-to-next day 11:00 returns are calculated over the pre and post-event sample period, by stock. Using prices at 11:00, rather than open-to-open returns and close-to-close returns, tests whether the change in call auction design reduces the dispersion of opening and closing prices around their true values (as proxied by 11:00 prices).[8] Open-to-same day 11:00 returns are defined as the log of the midpoint price prevailing in the market at 11:00, ($P_1$), minus the log of the opening price on the same day, ($P_o$). If there is no opening call auction trade, the first trade price of the day is used as the opening price. This tests return volatility across the market, rather than only on days where there is an opening call auction. As the change in call auction design applies at both the opening and closing call auction, the variance of open-to-same day 11:00 returns, pre-event, is divided by the variance of open-to-same day 11:00 returns, post-event. The resulting ratio is averaged across stocks. The process is repeated separately using closing call auction prices to calculate close-to-next day 11:00 returns. If there is no closing call auction, the last trade price of the day is used as the closing price. A ratio significantly greater than 1.0 indicates that the change in call auction design reduced return volatility.

Table 3 presents variance ratio estimates for active stocks and for less active stocks. An $F$ statistic is used to test whether the difference between the pre and post-event return variance estimates is statistically significant. Table 3, Panels A and B indicate that opening and closing return volatility, on average, has significantly declined across all stocks. For active stocks the average variance ratio is 1.53 at the open and 1.37 at the close. For less active stocks the variance ratio is 1.54 at the open and 1.39 at the close. In addition, Table 3 indicates that around 76 (62) percent of active (less active) stocks at the open experienced a significant decline in return volatility post-event. Fewer stocks at the close experienced a decline in return volatility; however, on average, the results indicate closing return volatility is reduced post-event. This result indicates that increased call auction transparency and the amended algorithm, on average, reduce the volatility of returns across the market.

## 8. The new call auction algorithm and efficiency of pre-open and pre-close prices

### *8.1. Analysis of the price setting process*

The focus of the analysis now shifts to the new matching algorithm and its impact on the efficiency of pre-open and pre-close prices. Table 4 presents an analysis of the call auction price setting process for all stocks. The frequency of the principle used to determine the final call auction price, the frequency of zero surplus volume indications, and the percentage of daily volume traded are presented, by principle.

The new algorithm is designed to move past Principle 1 only if there is more than one price at which executable volume is maximized. Table 4 indicates that the algorithm is able

[8] Variance ratios using open-to-open returns and close-to-close returns are also calculated. The results are generally consistent and are therefore not reported.

Table 3
Variance ratios

Table 3 presents return variances and variance ratios for the pre and post-event periods. In the pre-event period, the variance of open-to-same day 11:00 (Panel A) and close-to-next day 11:00 (Panel B) time series returns are calculated, by stock. This process is repeated in the post-event period. If there is no opening (closing) trade the first (last) trade price is used in the variance calculation. Return variances are presented below, averaged for the S&P/ASX 200 and for the ASX 201-500. For each stock, the variance of open-to-same day 11:00 pre-event returns is divided by the variance of open-to-same day 11:00 post-event returns, to obtain a variance ratio. This process is repeated for the close. Variance ratios are averaged for the S&P/ASX 200 and for the ASX 201-500. A variance ratio of greater than 1.0 implies that volatility has been reduced in the post-event period. An *F* statistic is calculated to test for a statistically significant difference in pre and post-event return variance estimates. The percentage of sample stocks with a variance ratio significantly greater than 1.0 is also reported.

| Stocks | Number of observations | | Open-to-same day 11:00 return variance | | Variance ratio | F statistic | Percentage of individual stocks with variance ratio > 1(%) |
|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | | | |
| *Panel A: Open-to-same day 11:00* | | | | | | | |
| S&P/ASX 200 | 24,124 | 24,124 | 0.000136 | 0.000122 | 1.530 | 1.684* | 76.11 |
| ASX 201-500 | 7,852 | 7,852 | 0.000508 | 0.000503 | 1.538 | 2.007* | 62.16 |
| *Panel B: Close-to-next day 11:00* | | | | | | | |
| S&P/ASX 200 | 24,124 | 24,124 | 0.000233 | 0.000253 | 1.371 | 1.758* | 62.83 |
| ASX 201-500 | 7,852 | 7,852 | 0.000862 | 0.000956 | 1.385 | 1.965* | 54.05 |

*Significant at the 0.01 level.

Table 4
Principles used to determine the auction price and frequency of zero surplus volume indications

The new call auction algorithm implemented by the ASX has four stages or principles. (See Appendix A for a comprehensive explanation and example). The frequency with which these principles are used in the price formation process is presented. If Principle 1 is considered only, this is recorded as Principle 1. If both Principles 1 and 2 are considered then this is recorded as Principle 2, etc. Zero surplus volume occurs when no buy or sell interest remains unmatched after the algorithm is run. The number of call auctions with zero surplus volume indications is divided by principle frequency to give zero surplus volume frequency. Call auction trade volume divided by total daily trade volume is also presented, by principle. The results are presented for the S&P/ASX 200 and for the ASX 201-500.

| Principle used to determine auction price | Opening call auction | | | | Closing call auction | | | |
|---|---|---|---|---|---|---|---|---|
| | Principle frequency | Percent of total call use (%) | Zero surplus volume frequency (%) | Relative trade volume (%) | Principle frequency | Percent of total call use (%) | Zero surplus volume frequency (%) | Relative trade volume (%) |
| *S&P/ASX 200* | | | | | | | | |
| 1 | 22,905 | 87.03 | 0.31 | 3.57 | 22,626 | 87.73 | 0.22 | 5.57 |
| 2 | 2,783 | 10.57 | 0.61 | 2.55 | 2,337 | 9.06 | 0.30 | 4.00 |
| 3 | 630 | 2.39 | 0.00 | 2.34 | 826 | 3.20 | 0.00 | 4.71 |
| 4 | 2 | 0.01 | 100.00 | 0.56 | 2 | 0.01 | 100.00 | 1.66 |
| *ASX 201-500* | | | | | | | | |
| 1 | 4,384 | 91.83 | 1.19 | 14.66 | 1,948 | 94.61 | 2.10 | 10.05 |
| 2 | 334 | 7.00 | 2.10 | 11.25 | 93 | 4.52 | 3.23 | 6.02 |
| 3 | 55 | 1.15 | 0.00 | 17.54 | 18 | 0.87 | 0.00 | 5.55 |
| 4 | 1 | 0.02 | 100.00 | 3.62 | — | — | — | — |

to determine an auction price using Principle 1 in nearly 90 percent of all opening and closing call auctions. The greatest percentage of daily trade volume also executes when the call auction price is set by Principle 1. This result implies that Principles 2 and 3 are not frequently utilized in the price setting process. Principle 2 or Principles 2 and 3 are required when a single auction price can not be set based on Principle 1, maximum trade volume. In active stocks, around 13 percent of final call auction prices are set using Principle 2 or Principles 2 and 3. Principle 2 selects the price that exhibits minimum surplus volume, and, if no one price exhibits minimum surplus volume, Principle 3 considers market pressure. Section 8.2 examines the differences in pricing efficiency based on the principles used to set the auction prices.

Table 4 also indicates that surplus volume indications are rarely zero, although call auctions in less active stocks are more likely to produce zero surplus volume. Therefore, in most call auctions, active and less active, not all interest in the call auction is able to trade at the opening or closing price. In addition, Table 4 indicates that call auction trade volume declines as additional principles are required to set call auction prices.

### 8.2. *Efficiency of pre-open and pre-close prices*

The regression technique of Biais et al. (1999) is adopted to examine the impact of the change in ASX call auction design on the efficiency of the IAP and call auction prices during the pre-open and pre-close.

Theissen (2000) argues that testing the efficiency of prices is difficult as it is impossible to observe the true value of an asset with certainty. The true value of the asset ($V_i$) is assumed to be the midpoint of the best quote prevailing in the market at 11:00.[9] This is consistent with Ciccotello and Hatheway (2000) who examine the pre-open period on the NASDAQ.

This value proxy allows examination of the characteristics of the pre-open price discovery process over the pre and post-event period. After a significant non-trading period, price discovery may prove difficult. As a result, it is expected that there will be noise in the IAP at the start of the pre-open period. As the pre-open progresses, order entry increases, prices are 'discovered' and noise should diminish.

The regression technique developed by Biais et al. (1999) also allows identification of any bias in pre-open prices. In Eq. (1) below, a regression coefficient ($\beta_i$) statistically different from 1.0 implies that pre-opening prices are biased and do not converge to fundamental values.

In the post-event period, if the new call auction design has enhanced the efficiency of pre-open prices, the IAP is expected to be more representative of value (i.e., the post-event estimate, ($\beta_i + \gamma_i$), will be significantly closer to 1.0 than the pre-event estimate, $\beta_i$). To test these expectations for the pre-open, the following equation is estimated:

$$V_{i,E} - P_{\mathrm{close},i,E} = \alpha_i + \beta_i(\mathrm{IAP}_t - P_{\mathrm{close},i,E}) + \gamma_i * \mathrm{Dummy}_{i,E} * (\mathrm{IAP}_t - P_{\mathrm{close},i,E}) + \mu_{i,E}, \tag{1}$$

where $\beta_i$ is the pre-event efficiency estimate and ($\beta_i + \gamma_i$) is the post-event estimate; $V$ is the true value of stock $i$, with $E$ representing either the pre-event period or the post-event period. The true value of the stock is assumed to be the midpoint of the best quote at 11:00

[9] The regression is also estimated based on the midpoint of the best quote (value) at 10:30, 11:30 and closing prices. The results indicate consistent patterns in pre-open prices and are not reported.

on that day, $t$. $P_{\text{close}}$ is the previous day's VWAP, calculated over the last ten minutes of trading for stock $i$, and $\text{IAP}_t$ is the IAP at time $t$ during the pre-open. The slope $\text{Dummy}_{i,E}$ is equal to 1 if the data is post-event and is equal to 0 if the data is pre-event. $\mu_{i,T,E}$ is the stochastic error term. The log of prices is used to control for heteroskedasticity caused by variation between stock price levels.

The above regression is run using the IAP at every time interval. During the pre-open, 15 one-min time intervals are created, 15 IAP indications are calculated, and 15 regressions are run over the sample data. To account for the random open, the intervals are measured from the open of the stock back in one-minute intervals. The IAP at the open is therefore the opening price for the stock and provides a test of opening price efficiency.[10]

The efficiency of the IAP over the pre-close is also tested. As with the open, the first interval tested is measured from the close of the stock. The IAP is then sampled every minute back to 16:00, the start of the pre-close. This is measured assuming the true value of the stock is the midpoint of the best quote at 11:00 on the day after the closing call auction.[11]

For active stocks, a comparison of the pre and post-event periods indicates evidence of increased price efficiency over the pre-open. Fig. 1 illustrates that post-event, pre-open prices are consistently more efficient than pre-event pre-open prices. At the open, in the pre-event period, the IAP consistently underestimates value, on average, by 0.4 15 minutes prior to the open to 0.2 at the open. In the post-event period, the IAP is significantly more efficient, underestimating value, on average, by 0.2 15 minutes prior to the open to 0.04 at the open. Fig. 1 also indicates that pre-open prices do not fully converge to their fundamental values. Final call auction prices are significantly different from 1.0 at the 0.05 level. This is consistent with Medrano and Vives (2001) who find similar results. Fig. 1 also illustrates that pre-open price efficiency is enhanced at the open when the regression is estimated only considering days when the final call auction price is set using Principle 2 or Principles 2 and 3. On these days there is no evidence of underpricing, on average, i.e., the post-event beta coefficient, $(\beta_i + \gamma_i)$, is not significantly different from 1.0 at the 0.05 level. Therefore, the new algorithm and increased transparency appear to have significantly enhanced pre-open and opening call auction price efficiency in active stocks. This result is consistent with the variance ratio results that indicate reduced return volatility at the open post-event.

Fig. 1 also illustrates that cumulative net order flow increases monotonically until the open. Cumulative net order flow is calculated as follows: for each one-minute time interval, obtain the total volume of orders entered, plus the volume of order amendments which increase the size of the order, less the volume of order amendments which decrease the size of the order, less the volume of orders cancelled. This is divided by total daily net order flow. These values are cumulated across the fifteen minute window prior to the open. The increase in cumulative net order flows observed represents the placement of orders intended to trade in the opening call auction. This order volume contributes to price discovery.

[10]The regression tests only consider days when there is a trade at the call auction. Therefore, the regression results may differ from the variance ratio results, as the variance ratios calculate return variances using all sample days.

[11]The regression is also estimated based on the midpoint of the best quote (value) at 10:30 on the day after the closing call auction. The results indicate consistent patterns in pre-close prices and are not reported.

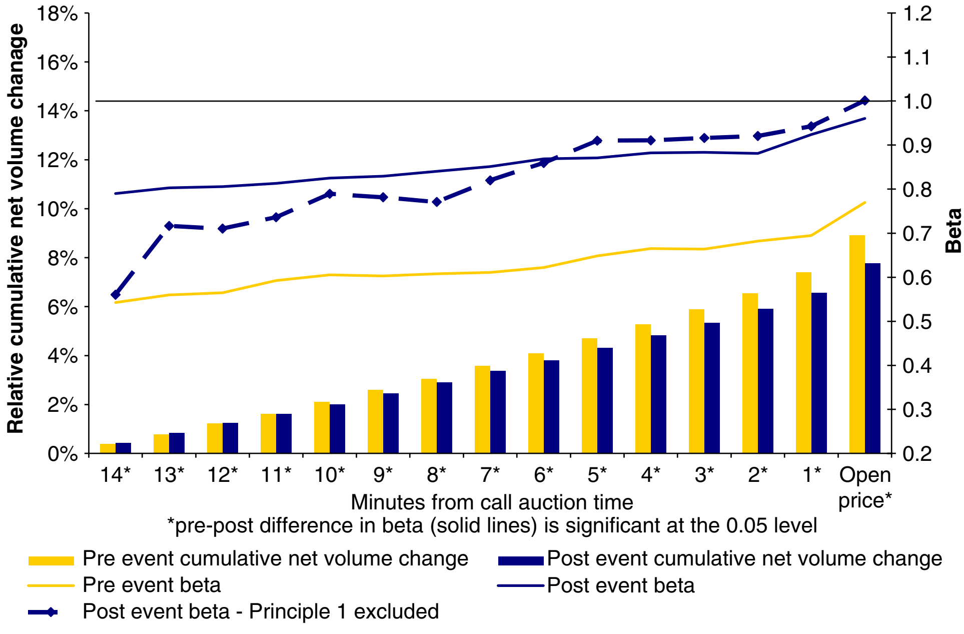


Fig. 1. Efficiency of the indicative auction price (IAP) over the pre-open for S&P/ASX 200 stocks. The IAP is sampled at the end of each one-minute interval starting at the open time and working back for fifteen minutes. The following regression is estimated; $(V_{i,E}-P_{\text{close},i,\text{E}}) = \alpha_i+\beta_i(\text{IAP}_t-P_{\text{close},i,E})+\gamma_i{*}\text{Dummy}_{i,E}{*}(\text{IAP}_t-P_{\text{close},i,E})+\mu_{i,E}$. A coefficient $(\beta_i+\gamma_i)$ significantly closer to 1.0 in the post-event period indicates that pre-open prices are more efficient. A value less (greater) than 1.0 indicates that pre-open prices underestimate (overestimate), on average, the true value of the security, as proxied by the midpoint price prevailing in the market at 11:00. Over each one-minute time interval the cumulative net change in order volumes in the order book is calculated. Net change is calculated as the volume of orders entered, plus volume amended up, less volume amended down, less volume cancelled, over each one-minute interval. Relative net change is calculated by dividing each one-minute observation by the net daily volume of orders entered, amended and cancelled. Relative cumulative net change is calculated by cumulating observations each minute until the opening call auction.

The pre-open period, 7:00–9:45, is not considered in this analysis. During this period, significant noise is present in pre-open prices, cumulative net order flow is consistently around zero, and there is little evidence of price discovery. Unrestricted order entry, amendment and cancellation over this time allows traders to adjust orders repeatedly and, consistent with Biais et al. (1999), unrestricted order movement may induce strategic behavior by informed traders at this time of increased price uncertainty. Such trading behavior may increase noise in pre-open prices. For example, a trader may place a large order to encourage price competition. This may impact the pre-open price and reduce the usefulness of the surplus volume indication. The trader may then cancel the order when the strategy is completed.

However, strategic traders face a heightened risk of trading near the random open. Therefore, as order flow arrives near the open, strategic traders are less likely to participate, and as a result, information revelation increases, surplus volume indications are more meaningful and price discovery occurs. This result is also consistent with Davies (2003), who argues that hectic order submission during the final minutes of the price

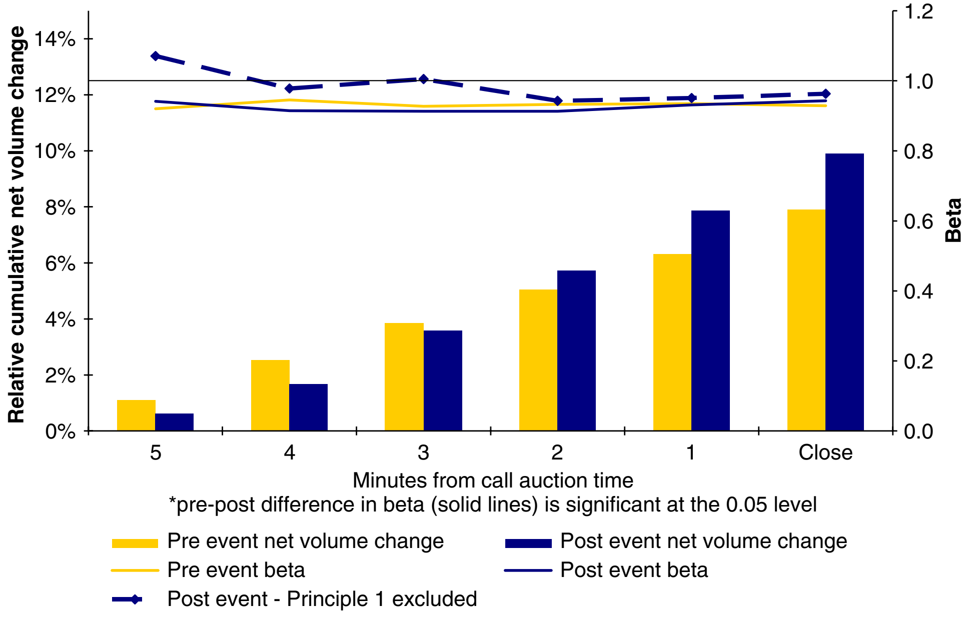


Fig. 2. Efficiency of the indicative auction price (IAP) over the pre-close for S&P/ASX 200 stocks. The IAP is sampled at the end of each one-minute interval starting at the closing auction time and working back. The following regression is estimated; $(V_{i,E} - P_{\text{open},i,E}) = \alpha_i + \beta_i(\text{IAP}_t - P_{\text{open},i,E}) + \gamma_i{*}\text{Dummy}_{i,E}{*}(\text{IAP}_t - P_{\text{open},i,E}) + \mu_{i,E}$. A coefficient $(\beta_i + \gamma_i)$ significantly closer to 1.0 for the post-event period indicates pre-close prices are more efficient. A value less (greater) than 1.0 indicates that pre-close prices underestimate (overestimate), on average, the true value of the security, as proxied by the midpoint price prevailing in the market at 11:00 the day after the closing call auction. Over each one-minute time interval the cumulative net change in order volumes in the order book is calculated. Net change is calculated as the volume of orders entered, plus volume amended up, less volume amended down, less volume cancelled, over each one- minute interval. Relative net change is calculated by dividing each one-minute observation by the net daily volume of orders entered, amended and cancelled. Relative cumulative net change is calculated by cumulating observations each minute until the opening call auction.

discovery period makes it difficult to exploit order imbalances and hence enhances price efficiency.

Examination of cumulative net order flow in one-second intervals, over the last thirty seconds of the pre-open prior to the random opening, indicates that cumulative net order flow continues to increase until the opening call auction is held.[12] This indicates that

[12]Each stock has a designated opening time. The stock opens randomly $\pm 15$ s around this time. Total net order flow is examined in the 15 s interval prior to the designated open time. The stock may open at any time during this 15 s. Net order flow is also examined over the interval $-15$ to $-30$ s prior to the designated open time. The stock cannot open during this 15 s. A t test is conducted to test for a significant difference in net order flow between these two groups. If strategic traders are present in the $-15$ to $-30$ s period, they should not be present in the 15 s period prior to the designated open time, or they will risk trading. Therefore, a significant decrease in net order flow between these two groups is expected if strategic traders withdraw. No significant difference is found between these two periods, indicating either that strategic traders have left the market earlier or that their trading has minimal impact near the open.

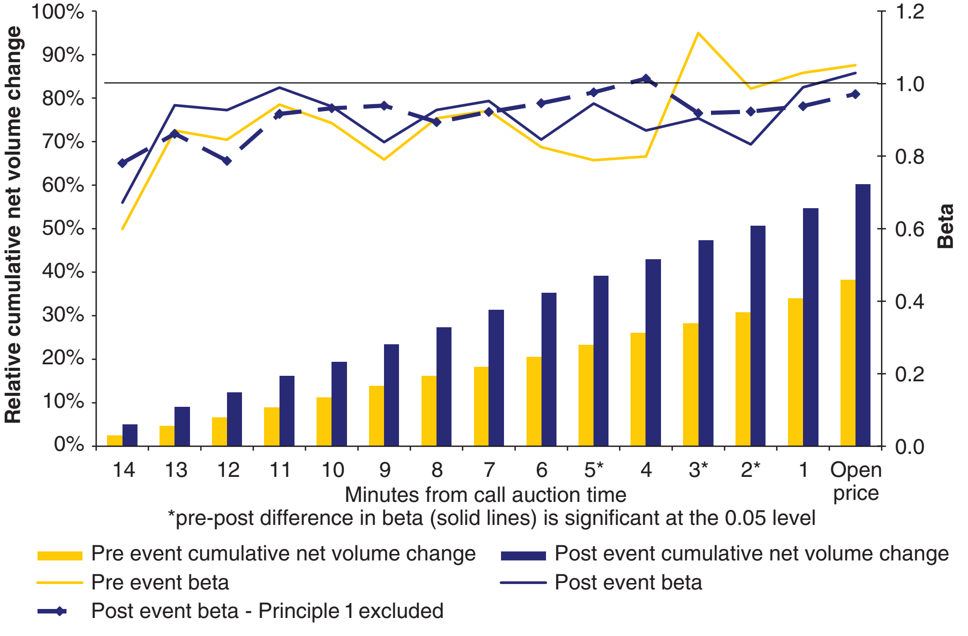


Fig. 3. Efficiency of the indicative auction price (IAP) over the pre-open for ASX 201-500 stocks. The IAP is sampled at the end of each one-minute interval starting at the open time and working back. The following regression is estimated; $(V_{i,E}-P_{\text{close},i,E}) = \alpha_i + \beta_i(\text{IAP}_t - P_{\text{close},i,E}) + \gamma_i{*}\text{Dummy}_{i,E}{*}(\text{IAP}_t - P_{\text{close},i,E}) + \mu_{i,E}$. A coefficient $(\beta_i+\gamma_i)$ significantly closer to 1.0 for the post-event period indicates pre-open prices are more efficient. A value less (greater) than 1.0 indicates that pre-open prices underestimate (overestimate), on average, the true value of the security, as proxied by the midpoint price prevailing in the market at 11:00. Over each one-minute time interval the cumulative net change in order volumes in the order book is calculated. Net change is calculated as the volume of orders entered, plus volume amended up, less volume amended down, less volume cancelled, over each one-minute interval. Relative net change is calculated by dividing each one-minute observation by the net daily volume of orders entered, amended and cancelled. Relative cumulative net change is calculated by cumulating observations each minute until the opening call auction.

meaningful price discovery occurs right up to the open and is actually interrupted by the open.

Fig. 2 indicates a small improvement in price efficiency, post-event, over the pre-close. Fig. 2 also reveals little variability in the efficiency of the IAP over the pre-close, with the IAP consistently underestimating value by around 0.05. Little variability in the efficiency of the IAP implies the pre-close is not being used for meaningful price discovery. This is not unexpected given the pre-close is five to six minutes in duration and is preceded by a significant period of price discovery.

The efficiency results at the close are not as strong as the variance ratio results for close-to-next day 11:00 returns. The demand to receive closing prices is high on call days. This may generate order imbalances and restrict efficiency gains. However, variance ratios consider all sample days, including non-call days when these factors are not present, which may contribute to this result. However, when the regression is estimated only considering days when the final call auction price is set using Principle 2 or Principles 2 and 3 (i.e., after

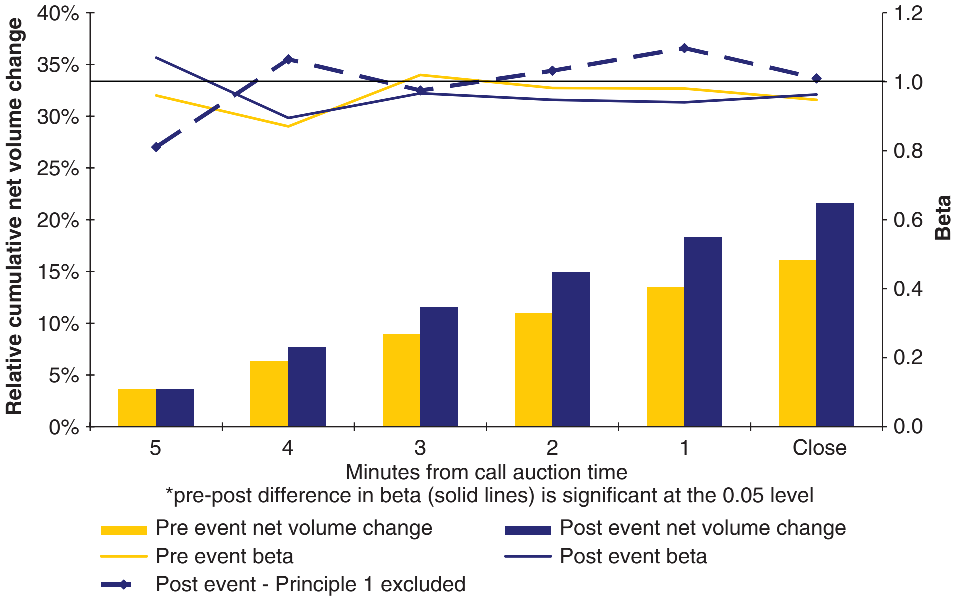


Fig. 4. Efficiency of the indicative auction price (IAP) over the pre-close for ASX 201-500 stocks. The IAP is sampled at the end of each one-minute interval starting at the closing auction time and working back. The following regression is estimated; $(V_{i,E}-P_{\text{open},i,E}) = \alpha_i+\beta_i(\text{IAP}_t-P_{\text{open},i,E})+\gamma_i{}^*\text{Dummy}_{i,E}{}^*(\text{IAP}_t-P_{\text{open},i,E})+\mu_{i,E}$. A coefficient $(\beta_i+\gamma_i)$ significantly closer to 1.0 for the post-event period indicates pre-close prices are more efficient. A value less (greater) than 1.0 indicates that pre-close prices underestimate (overestimate), on average, the true value of the security, as proxied by the midpoint price prevailing in the market at 11:00 the day after the closing call auction over each one-minute time interval the cumulative net change in order volumes in the order book is calculated. Net change is calculated as the volume of orders entered, plus volume amended up, less volume amended down, less volume cancelled, over each one-minute interval. Relative net change is calculated by dividing each one-minute observation by the net daily volume of orders entered, amended and cancelled. Relative cumulative net change is calculated by cumulating observations each minute until the opening call auction.

considering minimum surplus volume and market pressure) there is evidence of enhanced price efficiency. In addition, the post-event beta coefficient, $(\beta_i + \gamma_i)$, is not significantly different from 1.0 at the 0.05 level.

For less active stocks, Fig. 3 indicates no significant change in the efficiency of the opening auction price, with both pre and post-event opening prices not significantly different from 1.0. In addition, on days when opening call auction prices are determined using Principle 2 or Principles 2 and 3, prices are not significantly different from 1.0 at the open. Again, this result is not as strong as the variance ratio results which indicate reduced return volatility at the open in less active stocks. The regression results pre and post-event may be partly driven by the characteristics of less active stocks. On average, there are only 5 trades (standard deviation of 15) from the opening call auction until 11:00, the proxy for value. In comparison, in active stocks there is an average of 60 (standard deviation of 100) trades from the opening call auction until 11:00. Therefore, as continuous trading is infrequent in less active stocks on call days and information may be impounded more slowly than for active stocks, few trades may execute prior to 11:00 at prices different from the open price. This results in an opening price efficiency estimate not significantly different from 1.0 in both the pre and post-event period. As a result, no improvement in efficiency is observed post-event. In addition, only call days are used in the regressions and call frequency is low in less active stocks. This contrasts to the variance ratio calculations that use all sample days.

Despite the impact of infrequent trading in these stocks on these results, positive cumulative net volume change is evident prior to the open. In addition, the increase in cumulative net volume change observed between pre and post periods is statistically significant across all one-minute time intervals.

For less active stocks, during the pre-close, Fig. 4 indicates little change in pre-close price efficiency between the pre and post-event periods. Although variance ratio results, on average, indicate a decrease in return volatility at the close, only 54 percent of individual less active stocks at the close exhibit a decrease in return volatility. In addition, Fig. 4 indicates evidence of enhanced price efficiency when only Principle 2 or Principles 2 and 3 are considered, with the post-event beta coefficient, $(\beta_i + \gamma_i)$, not significantly different from 1.0 at the 0.05 level. This result indicates evidence of enhanced price efficiency post-event.

## 9. Conclusion

On 18 March 2002 the ASX implemented changes to its call auction design. These changes enhanced transparency in the call auction and introduced a new matching algorithm. This paper examines the impact of these changes on price efficiency.

The analysis indicates that the design of the call auction algorithm is important. Variance ratio analysis indicates that return volatility is reduced post-event across the market, i.e., in both active and less active stocks.

An examination of the pre-open price discovery process provides further support for increased call auction price efficiency post-event. In active stocks, pre-open prices are significantly more efficient post-event, especially when the final call auction price is determined using Principle 2 or Principles 2 and 3, which consider order imbalances and market pressure. In less active stocks, pre-open price efficiency is high both pre and post-event.

Pre-close prices do not display significant increases in efficiency post-event in active or less active stocks. However, when the final call auction price is determined using Principle 2 or Principles 2 and 3, there is evidence of enhanced call auction price efficiency, consistent with the variance ratio results. In addition, the results indicate little evidence that the pre-close is used for price discovery. This result is not unexpected given the significant continuous trading period that precedes the pre-close. Therefore, the closing call auction has a different role from the open; it facilitates trading at the closing price, rather than facilitating the resolution of price uncertainty.

The results suggest that the change in ASX call auction design has enhanced call auction price efficiency. This is further supported by evidence of increased call auction frequency, order entry and trade volumes. At the close in active stocks, there is evidence of an increased willingness to receive the closing price as call auction frequency, order entry and trade volumes have all significantly increased post-event. This implies that heightened transparency is valued by uninformed liquidity traders who are now more willing to trade in the closing auction to receive the closing price.

Benefits of this change in call auction design are also apparent in less active stocks. The results indicate increased order flow over the pre-open, increased trade volumes at both the open and close, which account for a substantial proportion of daily trade volumes, and reduced return volatility. This suggests that a call auction is an important trading mechanism in less active stocks and these call auction design changes have increased this importance.

Future research on call auction design is warranted to understand how various call auction design features interact to influence price efficiency. The results suggest that a variety of factors including stock type (active or less active), the time of day (open or close), the level of transparency and the matching algorithm all need to be considered when designing a call auction. Many markets around the world have recently adopted a call auction design similar to the new ASX call auction design. The results in this paper will have relevance to such markets.

## Appendix A. Comparison of the new and old SEATS algorithm

For expositional purposes the following order book scenario will be adopted and the new and old algorithm applied to determine the call auction price:

| Broker | Quantity | Bid | Ask | Quantity | Broker |
|---|---|---|---|---|---|
| 199 | 500 | **640** | **610** | 1,000 | 606 |
| 227 | 500 | **639** | **640** | 500 | 317 |
| 298 | 500 | **639** | **641** | 520 | 150 |
| 288 | 1,000 | **634** | **642** | 550 | 203 |
| 144 | 500 | **633** | **643** | 519 | 202 |

*Old algorithm*—a weighted average price is calculated from the last two remaining orders that are matched. This price is based on the following formula:

((buy quantity × buy price) + (sell quantity × sell price))/(buy quantity + sell quantity).

The last two orders matched in this example consist of a buy order for stock X at \$6.39 (broker 227), with an available quantity of 500 shares, and a sell order for stock X at \$6.10 (broker 606) with an available quantity of 500 shares. This gives an auction price of [((500 × \$6.39) + (500 × \$6.10))/(500 + 500))] = \$6.245. This price is applied to all trades in the auction.

*New algorithm*—to facilitate the application of the new algorithm it is useful to reconfigure the example order book by sorting all prices from highest to lowest. This is presented below. The algorithm is applied as follows:

*Principle* 1. Determine maximum trade volume. As is evident from the above table, maximum trade volume occurs at prices between \$6.10 and \$6.39. As there is more than one price that exhibits maximum trade volume of 1,000 shares, progress to Principle 2.

*Principle* 2. Determine the minimum surplus within the price range, \$6.10 to \$6.39, as established in Principle 1. Minimum surplus occurs at 500 shares at each price from \$6.35 to \$6.39. As there is more than one price with minimum surplus, progress to Principle 3.

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| Price | Buy Quantity | Cumulative Buy Quantity | Sell Quantity | Cumulative Sell Quantity | Principle 1 Maximum Tradeable Volume =Min(C,E) | Principle 2 Minimum Surplus =(C-E) | Principal 3 Market Pressure |
| 643 | - | 0 | 519 | 3,089 | 0 | | |
| 642 | - | 0 | 550 | 2,570 | 0 | | |
| 641 | - | 0 | 520 | 2,020 | 0 | | |
| 640 | 500 | 500 | 500 | 1,500 | 500 | | |
| 639 | 1,000 | 1,500 | - | 1,000 | 1,000 | 500 | + |
| 638 | - | 1,500 | - | 1,000 | 1,000 | 500 | + |
| 637 | - | 1,500 | - | 1,000 | 1,000 | 500 | + |
| 636 | - | 1,500 | - | 1,000 | 1,000 | 500 | + |
| 635 | - | 1,500 | - | 1,000 | 1,000 | 500 | + |
| 634 | 1,000 | 2,500 | - | 1,000 | 1,000 | 1,500 | |
| 633 | 500 | 3,000 | - | 1,000 | 1,000 | 2,000 | |
| 632-612* | - | 3,000 | - | 1,000 | 1,000 | 2,000 | |
| 611 | - | 3,000 | - | 1,000 | 1,000 | 2,000 | |
| 610 | - | 3,000 | 1,000 | 1,000 | 1,000 | 2,000 | |

Opening price

Principle 4 not required in this example

*prices between 633 and 611 are omitted.

*Principle* 3. Determine the market pressure. In this case the surplus of 500 shares is buy surplus at each price. Buy pressure is denoted by a + sign. In this case, as only buy pressure exists, the auction price is the highest price in the range of \$6.35 to \$6.39. Therefore the auction price is \$6.39.

In this example, under the new or old algorithm, the same volume of trades execute and the best bid and ask is the same. Brokers 199 and 227 buy 500 shares each at the opening price and broker 610 sells 1,000 shares at the opening price. The best bid and ask is left at \$6.39, \$6.40. However, under the old algorithm all trades execute at \$6.245, while under the new algorithm all trades execute at \$6.39. Therefore, the new algorithm has allowed the price to adjust upwards to reflect supply and demand.

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