

## **Limit Order Book Transparency, Execution Risk and Market Liquidity**

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## **Abstract**

This paper provides new evidence regarding the effect of limit order book disclosure on trading behavior. We examine the natural experiment affected by the Sydney Futures Exchange in January 2001 when it increased limit order book disclosure from the depth at the best bid and ask prices to depth at the three best bid and ask prices. We find evidence consistent with a change in trading behavior coinciding with the increase in pre-trade transparency. Consistent with predictions of a theoretical model based on execution risk, we find a statistically significant decline in depth at the best quotes. There is little evidence of an increase in bid-ask spreads. Further, the proportion of market orders exceeding depth at the best quotes increases in a transparent limit order book reflecting a reduction in execution risk. We conclude that in a transparent market, limit order traders charge market order traders a premium for execution certainty by withdrawing depth from the best quotes, but not by reducing bid-ask spreads.

## **1. Introduction**

This paper examines the impact of disclosing market depth information in the limit order book on market behavior. Securities markets worldwide differ in their disclosure of pre-trade information. The London Stock Exchange (LSE), Singapore Stock Exchange (SGX) and Australian Stock Exchange (ASX) disclose their entire limit order books to investors and can therefore be described as highly pre-trade transparent.<sup>1</sup> In contrast, the Hong Kong Stock Exchange (HKEX) restricts disclosure to the best five bid and ask prices and aggregate order volume while the Swiss Exchange (SWX) has the least pre-trade transparent regime, revealing only the best bid and ask prices. In the last 15 years, a number of markets have moved towards disseminating more information in the limit order book to investors. In 1990 the Toronto Stock Exchange (TSE) instituted a computerised trading system called Market by Price (MBP) which enabled an increase in disclosure from the best quotes to the five best quotes and order volume. More recently, the NYSE introduced Open Book in 2002, which disseminates a snapshot of all price steps and associated depth in the limit order book at ten second intervals. The Nasdaq stock market also enabled access to more order book information in 2002 via the introduction of their SuperMontage trading system.<sup>2</sup>

The trend towards increased pre-trade transparency appears to be encouraged by securities market regulators. For example, the US Securities and Exchange Commission (SEC, 1994) and UK Office of Fair Trading (Carsberg, 1994) believe that greater pre-trade transparency will enhance liquidity and specifically market depth.<sup>3</sup> This viewpoint is consistent with the rapid growth of off-exchange trading on

Electronic Communication Network's (ECN's) which is presumed to be driven in part by the high level of order flow information available on these systems [see Lehmann and Modest (1994) and Simaan et al. (2003)].<sup>4</sup> It also figures prominently in the debate surrounding the automation of securities markets, which may offer a higher level of pre-trade transparency than floor traded systems [see Madhavan et al. (2005)], and the efficiency of auction versus dealer markets, where auction markets typically operate electronic limit order book schedules [see Pagano and Roell (1996)].

Competition amongst securities markets for order flow, regulatory interest in transparency and changes to pre-trade (quote or limit order) and post-trade (trade reporting) disclosure practices by securities markets has led to a growing academic interest in the issue. Early studies, including Madhavan (1992), Biais (1993) and Pagano and Roell (1996), develop theoretical models comparing different market structures with differing levels of pre-trade and post-trade transparency. Changes to block trade publication rules on the LSE provided the first natural experiment of a transparency regime change. Both Gemmill (1996) and Board and Sutcliffe (2000) find that delayed trade publication, representing a decrease in post-trade transparency, has no impact on market liquidity.<sup>5</sup> Laboratory experiments executed by Bloomfield and O'Hara (1999) and Flood et al. (1999) also test the impact of trade and quote disclosure in multiple dealer markets on elements of market quality.<sup>6</sup> Bloomfield and O'Hara (1999) find that trade and quote disclosure improves liquidity at the expense of price efficiency while Flood et al. (1999) find the opposite result.<sup>7</sup> More recently, the use of hidden limit orders as a means of reducing pre-trade transparency is examined by Anand and Weaver (2004), who find no evidence of a change in bid-ask spreads, execution costs or visible depth around their introduction on the TSE.

Two recent studies focus specifically on the issue of disclosing market depth information in the limit order book. Madhavan et al. (2005) and Baruch (2003) construct theoretical models to address the question of how revealing the content of the limit order book to all traders in a market affects elements of market quality. Madhavan et al. (2005) find that disclosing the content of the limit order book will result in a decrease in liquidity, as measured by market depth and the price impact of trades. A transparent market is hypothesized to enable more informed and therefore profitable order placement by market order traders resulting in a withdrawal of limit orders, by liquidity suppliers, to reduce losses. In contrast, Baruch (2003) finds that in a specialist market, disclosure would improve liquidity as measured by the price impact of market orders. In this model, fully strategic limit order traders and a specialist have an oligopoly in the market for liquidity provision. Publication of the order book increases competition amongst liquidity suppliers, resulting in decreased profits but improved liquidity. The empirical evidence is also conflicting. Madhavan et al. (2005) document a reduction in liquidity on the TSE following the increase in order book disclosure, providing support for their theoretical predictions. The authors report an increase in quoted and effective bid-ask spreads, reduction in depth at the best quotes and an increase in volatility. In contrast, however, Boehmer et al. (2005) document a reduction in effective bid-ask spreads on the NYSE following the introduction of Open Book, consistent with an increase in market liquidity. Given this volume of conflicting evidence, Boehmer et al. (2005) call for further research on the impact of changes in limit order book transparency.

The increase in limit order book disclosure on the Sydney Futures Exchange (herein SFE) provides an ideal and rare natural experiment to study the effects of a change in

pre-trade transparency. Trade on SFE currently occurs via a computerized electronic limit order book based on price and then time priority, the Sydney Computerized Market (SYCOM).<sup>8</sup> SYCOM replaced the previous open outcry market modeled on the CME with an automated screen traded market in 1999.<sup>9</sup> Initially SFE disclosed only the best bid and ask prices and aggregate depth at these prices via SYCOM. On January 22, 2001, for the stock index contracts and January 29, 2001 for interest rate contracts, SFE began disseminating the best three bid and ask prices and aggregate order volume at those prices to market participants.

We begin our analysis by developing a simple theoretical model from which we deduce testable predictions on the impact of increased limit order book disclosure on trader behavior and the subsequent effects on depth in the limit order book. Our paper extends the previous literature in three main ways. First, the increase in pre-trade transparency on SFE represents an exogenous increase in limit order book disclosure affecting all participants in the market uniformly. Prior empirical examinations of limit order book transparency are contaminated in the sense that certain participants – specialists and floor traders in Boehmer et al. (2005) and registered traders and brokers<sup>10</sup> in Madhavan et al. (2005) – already had access to the complete order book information before the changes studied. Such traders with privileged access to the order book can communicate information regarding its content to other market participants [see Baruch (2003)]. Second, this study represents the first examination of limit order book transparency where trading is conducted solely in an automated limit order book. Both prior empirical studies are complicated by a floor traded market operating in tandem with an electronic limit order book. In a limit order book market, depth can be measured precisely, whereas

in a hybrid market orders held by floor brokers and specialists willingness to provide liquidity behind posted quotes are not observable. Finally, both Schwert (1981) and Madhavan et al. (2005) identify the risk inherent in attributing any effects on market quality to a microstructural change when only a single or small number of events have been examined. This paper addresses this limitation by providing additional evidence on the impact of disclosing market depth information in the limit order book on market quality.

The remainder of this paper is structured as follows. Section 2 provides a theoretical model and develops some testable hypotheses. Section 3 describes the data set employed in the study, and the research design. Section 4 presents the results. Robustness tests are discussed in Section 5, while Section 6 provides a summary and conclusion.

## **2. Theory**

Previous theoretical literature examining the effects of disclosing market depth information in the limit order book is confined to models of hybrid auction-dealer markets. Both Baruch (2003) and Madhavan et al. (2005) feature a strategic specialist or designated dealer who has privileged access to the order book prior to the increase in pre-trade transparency and are not strictly applicable to the setting examined in this study. SFE operates a purely electronic limit order book market without the presence designated dealers or market makers.<sup>11</sup> In addition, no individual or group of individuals had privileged access to order flow prior to the change in transparency. This market setting therefore requires a theory which accounts for a uniform increase

in transparency across all market participants. In this section, we develop some theoretical rationale in such a setting, which predicts the effect of increasing the transparency of the limit order book on trading behavior, including depth and bid-ask spreads – two common measures of liquidity.

Consider a limit order book containing bid and ask quotes at different price levels and their associated order sizes. Assume that on either side of the book there are only three quoted price levels,  $p_1, p_2, p_3$ , where  $p_1$  is the best quote,  $p_2$  the second best and  $p_3$  the third best. For bid quotes  $p_1 > p_2 > p_3$  and for asks  $p_1 < p_2 < p_3$ . The distance separating consecutive prices is taken as fixed and exogenous to the model. Aggregate market depth is defined as the total volume of orders in the order book over  $p_1, p_2$  and  $p_3$ .

Two visible forms of the order book are considered. The first lacks an important element of transparency in that traders can see only the best quoted price  $p_1$  and the volume of orders at that price. Market depth beyond the best quotes is therefore unobservable. This is compared with a transparent order book, where traders can see all three prices and their associated volumes. The theoretical issue addressed here is how the probability (frequency) distribution of orders over  $p_1, p_2$  and  $p_3$  will change when the market shifts from showing depth only at  $p_1$  to  $p_1, p_2$  and  $p_3$ .

Consider a trader who wishes to fill a market order of some given size larger than the volume available at  $p_1$ , but less than total available volume at any price  $p_1, p_2$  or  $p_3$ . When the trader can see market depth only at only  $p_1$ , any market order size greater than the volume offered at  $p_1$  is risky. It may be that there is zero volume available at

$p_2$ , in which case the remainder of the market order will be filled at the least favorable price  $p_3$ .

The trader is therefore faced with a decision problem. Either he risks an unknown average price by ordering more than the volume showing at  $p_1$  or he incurs a bundle of related search costs<sup>12</sup>, including perhaps most importantly the added cost of completing his order in a market informed of his arrival and motivated by his initial clearance of the total volume showing at  $p_1$ . Whichever of these two possible execution strategies the trader follows, the expected average price (per unit) achieved in a non-transparent market over the total required order size is a random variable:

$$\lambda_1 p_1 + E[\lambda_2 p_2 + \lambda_3 p_3],$$

where  $\lambda_i$  is the proportion of the total order transacted at price  $p_i$  ( $i=1,2,3$ ) and  $\lambda_2$  and  $\lambda_3$  are unknowns ( $\lambda_1+\lambda_2+\lambda_3=1$ ).<sup>13</sup>

Now consider a fully transparent market, where by definition the average price of a market order is, with certainty:

$$\pi_1 p_1 + \pi_2 p_2 + \pi_3 p_3,$$

where  $\pi_i$  is the known proportion of the total order transacted at fixed price  $p_i$  ( $i=1,2,3$ ) ( $\pi_1+\pi_2+\pi_3=1$ ). Risk averse traders placing market orders will by definition trade at a less favorable expected (average) price when that price is certain than when it is risky. That is, for market sell orders:

$$\lambda_1 p_1 + E[\lambda_2 p_2 + \lambda_3 p_3] > \pi_1 p_1 + \pi_2 p_2 + \pi_3 p_3,$$

and *vice versa* for market buy orders. Sellers will rationally expect a lower average price, and buyers a higher average price, when this price is executed with certainty than when it is a random variable. Expected return is therefore *lower* for market order traders in an environment where execution *risk is lower*. The flip side of this argument is that limit order traders, who show more of their hand under a transparent market and therefore provide greater certainty to market order traders, are rewarded with a better average price.

The difference between the certain price available to market order traders in a transparent market and the expected price offered in a less transparent market is the premium imposed by the market (i.e. by limit order traders) in exchange for certainty. This premium is evident in the limit order book when *ceteris paribus* either (or both)  $\pi_1 < \lambda_1$  or  $\pi_2 < \lambda_2$ , meaning that less volume is available at a given price level when market depth at the next best price is transparent than when it is unobservable.

The more pronounced difference is likely to be a shift of order volume away from the best price  $p_1$  to either  $p_2$  or  $p_3$ , since limit order traders who want their orders to show can now order at either  $p_2$  or  $p_3$  when previously they had no choice but to order at  $p_1$ . There is no equivalent motivation for a shift from  $p_2$  to  $p_3$ . Orders previously at  $p_2$  did not show, but in a transparent market they will show either at  $p_2$  or  $p_3$ , making the limit trader indifferent between these two price levels from the perspective of transparency. Hence, the following testable hypothesis:

$H_1$ : Average market depth at the best available quote is less when traders are informed of market depth at the next best quoted prices.

It remains to consider the effect of transparency on bid-ask spreads (defined as the best ask price minus the best bid price). Although some proportion of limit order traders can be expected to shift their orders away from  $p_1$  when order volume shows at  $p_2$  and  $p_3$ , thus reducing average depth at the best price, there is no reason to expect that *all* limit order traders will do so. It is plausible that the marginal limit order trader will continue under most conditions, if not always, to order at  $p_1$ , thereby ensuring the earliest possible trade and maximum liquidity. The effect of transparency at price levels  $p_2$  and  $p_3$  on bid-ask spreads is therefore uncertain. It can be deduced from the economic model described above only that the average bid-ask spread will stay the same or perhaps widen on average, under transparency. Thus:

$H_2$ : Average bid-ask spreads when traders are informed of order volume at the second (and third) best prices is greater than, or equal to, average bid-ask spreads when volume is revealed only at the best price.

Suppose now that the limit order volumes available at the three prices shown are  $v_1$ ,  $v_2$ , and  $v_3$  respectively. The realized average price of market order trader is then certain up to a total volume of  $v_1+v_2+v_3$ . Pre-transparency the price risk of a market order increased for every extra unit ordered over and above  $v_1$ . Once  $v_1$ ,  $v_2$ , and  $v_3$  become transparent, a risk averse market order trader wishing to fill an order of size greater than  $v_1$  is able to do so without considering risk, and is therefore likely to order more than  $v_1$  more frequently than when the total price of such an order is uncertain. This remains the case even though the certain realized price is (per  $H_1$ ) greater than the

expected price of such an order under a non-transparent market. The risk averse market order trader is ready to pay for certainty in the total realized price, but if  $v_1$  is less under the transparent market than previously, the overall advantage from certainty is realized only by making orders generally larger than  $v_1$ , or doing so more often at least, than under a non-transparent market:

$H_3$ : The relative frequency of market order sizes greater than the volume available at the best available quote is greater when traders are informed of market depth at the next best quoted prices.

### **3. Data and Method**

The Reuters data used in this study are provided by SIRCA and are captured in real time from SYCOM. The data extends from September 15, 2000 to June 19, 2001 and straddles the dates that limit order book disclosure changed on SFE. The data contains records describing every transaction, quote change and change in aggregate limit order volume at each *disclosed* price step, time stamped to the nearest second.<sup>14</sup> SYCOM data is disseminated by SFE instantaneously to quote vendors such as Bloomberg and Reuters. They are provided with only the content of the limit order book disclosed to traders on SYCOM. The four most actively traded futures contracts on SYCOM are examined in this study. These include the Share Price Index (SPI), Bank Accepted Bills, the Three Year Bond and the Ten Year Bond futures contracts. Consistent with prior event studies in futures markets, we confine our analysis to daytime trading in the near term contract [eg. Bortoli et al. (2004), Aitken, et al. (2004)].

We apply a pre-post research design centered on the change in the transparency regime on SFE. Two subsamples of data are examined, one including days for the period when only the first *best* bid and ask prices and aggregate order volume are disclosed in the limit order book (the pre-event period) and the other including days when the *three best* bid and ask prices and aggregate order volume at each price step is disclosed (the post-event period). The increase in disclosure of the limit order book occurs part way through trading in the near term March expiry contract on January 22, 2001 for the SPI futures contract and January 29, 2001 for the interest rate futures contracts. The sampling procedure examines one complete sequence of futures data from a near term futures contract series both before and after the change in transparency for stock index and interest rate futures contracts. Hence, the pre-event period samples trading activity in the December 2000 contracts, while the post-event period samples trading activity in the June 2001 contracts, both over periods that these contracts were nearest to maturity. Specifically, the pre-event sample period chosen extends from October 2, 2000 to December 29, 2000 for the SPI futures contract and from September 15, 2000 to December 16, 2000 for the interest rate futures contracts. The post-event sample period extends from April 2, 2001 to June 29, 2001 for the SPI futures contract and from March 15, 2001 to June 15, 2001 for the interest rate futures contracts.<sup>15</sup>

The sampling procedure is designed to control for possible time to expiration effects in liquidity as the average time to maturity of the contracts for the days sampled in the pre-event period is approximately equal to that of the days sampled in the post-event period [Grammatikos and Saunders (1986)]. Consistent with Madhavan et al. (2005) the sampling procedures also allow a time delay between the event date and the

beginning of the post-event sample period mitigating possible biases from proximity to the event such as a learning effect. The final sample period consists of 123 trading days in the SPI, 126 trading days in Bank Accepted Bills and 128 trading days in the Three and Ten Year Bond futures contracts. The data includes 266,510 transactions and 551,581 quote changes in the SPI, 32,159 transactions and 109,203 quote changes in Bank Accepted Bills, 110,987 transactions and 263,350 quote changes in Three Year Bonds and 104,647 transactions and 254,453 quote changes in Ten Year Bonds.

$H_1$  and  $H_2$  are tested by examining the change in depth at the best quotes, as well as bid-ask spreads in the pre and post-event samples. Depth and bid-ask spreads are sampled each 20 minutes during the trading day and then averaged for each day. Depth is defined as the total volume available at the best standing buy and sell quotes in the limit order book at the end of each interval. The standing bid-ask spread in points is also examined. Averaging bid-ask spreads and depth to produce one observation for each day removes intraday variation across these variables, which is not of interest in this study. The actual as apposed to proportional bid-ask spread is employed in the present study since the analysis is confined to single futures contract series.<sup>16</sup> A  $t$ -test is used to examine whether the means of the variables in the pre- and post-event periods are significantly different. A non-parametric Wilcoxon rank sum test is also applied to determine if there is a change in the distribution of depth and bid-ask spreads.

Harris (1994) develops a model which identifies a number of variables that explain changes in depth, namely trading volume and price volatility. It is important to control for changes in these variables in order to ensure that any changes in depth

observed in this study are attributable to the change in transparency, and not merely to changes in market conditions which influence these variables. The model below is estimated using OLS to test the impact of increased pre-trade transparency on market depth, controlling for possible changes in known determinants;

$$DEPTH_t = a + \beta_1 D_t^L + \beta_2 VOLUME_t + \beta_3 VOLATILITY_t \quad (1)$$

where the dependent variable  $DEPTH_t$  is the logarithm of the daily average limit order volume at the best buy and sell prices. The log transformation of depth and trading volume is consistent with Harris (1994). The dummy variable  $D_t^L$  is assigned a value of 1 if the observation is drawn from the period where the best three bid-ask price steps and associated aggregate order volume are disclosed, or 0 otherwise.  $VOLUME_t$  is the logarithm of total daily traded contract volume.  $VOLATILITY_t$  is measured as the logarithm of the highest price traded divided by the lowest price traded each day [see Wiggins (1992)]. All  $t$ -statistics are adjusted for heteroskedasticity and autocorrelation using the procedure developed by Newey and West (1987).

McInish and Wood (1992) identify that trading volume and price volatility also influence bid-ask spreads. Specifically, they document that bid-ask spreads are negatively related to volume and positively related to price volatility. Hence, the parameters of the regression model presented below are estimated to control for the possibility that changes in broad market conditions may have influenced bid-ask spreads during the sample period;

$$BAS_t = \alpha + \beta_1 D_t^L + \beta_2 VOLUME_t + \beta_3 VOLATILITY_t \quad (2)$$

where the dependent variable  $BAS_t$  is the logarithm of the average bid-ask spread over day  $t$ , with bid-ask spreads sampled each twenty minutes during the trading day. The explanatory variables are as previously defined for model (1). Again, all  $t$ -statistics are adjusted for heteroskedasticity and autocorrelation following Newey and West (1987).

$H_3$  predicts that a reduction in execution risk following the increase in transparency of the limit order book is likely to encourage traders to place market orders which execute against limit orders beyond the best quotes. We calculate the number of such orders, and the number of such orders relative to the total number of transactions. A chi-square test of the difference in proportions is used to determine whether the ratio changed significantly from the pre to post samples.

## **4. Results**

### ***4.1 Tests of Hypotheses 1 and 2***

Table 1 provides summary statistics and results from tests of the impact of increased pre-trade transparency on the two liquidity measures, depth and bid-ask spreads. Panel A of Table 1 reports results for depth at the best quotes. Consistent with  $H_1$ , Panel A of Table 1 documents a decline in average depth across the four contracts examined. Increased transparency of the limit order book corresponds with a reduction in depth of 9.34 contracts in the SPI, 560.49 contracts in the Bank Accepted Bills, 722.90 contracts in the Three Year Bonds and 60.12 contracts in the Ten Year Bonds. This translates to a decline in depth of 24.58% for the SPI, 39.26% for Bank

Accepted Bills, 37.76% for Three Year Bonds and 34.07% for Ten Year Bonds. Additionally, *t*-tests comparing the means in the pre-event and post-event periods are significant at the 0.01 level for all contracts. The reduction in median depth is similar in magnitude to that documented for average depth, and is statistically significant at the 0.01 level using a Wilcoxon rank sum test.

These findings provide preliminary evidence of a deterioration in liquidity following an increase in limit order book disclosure. Consistent with  $H_1$  it appears that limit order traders retract limit order volume from the best quotes. Although consistent in direction with the results of Madhavan et al. (2005) the magnitude of reductions in depth on SFE are considerable larger than the 2% to 4% reductions reported for the TSE. We conjecture that this difference in magnitude is driven by the differences in the relative importance of the limit order books in each market. Prior to the transparency regime change the content of the TSE's limit order book was already available to exchange members and registered traders. Information pertaining to liquidity beyond the best quotes could therefore be communicated to other market participants, thereby reducing the efficacy of any increase in public limit order book disclosure. Furthermore, the TSE's limit order book market was dedicated to small market capitalization, less liquid stocks at the time of the increase in transparency examined. Thus, the market wide impact (the impact across all stocks) of the transparency change could not be evaluated. The bulk of the market, including large capitalization and more actively traded stocks, were traded on the TSE's floor, where, due to the presence of specialists providing additional liquidity to the limit order book, depth could not be reliably measured.

Panel B of Table 1 reports descriptive statistics for bid-ask spreads in the pre- and post sample periods. Average bid-ask spreads increase by 0.013068 index points or 1.24% in the SPI, 0.000128 yield points or 1.14% for Bank Accepted Bills, 0.000115 yield points or 1.14% for Three Year Bonds and 0.000093 yield points or 1.82% for Ten Year Bonds.<sup>17</sup> Consistent with  $H_2$  there appears to be a widening of bid-ask spreads following the increase in pre-trade transparency. However, evidence of this change in bid-ask spreads is generally weak. The increase in average bid-ask spreads is statistically significant for Three Year Bonds at the 0.01 level and Ten Year Bonds at the 0.05 level. Bank Accepted Bills experience a change in average bid-ask spreads which is significant at the 0.10 level while the change for the SPI contract is not statistically significant at conventional levels.

Panel B of Table 1 documents an increase in the median bid-ask spreads for the Three Year and Ten Year Bonds, significant at the 0.01 and 0.05 levels of significance respectively. There is no evidence of a change in median bid-ask spreads for SPI and Bank Accepted Bills futures contracts. Further inspection of the sample data reveals that trading is at the minimum tick for 87.76% of observations in the SPI, 95.16% of observations in Bank Accepted Bills, 97.74% of observations in Three Year Bonds and 94.39% of observations in Ten Year Bonds in the pre- and post-event periods. It is therefore not surprising to see weak evidence of a change in bid-ask spreads. In summary, consistent with  $H_2$  there is little evidence of a statistically significant change in bid-ask spreads across the futures contracts examined.

Table 2 reports descriptive statistics for the variables volume and volatility. Panel A of Table 1 documents a decrease in mean and median daily contract volume for the

SPI in the period following increased limit order book disclosure. The reduction in trading volume is significant at the 0.05 level according to both the  $t$  and  $z$ -statistics. In contrast, the interest rate futures contracts show an increase in mean and median daily traded volume, which is significant for Three Year Bonds at the 0.01 level, for Ten Year Bonds at the 0.05 level and insignificant at conventional levels for Bank Accepted Bills. An increase in volatility in the post-event period is also documented across the three interest rate futures contracts. There is little evidence of a change in volatility for SPI futures contracts. These results provide evidence of significant changes in the determinants of depth and bid-ask spreads surrounding the change in pre-trade transparency on SFE. Consequently, it is important to control for these variables in order to attribute the changes in depth and bid-ask spreads to transparency.

Table 3 reports the results of regression analysis of depth and bid-ask spreads against the explanatory variables, volume, volatility and a dummy variable for the change in limit order book transparency. The regression analysis presented below reports the effects of an increase in pre-trade transparency after controlling for changes in volume and volatility. Panel A of Table 3 presents the adjusted  $R^2$ ,  $F$ -statistic and estimates of the depth regression parameters, for each of the four contracts examined. The independent variables explain between approximately 25% and 35% of variation in the logarithm of average depth ( $DEPTH_t$ ) depending on the contract examined. This compares to Boehmer et al. (2005) who document adjusted  $R^2$  values of between 5% and 19% for models estimated in equities market.

Coefficients on the log of trading volume ( $VOLUME_t$ ) and price volatility ( $VOLATILITY_t$ ) are in the expected direction and significant at the 0.01 level across

the four contracts examined. Consistent with Harris (1994) a positive relationship is documented between  $DEPTH_t$  and  $VOLUME_t$  and a negative relationship is documented between  $DEPTH_t$  and  $VOLATILITY_t$ . Panel A of Table 3 also indicates that after controlling for the known determinants of depth, the coefficient on the dummy variable ( $D_t^L$ ) is negative and significant for all contracts at the 0.01 level. These results are consistent with  $H_1$ , that increased limit order book transparency results in a decline in depth, even after controlling for changes in possible determinants of depth. In summary, these results provide evidence of a change in the behavior of limit order traders in response to increased pre-trade transparency. The results imply that limit order traders withdraw depth from the best quotes in response to disclosure of limit order depth beyond the first price step.

Results of the regression analysis on bid-ask spreads is presented in Panel B of Table 3. The explanatory power of the models range between 10% and 46% and are similar in magnitude to those documented by Boehmer et al. (2005) and Madhavan et al. (2005) of between 5% and 58%. Consistent with McInish and Wood (1992), Panel B of Table 3 provides evidence of a negative relationship between bid-ask spreads and volume and a positive relationship between bid-ask spreads and price volatility across all contracts. The coefficient on  $VOLUME_t$  is negative and significant and the coefficient on price  $VOLATILITY_t$  is positive and significant, both at the 0.01 level, for the four contracts examined. After controlling for the determinants of bid-ask spreads, the coefficient on the dummy variable ( $D_t^L$ ) is positive for the four contracts consistent with  $H_2$ . For the Three Year Bond and Ten Year Bond contracts the coefficients on the event dummy variables are positive and significant at the 0.05 and 0.10 levels, respectfully. However, while estimated coefficients on the dummy

variable ( $D_t^L$ ) are positive for the SPI and Bank Accepted Bills, they are not significant at conventional levels. Overall, these results provide weak evidence of a widening in bid-ask spreads following the increase in pre-trade transparency. The results suggest that limit order traders withdraw depth from the best quotes, but not to the extent that bid-ask spreads often widen, consistent with  $H_2$ .

#### ***4.2 Test of Hypothesis 3***

Table 4 provides results of tests of  $H_3$ . Consistent with  $H_3$ , the number and proportion of market orders (i.e. transactions) whose volume exceeds limit order volume at the best quotes increases following the change in transparency. The number of such market orders, while small, increase from 753 to 2,320 in the SPI, 43 to 136 in Bank Accepted Bills, 142 to 1,035 in Three Year Bonds and 243 to 985 in Ten Year Bonds. In addition, the number of market orders that clear the best quotes as a proportion of the total number of transactions also increases across the four contracts examined. Table 3 documents that the increase in the proportion of market orders *clearing the best quotes* across all four contracts is significant at the 0.01 level based on a chi-square test.

These results are consistent with  $H_3$ , and provide evidence of a change in trading behavior surrounding the increase in pre-trade transparency on SFE. Large market order traders in the transparent environment no longer avoid executing orders which exceed depth available at the best quotes. In a transparent environment, depth information in the limit order book provides execution certainty for large orders and hence traders no longer suffer execution risk. Consistent with this argument, traders

execute a larger number of orders that exceed depth at the best quotes following the increase in pre-trade transparency.

## 5. Robustness Tests

This section provides additional tests to examine the robustness of the evidence presented above which documents a decline in liquidity, by way of a reduction in depth and widening in bid-ask spreads, following increased limit order book disclosure. The first robustness test divides the pre-event and post-event sample periods into subsamples in order to determine if the change in depth and bid-ask spreads presented in Table 3 is permanent through time. The pre and post-event sample periods are divided into two subsamples of an approximately equal number of trading days and assigned time period dummy variables. Subsample 1 in the pre-event period extends from October 2, 2000 to November 14, 2000 for the SPI and from September 15, 2000 to October 31, 2000 for the interest rate futures contracts.<sup>18</sup> Subsample 1 in the pre-event period is not assigned a dummy variable. Subsample 2 in the pre-event period extends from November 14, 2000 to December 29, 2000 for the SPI and from November 1, 2000 to December 16, 2000 for the interest rate futures contracts.<sup>19</sup> The dummy variable *Pre-D* is assigned a value of 1 if the observation is drawn from subsample 2 in the pre-event period, or 0 otherwise. In the post-event sample period, subsample 1 extends from April 2, 2001 to May 16, 2001 for the SPI and from March 15, 2001 to May 1, 2001 for the interest rate futures contracts. The dummy variable *Post-D*<sub>1</sub> is assigned a value of 1 if the observation is drawn from subsample 1 in the post-event period, or 0 otherwise. Finally, Subsample 2 in the

post-event period extends from May 17, 2001 until June 29, 2001 for the SPI and from May 2, 2001 until June 15, 2001 for the interest rate futures contracts and is denoted by dummy variable  $Post-D_2$ .

Table 5 reports the results of regression analysis on depth and bid-ask spreads with the inclusion of the time period dummy variables defined above. Panel A of Table 5 documents a reduction in  $DEPTH_t$  for all contracts which is persistent across both the post-event period subsamples. The coefficients on dummy variables  $Post-D_1$  and  $Post-D_2$  are negative and significant at the 0.01 level for all contracts. The robustness of our results is further emphasized by the significant decline in depth remaining despite the rise in depth prior to the opening of the limit order book, captured by  $Pre-D_2$ . The inclusion of time period dummy variables increases the explanatory power of the regression models to between 24% and 63% and they remain significant at the 0.01 level according to the  $F$ -statistics. In summary, these results provide further evidence consistent with  $H_1$  suggesting that public display of the limit order book beyond the best quotes is associated with a permanent decrease in depth.

Results for the regression on bid-ask spreads are presented in Panel B of Table 5. Coefficients on the post-event dummy variables suggest that the change in pre-trade transparency does not have a consistent effect on bid-ask spreads in the two post-event subsample periods. The coefficients on  $Post-D_1$  and  $Post-D_2$  are opposite in sign for the Bank Accepted Bills and Ten Year Bonds futures contracts. Although the coefficients on both post-event dummy variables are consistent in sign for the SPI and Three Year Bonds futures contracts, there is little evidence of a statistically significant change in bid-ask spreads. The coefficient on  $Post-D_2$  is significant at the 0.05 level

for the Three Year Bond contract only. Hence the finding that bid-ask spreads change following an increase in the transparency of the limit order book, is not robust to this alternative sampling procedure.

As a second test of robustness, regressions on depth and bid-ask spreads are estimated using an extended sample period, using six months either side of the event dates. This sampling procedure includes futures data from five near term futures contract series surrounding the increase in pre-trade transparency and provides evidence as to whether the results presented in Table 3 are robust to different sampling periods. The pre-event sample period extends from July 21, 2000 to January 21, 2001 for the SPI and from July 28, 2000 to January 28, 2001 for the interest rate futures contracts. The post-event period extends from January 22, 2001 to July 22, 2001 for the SPI and January 29, 2001 to 29 July 2001 for the interest rate contracts.

The results for the depth and bid-ask spread regression models are presented in Panel C and Panel D of Table 5 respectfully. The overall explanatory power of the regression models and  $t$ -tests are marginally lower over the longer sample period. One possible explanation is the failure to exclude a gestation period or control for time to expiration effects as in the main results. However, coefficients on the dummy variable ( $D_i^t$ ) in depth regressions (Panel C) remain negative and significant across the four contracts examined at the 0.05 level. The decline in depth following the opening of the limit order book is therefore robust to the extended sample period. The finding of a change in bid-ask spreads following the increase in pre-trade transparency, is however, not robust to the alternative sampling procedure. Panel D of Table 5, provides little evidence of a significant change in bid-ask spreads. While coefficients

on the dummy variable  $D_i^l$  are positive across the four contracts examined, they are significant only at the 0.10 level for the Bank Accepted Bills and Ten Year Bond contracts.

## **6. Conclusion**

This paper examines the effect of limit order book disclosure on trading behavior by examining an exogenous increase in pre-trade transparency affected on SFE in the year 2000. We begin by developing theoretical rationale which suggests market order traders pay a liquidity premium for execution certainty, and consequently predict that depth will fall in a transparent market while bid-ask spreads will be greater than or equal to bid-ask spreads in a non-transparent market. Consistent with these predictions, the increase in limit order book disclosure coincides with a statistically significant reduction in depth at the best quotes. The reduction in depth persists even after controlling for known determinants of depth. Furthermore, there is little evidence of a statistically significant change in bid-ask spreads. Finally, the frequency of market orders exceeding depth at the best quotes increases significantly. We conclude that in a transparent market, limit order traders charge market order traders a premium for execution certainty by withdrawing depth from the best quotes, but not by reducing bid-ask spreads. Market order traders are also more willing to submit orders which clear the best quotes and execute with limit orders behind the best quotes.

Proposed changes to limit order book disclosure on SFE provide opportunities for further research into pre-trade transparency. At the time of writing the exchange is considering a change in limit order book disclosure from the best three to the best five prices for its equity and interest rate futures contracts. The effect of this additional increase in pre-trade transparency on market behavior is worthy of examination. The further opening of a limit order book, an increase in pre-trade transparency beyond the first three best prices, is yet to be examined and will provide evidence relevant to literature concerning the information content of limit orders as well as transparency. A second change to pre-trade transparency on SFE occurred in February, 2004 when the exchange introduced pre-trade anonymity in all Australian interest rate futures contracts. The effect of removing broker identities, a decrease in pre-trade transparency, is both a topic that has received little attention in the literature and one that has yet to be examined in the context of a futures market.

**Table 1**  
**Limit Order Book Liquidity**

	Share Price Index			Bank Accepted Bills			Three Year Bonds			Ten Year Bonds		
	Pre	Post	$\Delta$	Pre	Post	$\Delta$	Pre	Post	$\Delta$	Pre	Post	$\Delta$
<i>Panel A: Depth</i>												
Mean	37.99	28.65	-9.34	1427.61	867.13	-560.49	1914.00	1191.10	-722.90	176.48	116.36	-60.12
Median	32.45	29.23	-3.22	1264.61	801.82	-462.79	1796.98	1156.75	-640.22	159.68	114.53	-45.16
Std Dev	17.05	7.18		564.15	268.13		797.46	276.48		79.78	23.39	
<i>n</i>	63	60		65	61		66	62		66	62	
<i>t</i> -stat			-3.92*			-7.19*			-6.76*			-5.71*
<i>z</i> -stat			-3.37*			-6.43*			-6.45*			-6.37*
<i>Panel A: Bid-Ask Spreads (Contract Points)</i>												
Mean	1.048950	1.062018	0.013068	0.010056	0.010184	0.000128	0.010060	0.010175	0.000115	0.005114	0.005207	0.000093
Median	1.050000	1.050000	0.000000	0.010000	0.010000	0.000000	0.010000	0.010100	0.000100	0.005000	0.005104	0.000104
Std Dev	0.039784	0.068827		0.000164	0.000498		0.000186	0.000222		0.000190	0.000319	
<i>n</i>	63	60		65	61		66	62		66	62	
<i>t</i> -stat			1.30			1.96***			3.18*			2.02**
<i>z</i> -stat			0.60			0.07			7.87*			1.73**
*	Significant at the 0.01 level											
**	Significant at the 0.05 level											
***	Significant at the 0.10 level											

Descriptive statistics are provided for measures of market liquidity surrounding the increase in pre-trade transparency on the Sydney Futures Exchange (SFE). The transparency of the limit order book was increased from the best bid-ask prices to the three best bid-ask prices for the Share Price Index futures contract on January 22, 2001 and for the interest rate contracts on January 29, 2001. The pre-event sample period extends from October 2, 2000 to December 29, 2000 for the Share Price Index futures contract and from September 15, 2000 to December 16, 2000 for the interest rate futures contracts. The post-event sample period extends from April 2, 2001 to June 29, 2001 for the Share Price Index futures contract and from March 15, 2001 to June 15, 2001, for the interest rate futures contracts. Depth and bid-ask spreads are sampled each 20 minutes during the trading day. Depth is defined as aggregate limit order volume at the best buy and best sell price. The bid-ask spread is the best ask price minus the best bid price in contract points. A time series of daily averages are calculated. Both *t*-tests and Wilcoxon *z*-tests are used to determine whether the change in variables across the pre- and post-event periods is significant.

**Table 2**  
**Determinants of Limit Order Book Liquidity**

	Share Price Index			Bank Accepted Bills			Three Year Bonds			Ten Year Bonds		
	Pre	Post	$\Delta$	Pre	Post	$\Delta$	Pre	Post	$\Delta$	Pre	Post	$\Delta$
<i>Panel A: Volume</i>												
Mean	8675	7664	-1011	8363	9436	1073	21959	29968	8009	7633	9072	1439
Median	8631	7630	-1001	7402	8320	918	19192	24791	5599	6512	8114	1602
Std Dev	2373	2419		4945	5315		12375	16822		4219	5452	
<i>n</i>	63	60		65	61		66	62		66	62	
<i>t</i> -stat			-2.34**			1.17			3.08*			1.68**
<i>z</i> -stat			-2.22**			1.33			2.68*			1.59**
<i>Panel B: Volatility</i>												
Mean	0.008129	0.008473	0.000344	0.000372	0.000595	0.000223	0.000545	0.000826	0.000281	0.000546	0.000709	0.000163
Median	0.007473	0.007373	-0.000100	0.000321	0.000524	0.000203	0.000478	0.000736	0.000259	0.000506	0.000639	0.000133
Std Dev	0.002516	0.003888		0.000208	0.000339		0.000266	0.000350		0.000226	0.000242	
<i>n</i>	63	60		65	61		66	62		66	62	
<i>t</i> -stat			0.59			4.48*			5.13*			3.94*
<i>z</i> -stat			-0.50			3.49*			4.62*			3.83*
*	Significant at the 0.01 level											
**	Significant at the 0.05 level											
***	Significant at the 0.10 level											

Descriptive statistics are provided for volume and volatility surrounding the increase in pre-trade transparency on the Sydney Futures Exchange (SFE). The transparency of the limit order book was increased from the best bid-ask prices to the three best bid-ask prices for the Share Price Index futures contract on January 22, 2001 and for the interest rate contracts on January 29, 2001. The pre-event sample period extends from October 2, 2000 to December 29, 2000 for the Share Price Index futures contract and from September 15, 2000 to December 16, 2000 for the interest rate futures contracts. The post-event sample period extends from April 2, 2001 to June 29, 2001 for the Share Price Index futures contract and from March 15, 2001 to June 15, 2001, for the interest rate futures contracts. Volume is measured as the daily total number of contracts traded. Price volatility is measured as the logarithm of the highest price traded divided by the lowest price traded each day. Daily contract volume and price volatility time series are constructed. Both *t*-tests and Wilcoxon *z*-tests are used to determine whether the change in variables across the pre- and post-event periods is significant.

**Table 3**  
**Regression Analysis**

	Share Price Index		Bank Accepted Bills		Three Year Bonds		Ten Year Bonds	
	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic
<i>Panel A: Depth</i>								
Constant	1.4685	2.65*	6.0327	21.66*	5.9281	22.92*	3.3543	9.69*
D	-0.1899	-4.20*	-0.4427	-6.03*	-0.4161	-7.12*	-0.3408	-8.12*
Volume	0.2586	3.99*	0.1535	6.66*	0.1714	6.28*	0.2220	5.86*
Volatility	-29.1460	-3.16*	-466.2962	-3.26*	-236.2039	-4.09*	-371.3840	-4.63*
Adj <i>R</i> <sup>2</sup>		0.2482		0.4492		0.3610		0.3775
<i>F</i> -stat		14.42*		34.98*		24.91*		33.39
<i>n</i>		123		126		128		128
<i>Panel B: Bid-ask spreads (contract points)</i>								
Constant	0.372628	8.72*	-4.357126	-110.01*	-4.509972	-187.86*	-4.952354	-44.02*
D	0.003170	0.95	0.002439	1.20	0.004845	2.61**	0.011784	1.91***
Volume	-0.038691	-8.06*	-0.030231	-6.59*	-0.010919	-4.46*	-0.040792	-3.00*
Volatility	2.915051	4.04*	64.763851	6.16*	31.666177	16.61*	63.824053	4.07*
Adj <i>R</i> <sup>2</sup>		0.1030		0.3528		0.4596		0.1854
<i>F</i> -stat		5.67*		23.72*		37.01*		10.63*
<i>n</i>		123		126		128		128
*	Significant at the 0.01 level							
**	Significant at the 0.05 level							
***	Significant at the 0.10 level							

This table reports regression results for models of depth and bid-ask spreads surrounding the increase in pre-trade transparency on the Sydney Futures Exchange (SFE). The transparency of the limit order book was increased from the best bid-ask prices to the three best bid-ask prices for the Share Price Index futures contract on January 22, 2001 and for the interest rate contracts on January 29, 2001. The pre-event sample period extends from October 2, 2000 to December 29, 2000 for the Share Price Index futures contract and from September 15, 2000 to December 16, 2000 for the interest rate futures contracts. The post-event sample period extends from April 2, 2001 to June 29, 2001 for the Share Price Index futures contract and from March 15, 2001 to June 15, 2001, for the interest rate futures contracts. The parameters of the following model of depth are estimated:

$$DEPTH_t = \alpha_0 + \beta_1 D_t^L + \beta_2 VOLUME_t + \beta_3 VOLATILITY_t$$

The parameters of the following model of bid-ask spreads are estimated:

$$BAS_t = \alpha_0 + \beta_1 D_t^L + \beta_2 VOLUME_t + \beta_3 VOLATILITY_t$$

Where  $DEPTH_t$  is the logarithm of average limit order volume at the best buy and best sell quotes for day  $t$ .  $BAS_t$  is the logarithm of the average bid-ask spread for day  $t$ . Depth and bid-ask spreads are sample each 20 minutes during the trading day.  $D_t^L$  is a dummy variable assigned a value of 1 if the observation is drawn from the post-event period, or 0 otherwise.  $VOLUME_t$  is the logarithm of total daily contract volume.  $VOLATILITY_t$  is measured as the logarithm of the highest price traded divided by the lowest price traded each day. All *t*-statistics are adjusted for heteroskedasticity and autocorrelation using the procedure developed by Newey and West (1987).

**Table 4**  
**Market Orders Clearing Depth at the Best Quotes**

	Share Price Index			Bank Accepted Bills			Three Year Bonds			Ten Year Bonds		
	Pre	Post	$\Delta$	Pre	Post	$\Delta$	Pre	Post	$\Delta$	Pre	Post	$\Delta$
<i>Panel A: Market Orders Clearing Depth at the Best Quotes</i>												
<i>n</i>	753	2320	1567	43	136	93	142	1035	893	243	985	742
<i>n</i> as a Proportion of Total	0.5384	1.8320	1.2936	0.3220	0.7232	0.4012	0.3214	1.5493	1.2279	0.5531	1.6225	1.0694
No. Transactions (%)												
Total No. Transactions	139869	126641		13354	18805		44175	66803		43937	60710	
Chi-square stat.			975.80 *			22.71 *			382.07 *			251.36 *
*	Significant at the 0.01 level											
**	Significant at the 0.05 level											
***	Significant at the 0.10 level											

This table presents descriptive statistics for market orders clearing depth at the best quotes. Trading in the near term contract for the four most liquid series trading on the Sydney Futures Exchange (SFE) is examined surrounding the increase in pre-trade transparency on the exchange. The transparency of the limit order book was increased from the best bid-ask prices to the three best bid-ask prices for the Share Price Index futures contract on January 22, 2001 and for the interest rate contracts on January 29, 2001. The pre-event sample period extends from October 2, 2000 to December 29, 2000 for the Share Price Index futures contract and from September 15, 2000 to December 16, 2000 for the interest rate futures contracts. The post-event sample period extends from April 2, 2001 to June 29, 2001 for the Share Price Index futures contract and from March 15, 2001 to June 15, 2001, for the interest rate futures contracts. Panel A presents the number and proportion of market orders that exceed limit order volume at the best quotes. Tests of significance of the difference in proportions between the pre- and post-event period sample periods are made using a chi-square test.

**Table 5**  
**Robustness Tests**

	Share Price Index		Bank Accepted Bills		Three Year Bonds		Ten Year Bonds	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
<i>Panel A: Depth – Time Period Dummy Variables</i>								
Pre-D <sub>2</sub>	0.0817	1.82***	0.5141	10.77*	0.2821	5.71*	0.1862	5.11*
Post-D <sub>1</sub>	-0.1577	-4.30*	-0.1669	-4.88*	-0.3039	-6.62*	-0.2945	-10.19*
Post-D <sub>2</sub>	-0.1343	-3.57*	-0.2621	-7.83*	-0.2599	-5.56*	-0.2200	-9.17*
Adj R <sup>2</sup>		0.2435		0.6297		0.4257		0.4118
F-stat		8.85*		43.52*		19.83*		18.79*
N		123		126		128		128
<i>Panel B: Bid-ask spreads – Time Period Dummy variables</i>								
Pre-D <sub>2</sub>	-0.004196	-1.01	-0.001287	-0.43	0.004241	1.05	0.001454	0.31
Post-D <sub>1</sub>	0.000587	0.09	-0.001881	-0.65	0.005235	1.50	0.031061	7.16*
Post-D <sub>2</sub>	0.001241	0.21	0.005112	1.45	0.008318	2.49**	-0.003080	-1.11
Adj R <sup>2</sup>		0.0886		0.3477		0.4594		0.2343
F-stat		3.37*		14.32*		22.59*		8.77*
n		123		126		128		128
<i>Panel C: Depth – Increased Sample Period</i>								
D	-0.0641	-2.09**	-0.2020	-2.65*	-0.1946	-2.13**	-0.1700	-3.11*
Adj R <sup>2</sup>		0.2169		0.2736		0.1714		0.2187
F-stat.		17.79*		23.91*		13.37*		17.82*
n		247		247		245		245
<i>Panel D: Bid-ask spreads – Increased Sample Period</i>								
D	0.000880	0.13	0.008829	1.84***	0.000002	0.01	0.006316	1.892508***
Adj R <sup>2</sup>		0.1185		0.2156		0.2090		0.1330
F-stat.		9.02*		17.65*		16.87*		10.23*
n		247		247		245		245
*	Significant at the 0.01 level							
**	Significant at the 0.05 level							
***	Significant at the 0.10 level							

This table reports results of robustness tests. Panel A presents results of regression models on depth and bid-ask spreads when the pre-event and post-event sample periods are each divided into two subsamples of an approximately equal number of trading days. The subsamples are assigned time period dummy variables in order to determine if the changes in depth and bid-ask spreads are permanent through time. In the pre-event period, subsample 1 is not assigned a dummy variable while subsample 2 is denoted by the dummy variable *Pre-D*. In the post-event period, subsample 1 and subsample 2 are assigned dummy variables *Post-D<sub>1</sub>* and *Post-D<sub>2</sub>* respectively. A dummy variable takes a value of 1 if the observation is drawn from the time period to which it is assigned, or 0 otherwise. Panel B presents results of regression models on depth and bid-ask spreads using an extended sample period of six months either side of the transparency change event dates. The parameters of the following depth regression model are estimated:

$$DEPTH_t = \alpha_0 + \beta_1 VOLUME_t + \beta_2 VOLATILITY_t + \beta_k D_k$$

The parameters of the following bid-ask spread regression model:

$$BAS_t = \alpha_0 + \beta_1 VOLUME_t + \beta_2 VOLATILITY_t + \beta_k D_k$$

All t-statistics are adjusted for heteroskedasticity and autocorrelation using the procedure developed by Newey and West (1987).

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<sup>1</sup> Both the ASX and LSE allow hidden orders which reduce order book transparency. These hidden orders take the form of an order where part of the order volume is disclosed and the remainder is hidden. The entire order volume can also be hidden on the ASX.

<sup>2</sup> Supermontage was introduced on Nasdaq on October 14, 2002. The system displays the depth at the five best bid and ask prices. The complete schedule of limit orders is available for an additional subscription fee.

<sup>3</sup> Both regulatory bodies also argue that pre-trade transparency promotes fairness and efficiency in securities markets.

<sup>4</sup> ECN's include Instinet, Tradebook and Terra Nova. Some ECN's allow participants to view real time depth information from a limit order book managed by the ECN, for securities traded on organised secondary equities markets. However, other ECN's provide trader anonymity which represents a decrease in pre-trade transparency. Orders matched on an ECN are routed directly to the exchange avoiding execution by a broker.

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<sup>5</sup> Porter and Weaver (1998) document the use of delayed trade reporting on Nasdaq. The authors do not explicitly examine the impact of delayed reporting on market quality, however evidence consistent with the use of late trade reporting to delay the release of strategic information is found.

<sup>6</sup> Bloomfield and O'Hara (1999) find that trade disclosure leads to greater informational efficiency, higher bid-ask spreads and a wealth transfer from informed and uninformed traders to market makers. In contrast, when quotes are disclosed Flood et al. (1999) find that opening spreads are smaller, volume is higher and price efficiency declines.

<sup>7</sup> Anand and Weaver (2003) observe that differences in the microstructure of the two experimental markets and as well as the type of transparency studied are likely to drive these differences.

<sup>8</sup> SYCOM was launched on 30 November 1989 as an overnight trading system. SYCOM enabled overseas investors to trade the Australian futures market during their day trading hours and allowed Australian investors to manage risk overnight. Upon its launch, SYCOM was the first after hours electronic trading system in the world.

<sup>9</sup> Prior to October 4, 1999 for interest rate products and November 15, 1999 for the Share Price Index futures contracts, day trading occurred in an floor traded market.

<sup>10</sup> During the period examined by Madhavan et al (2005) the TSE operated two separate trading systems; an electronic limit order book market, the Computer Aided Trading System (CATS), and a floor traded system which operated much like the NYSE. Prior to the change in pre-trade transparency on April 12, 1990 Participating Organizations and Member Firms of the TSE already had access to the complete order book for stocks listed on CATS. It was only the dissemination of the order book to the public which was restricted to the best bid and ask prices and aggregate limit order volume at those prices. For stocks listed on the floor traded market Registered Traders (specialists) were also provided with complete access to the limit order book. Public dissemination of the order book was again restricted to the best prices and associated aggregate order volume.

<sup>11</sup> The four major contracts examined in this study do not have designated dealers. Smaller less liquid series are assigned designated market makers.

<sup>12</sup> One possible strategy to reduce risk is for the traders to make an initial order just sufficient to clear away all the available volume at  $p_1$  thereby revealing order volume at the next best price  $p_2$ . This trading strategy has its own risk in that the market will infer from an order of exactly this size that the trader is interested to some extent in proceeding with further trades in the same direction. The market may therefore move immediately against the trader, before any further trade is executed. Specifically, much or all of the volume available at  $p_2$  may shift to  $p_3$ , meaning that the trader can only complete a larger order size at a worse average price than if he had made a single market order of this size in the first instance. This is one possible strategy to reduce risk, others are possible.

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<sup>13</sup> Traders may employ other more elaborate or covert search strategies than merely clearing all the volume at  $p_1$ , but whatever strategy they apply they cannot achieve a certain average price per unit.

<sup>14</sup> Unfortunately data beyond depth at the best price steps prior to the change in limit order book disclosure is unavailable.

<sup>15</sup> The robustness of results to alternative sampling periods are discussed in Section 5.

<sup>16</sup> Spurious results may be generated by the proportional bid-ask spreads in time series futures data. If a contracts bid-ask spread remains constant over time and the contracts price is trending, the proportional bid-ask spread will change. A proportional bid-ask spread is employed to control for heterogeneity across stocks in cross sectional analysis of time series equities data [see for example McNish and Wood (1992) and Harris (1994)].

<sup>17</sup> Interest rate futures are quoted in yield points on SFE. Specifically the price of an interest rate futures contract is expressed as 100 minus the yield to maturity expressed in cents per annum. This pricing convention reflects the pricing of interest rate securities on the basis of yield to maturity in the cash market in Australia. In contrast, interest rate securities in the US are traded on the basis of their capital price and are quoted in dollars. A bond price is quoted as the value per 100 dollars of the face value of the bond.

<sup>18</sup> The pre-event period consists of 63 trading days in the SPI futures contract. This odd number prohibits an equal division of trading days. Sub-sample 1 is assigned the first 32 trading days and sub-sample 2 consists of the remaining 31 trading days.

<sup>19</sup> There are two days of missing data for the Bank Accepted Bills futures contracts, one day in each of the pre-event subsamples.