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DMA Trading and Crossings on the Australian Stock Exchange

Vladimir Kazakov and Tom Vasak

DMA Trading and Crossings
on the Australian Stock Exchange

Vladimir Kazakov[1] and Tom Vasak[2]

Abstract

The feature that differentiates the Australian Stock Exchange (ASX) from all other markets is the unique set of rules that govern crossings – internal trades between two clients of the same broker. The recent rise of the low-margin direct market access (DMA) trading has created new interest for the use of crossing. In this paper we discuss the use of crossings on the ASX, its benefits, risks and costs. We identify stock properties that determine these benefits and risks. We estimate these properties from the historic data.

[1] UTS, *vladimir.kazakov@uts.edu.au*
[2] Open Data Pty Ltd*, tomv@open-data.net*

1. Introduction

Qualitative benefits of internalisation are well-known – reduced market impact and volatility, faster execution and price improvement. Internalisation has been quite widely studied in the electronic US markets where brokers can divert flows to ECN markets where crossing usually takes place generally at the mid-price of best bid/ask spread. There is no compulsion for brokers to trade through the exchange on which the security is listed or even to report the trade to that exchange. Furthermore the execution fees for any trades matched on an ECN will typically be at a discount to having executed through the listing exchange.

In comparison, the Australian market is considerably more regulated in that crossings need to take place in accordance with a rigid set of ASX business rules. For parcels of stock with a value of under $AU1m, these must be crossed via an on-market crossing. Crossings in excess of this value can be executed as an off-market crossing and are subject to less onerous rules – they can be transacted at any price and other market participants cannot interfere in their transaction[1]. This paper will constrain its discussion exclusively to on-market crossings.

The current interest in use of crossing is the direct result of the recent increase in the DMA trading. DMA orders submitted to the broker by electronic means from the buy side and are routed with the lowest latency possible into the market. It allows the buy side to have almost complete control over the trading of their orders in the market. DMA as a percentage of total broker order flow is growing steadily. In the US, DMA accounted for somewhere between 33% and 39% (as of 2004) of all activity [1,3] and in Australia, it is 7% [2] and growing steadily. Typically the broker provides the buy side with a fast electronic pipe into the market. The broker does not interact with the order flow other than to perform a range of compliance checks than ensure that the orderly conduct of the market is maintained. The buy side pays a significantly discounted brokerage fee.

The growth of DMA at the expense of traditional full service broking is eroding broker profit margins. One possible way for brokers to compensate for this is to leverage this flow by crossing it against complementary order flows. Unlike conventional order flow that has no real latency constraints, speed to market is critical for DMA platforms to support buy-side algorithmic trading strategies. This means that the ability for the broker to leverage the full value of the DMA flow by being able to cross other agency flow against it is very difficult. The only way to derive additional value from this flow is through the use of a very high speed fully automated crossing program.

The aims of this paper are to
- (a) Determine the risks and benefits of crossing orders on the ASX
- (b) Find factors that determine these risks and benefits and then estimate them from trading data.
- (c) Estimate risks and benefits for different stocks and intra-day periods.

2. Definitions

There are two types of on-market crossings that can be transacted.

The first type is where a broker enters an order that, due to normal order priority, matches one of the broker's own pre-existing orders already in the market. Such a crossing can occur either intentionally or accidentally. If the order that matches the broker's pre-existing order is placed intentionally, ASX business rules dictate that the pre-existing order had to be in the market at the current price for at least 10 seconds. If the order that matches the broker's pre-existing order is placed as a result of client-originated DMA flow, this 10 second rule is waived.

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[1] Consequently off-market trades are typically not included in the calculation of the value-weighted average price (VWAP).

The other type of crossing is called a priority crossing. Here the broker submits a cross order to the market which consists of two complementary buy/sell orders at the specified crossing price. It is intended that these orders execute against each other if circumstances permit. One of these orders can be thought of as the market order (crosses the prevailing spread), while the other is a limit order (does not cross the spread). In the context of the DMA trading, the market order is typically a DMA order while the limit order is an order from the broker's internal liquidity pool. An alternative nomenclature is to refer to the market order as the active side while the limit order is termed the passive side. Crossing order receives time priority at the crossing price ahead of all the other orders, already waiting in the book. However, any orders at a better price than the crossing price will be executed before the crossing orders. Crossing engine uses such time-priority suppressing on-market crossings to transact in the market. In the remainder of the paper, we shall refer to an on-market priority crossing simply as a crossing.

ASX Market Rule 17.2.4 imposes a condition that a so-called "crossing market" (where the bid-ask spread of the security is a single price step has been in place for at least 10 seconds) before a priority crossing can be executed. This is known as the ACE rule:
- Appear at the crossing price (have a quote at this price);
- Create a crossing market; and
- Execute the crossing.

If broker wants to cross two orders and spread is wider than the minimal price step, then he submits a dummy order (typically one share order) one price step from the bid or ask and waits 10 sec to see if crossing market will be established. If spread widens again before 10 sec ends, then he may choose to try again or abandon the crossing attempt. The frequent use of one share orders on the ASX is the direct consequence of this unique microstructure rule.

3. Pools of Liquidity

There are two logical pools of liquidity available to the broker. One is the broker's internal liquidity pool of orders being worked over the day. This is termed just as the Liquidity Pool. The other pool is the set of broker's limit orders currently sitting in the market's order book.

4. Crossing Benefits

4.1 Immediacy for liquidity supplier

When the broker decides to cross two orders, he checks if a crossing market exists. If it does then the crossing order at the best book price will result in immediate trade between limit and market order components of the crossing, ahead of all the other orders in the book. If spread widens by the time the crossing order is received, then the crossing fails and its liquidity (both components) are returned to the broker without exposing it to the market.

4.2 Better price or higher volume at the same price for market order side

When the crossing price is not the current best bid or best ask price, then price priority intervenes. The market order side of the cross first executes all orders in the market's limit order book at a better price, and then crosses its residual volume against its limit order side. Suppose a crossing market exists, the broker has liquidity he is prepared to trade at the second best book price and which he does not want to show to the market, and he also has a market order with the quantity exceeding all quantity at the first and second price levels in the book. If he submitted this market order directly into the market then it would "walk up" the book, trading partially at first, second and third best prices. If the cross order at the second best book price is submitted which consists of the same market order and of a limit order for the quantity equal to the market order's quantity minus best price quantity in the book, then the market order will be partially traded against book's liquidity at best price and its residual will be traded against limit side of the cross. Here again liquidity will not be shown to the market before trade occurs or if it fails, and this liquidity will be traded ahead of all orders already waiting execution at the second best price. Thus, the market order side of

the cross obtains better price that if it would if traded directly in the market. Limit order side traded more volume without disclosing it if cross fails to execute. Thus, the cross can be constructed with market side volume larger than the limit book side's volume, to rely on time priority to execute its market side volume partly against market's limit book and partially against broker's liquidity pool.

To summarize, the benefits of crossing in comparison to the direct on-market execution are:

1. Market order side of the cross may get better price and may make lesser price impact if crossing price is different from the current best bid/ask price;
2. Market order side of the cross may get to trade more volume at the same price.
3. Limit order side may be able to trade immediately and still collect the spread, and be able to conceal liquidity from the market in cross fails.
4. Limit order side may be able to transact faster.
5. Limit order side may get to trade more volume at the same price over the same period.

5. Crossing Risks

5.1 Under-execution of the limit order side

If the crossing price is worse than the best bid or the best ask then the broker needs to know the depths at all price levels below the crossing price in order to achieve execution he planned, which includes trade of all volume in the limit order side against a part of the volume in market order side of the cross. The necessary condition for the predicted and achieved execution being the same (including predicted and achieved prices being the same) is the state of the limit order book when crossing order is transacted being the same as broker assumed it to be when he formulated the crossing.

It is possible that when a crossing order is transacted, then this depth is larger, that is, the limit book contains more limit orders from other brokers priced better than the crossing price than it had when this crossing order was constructed. The crossing order then will transact more volume from other brokers and less broker's own volume of the limit side than it was planned. Theoretically this could happen extremely rarely, when another broker happens to submit his order during short time window between submission of the cross and its transaction. In practice, various delays in SEATS engine operations/ communications may result in the broker observing a slightly out-of-date state of the market's limit order book. Therefore, the information about book depths used to plan the crossing order execution can be inaccurate resulting in under execution on the limit side much more frequently than in the ideal system with instantaneous communications/ transactions and no errors/ delays.

Another factor that prevents the broker from finding the true depth is the appearance of orders with hidden volume in the book – undisclosed orders (currently used on the ASX) and/or iceberg orders (to be introduced by the ASX in its new ITS trading system in October 2006). It is known that hidden orders are widely used in other order-driven markets, e.g. on the NASDAQ, where hidden liquidity represents 20% of the inside depth on the 100 largest stocks [4][5], on Spanish Stock Exchange where 26% of all trades involve hidden volume [6], on Euronext Paris, the hidden depth represents 45% of the total depth at the five best quotes and 55% of the total depth at the best price [7]. This large scale use of hidden liquidity leads to the discrepancy between the pre-calculated crossing behavior using data from the observed limit order book and the actual achieved transaction prices for 37% of all orders submitted to Euronext, with average size of 0.86% [8].

It was reported [9] that in 1993, 6% of orders on the ASX with approximately 28% of the total volume where undisclosed. Subsequent increases in the threshold in 1994 and 1996 led to the reported decrease in the share of undisclosed orders by 32% for low cap stocks and by 9% for high cap stocks [10].

Our own analysis shows that currently the use of the undisclosed orders on the ASX has become so infrequent that it poses virtually no risk of under execution for crossing orders.

5.2 Over-execution on the limit order side

When crossings are transacted against limit orders already in the market, there is no explicit connection between the crossing limit order and the limit order in the market being crossed. The broker effectively submits an independent pair of orders when executing a crossing. The existing limit order that is notionally being crossed must be reduced or cancelled. It is possible that in times of high market activity that the crossing could be transacted successfully but the limit order that was logically crossed could also execute before it could be cancelled. In order to minimize the chance of over-execution, it might appear to be wise to first reduce the quantity of this order to one share, before transacting the crossing. However, this sacrifices the ability to take advantage of a favorable time-priority position in the order book if there is further liquidity in the Liquidity Pool at a compatible price that can be shifted into the market.

5.3 Market order side price risk from delayed execution

In effect when the broker commits to a cross, he takes a position on the market order side of this cross. If crossing market does not exist then the broker has to wait until it is created. He has to hold this position when he waits. There is no certainty that waiting will be successful and cross will be executed as planned. If crossing market is not established then the marker order side of the cross must be liquidated – either at the current price which may be inferior to the crossing price or by trading it over some time period. Either way, the broker here bears the risk. The longer the wait is, the higher is this risk. The waiting time (or its proxy - the number of attempts to create crossing market by submitting dummy one share orders) as well as the crossing price, volume of the limit/market order sides and where the limit side is (in the book or in the liquidity pool) are the control parameter of a cross.

6. Simulation and Analysis Techniques

Analyses and simulations were based upon data captured from the ASX SEATS Open Interface. Captured ASX data include the complete set of order quotes, trading records and market status changes for the entire market. Software has been developed for replaying market trading using these quotes and market status changes. It includes the complete trade execution logic of the ASX. The user can modify the quotes and then to replay the modified market. The result of the simulation will be exactly the same as if clients modified their quotes in this way in the original market. This market trading simulation model has two principal weaknesses. Firstly, it is not possible to determine whether the order that crossed the spread was a market order with no price limit (that is, that order was to buy the given amount of shares) or market order with price limit (to buy everything up to some price) which leaves the residual in the market's limit order book. Both interpretations are equivalent for the actual trading trajectory and remain equivalent as long as the perturbed trajectory remains close to the original one. Secondly, because the replayed market cannot react to the user modification of the quotes, the amount of perturbance has to be low, to make simulations valid. For example, this can be achieved if the volume of the modified quoted is kept below 3% of the daily turnover.

7.   Empirical Analysis of the aspects of trading on the ASX relevant for crossing

This section examines empirical factors that determine the risks and benefits associated with crossing on the ASX

- The higher is the **average fraction of the trading day** when crossing market "naturally" exists in a given security, the lower is the probability that the crossing market does not exist when required, less expected waiting time is necessary, and the smaller is the price risk for market side from delayed execution.
- The **intra-day variation of the fraction of the trading time** when crossing market exists in a given security determines the distribution of the price risk for market side across trading day.
- The **waiting time for a limit order** submitted at the best bid/ask price . The higher is this time, the higher is the potential time saving if a cross is used instead of limit order. The higher the average **depth in the book**, the higher is the potential saving in execution time from a cross.

- The lower is **the fraction of limit orders submitted at the best bid or ask which were executed**, the higher will be the potential from being able to cross at the current best price rather than being forced to offer an inside spread or market order to force execution.
- The more **minimal price steps between is between two best priced asks/ bids,** the higher is the feasible reduction in price impact that can be negotiated between the market side and limit sides of crossing.
- The higher is the **fraction of the stocks with undisclosed orders and higher is their frequency**, the higher is the probability on under execution on the limit order side. The higher is the **average size of undisclosed orders in comparison to the current depth**, the more inaccurate will be the depth measurement and the higher will be the expected under-execution.

7.1 Crossing Risk by Security via the average portion of the trading day with crossing market

It is clear that the price risk of crossing due to delayed execution for a particular security is inversely proportional to the fraction of the trading day when a crossing market existed for the security. We measured it for stocks over 45 day sample. The results are shown in Figure 1. The summary tables 1 and 2 list stocks with low and high crossing risks. Complete table of crossing risks for all stocks in the sample are given in the Appendix A.
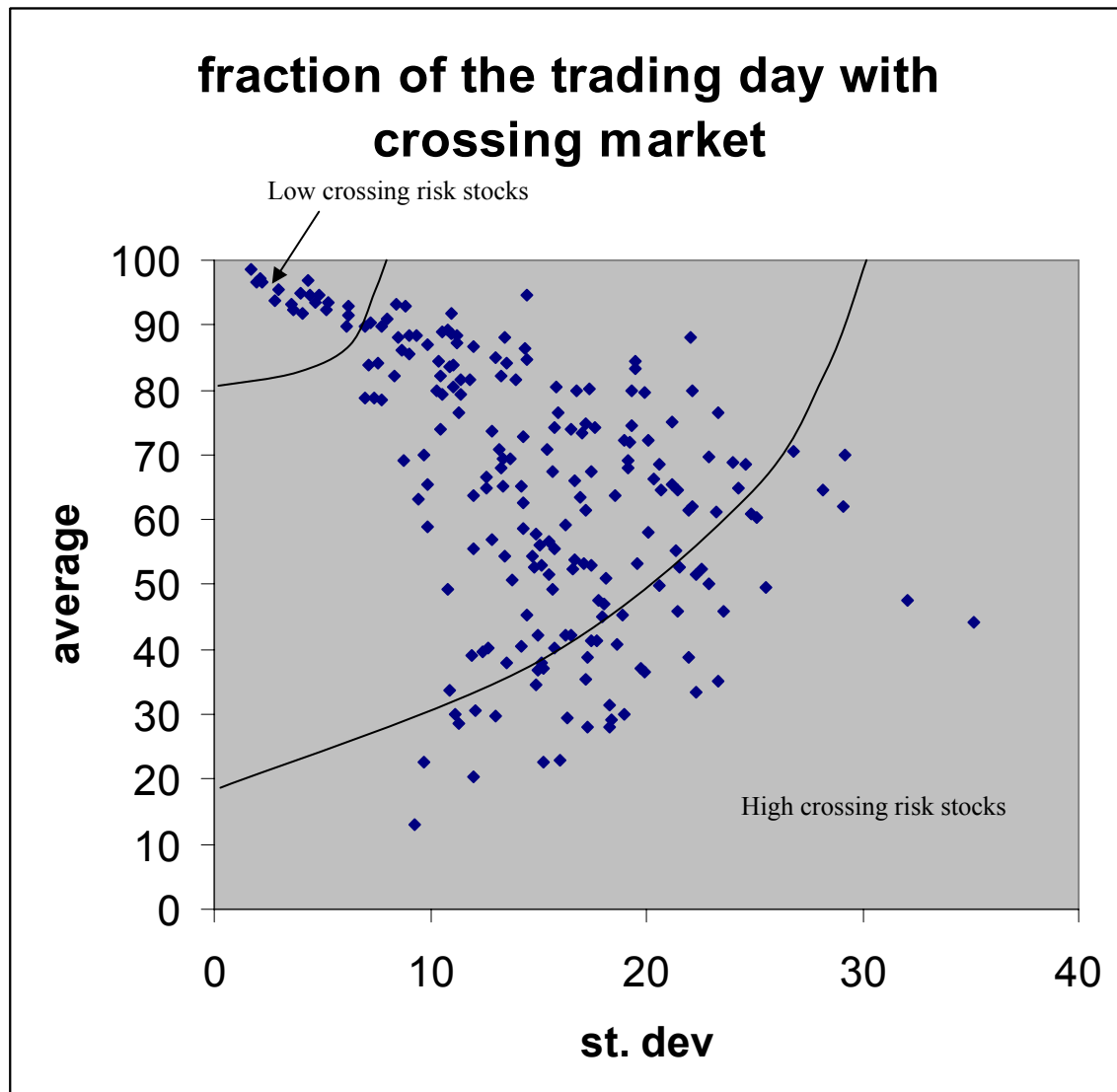
Figure 1. *Average vs. standard deviation of the fraction of the trading day when crossing market exists for securities in the sample, measured over 45 trading days.*

security	average	stdev	S&P100	security	average	stdev	S&P100
TSO	98.699	1.665	N	CSR	93.344	5.312	Y
MAP	97.128	2.086	Y	AMP	91.741	4.114	Y
LHG	96.578	1.931	Y	OSH	92.224	5.221	Y
DRT	96.712	2.196	Y	TEN	92.932	6.211	Y
BPC	96.893	4.327	N	OST	91.501	6.198	Y
QAN	95.395	2.961	Y	OXR	93.292	8.462	Y
MYP	93.762	2.843	Y	MPR	93.027	8.862	N
MOF	94.804	4.034	Y	GNS	89.735	6.169	N
PBG	94.591	4.414	Y	PMN	90.361	7.198	Y
CPA	94.709	4.848	Y	DJS	90.937	7.981	N
MXG	93.131	3.557	Y	DVC	89.844	7.013	Y
FGL	93.539	4.664	Y	CEU	89.752	7.749	Y
IAG	92.428	3.665	Y				

Table 1. *List of stocks where the risk crossing failure is low. For each security it lists the average percentage of trading day that a crossing market existed, the standard deviation and whether the security is in the S&P100.*

security	average	St dev	S&P100	security	average	St dev	S&P100
JBM	51.502	15.529	N	LEI	38.088	15.108	Y
FWD	52.305	16.616	N	WPL	33.627	10.928	Y
GUD	52.97	17.444	N	APA	45.924	23.552	N
CDR	60.202	25.104	N	UTB	40.659	18.636	Y
TPI	55.227	21.333	N	TSE	37.162	15.234	N
KCN	53.245	19.535	N	CTX	36.763	14.948	Y
ADB	49.322	15.655	N	ANN	38.875	17.253	Y
HIL	51.132	18.17	N	BEN	34.623	14.859	N
THG	62.082	29.14	N	CSL	29.914	11.126	Y
IVC	52.641	21.517	N	ASX	30.482	12.077	Y
SHL	45.292	14.429	Y	WOR	35.418	17.161	N
BBG	47.561	17.754	Y	RIO	28.604	11.299	Y
SIG	52.304	22.541	N	SPT	37.023	19.724	N
FKP	49.89	20.606	N	SDG	38.849	21.982	N
VSL	51.435	22.263	N	SGM	29.651	13.045	Y
BKN	47.014	18.016	N	SMS	36.455	19.934	N
WES	40.184	12.654	Y	LSG	47.684	32.062	N
MYO	50.281	22.86	N	CRG	29.499	16.372	N
NWSLV	39.19	11.878	N	NUF	31.404	18.336	N
ORI	42.275	15.017	Y	MBL	22.534	9.696	Y
SGB	39.556	12.463	Y	IFL	35.102	23.302	N
ALS	45.059	17.99	N	AEO	33.346	22.303	N
BNB	40.621	14.183	Y	NRT	30.023	19.014	N
SEV	45.252	18.858	N	SBC	28.138	17.303	N
FMG	42.291	16.259	N	CXP	29.205	18.405	N
RHC	42.23	16.543	N	FLT	27.992	18.268	N
NCM	38.082	13.502	Y	PBB	44.194	35.16	N
UGL	40.272	15.747	N	COH	20.374	12.03	Y
IRE	45.898	21.438	N	AQP	22.721	15.207	N
ADZ	49.579	25.558	N	FOA	22.969	16.04	N
BOQ	41.368	17.465	N	PPT	13.166	9.266	Y
SFE	41.344	17.714	N				

Table 2. *List stocks where the risk of crossing failure is high. For each security, it lists the average percentage of trading day that a crossing market existed, the standard deviation and whether the security is in the S&P100.*

These tables clearly show that high cap securities from S&P100 tend to have low crossing risk and high crossing risk securities tend to be low cap (non S&P100) ones. The banking stocks are an exception, with high/medium level of crossing risk.

7.2 Estimating intra-day Distribution of Crossing Market Risk

Analysis of the percentage of trading time when crossing market exists within equal-size time bins shows that typically the first 36 trading minutes have the highest relative risk of crossing failure. This is most likely attributable to the settling of inherent imbalances of liquidity immediately following the opening auction period. Figures 2 and 3 show intraday distributions of crossing markets for AXA and TOL. Their character appears to be similar to the inverted J-shape in the US market [8] – a large spread in the first minutes of trading declining over about 15 minutes to a level which lasts until the last few minutes of the day. The absence of the increase in the spread on the ASX during last trading minutes in comparison with NYSE can be possible explained by the absence of the closing auction on the NYSE.
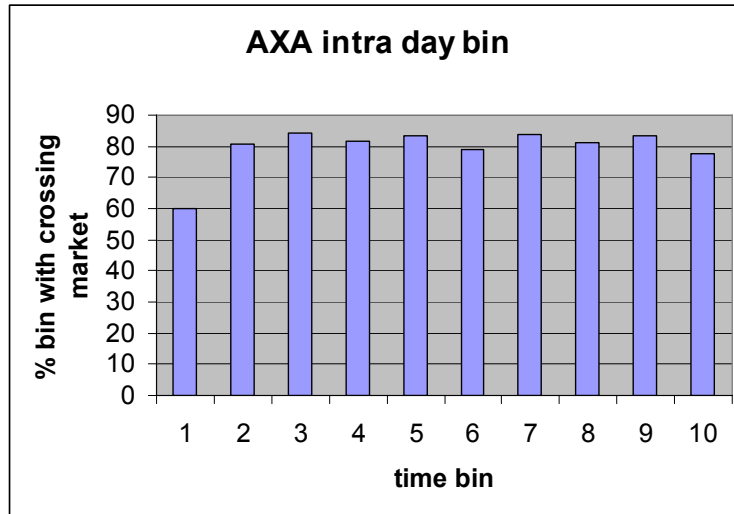
Figure 2. *Percentage of time that a crossing market existed for AXA over 10 equal time buckets over the day (averaged over 45 trading days).*
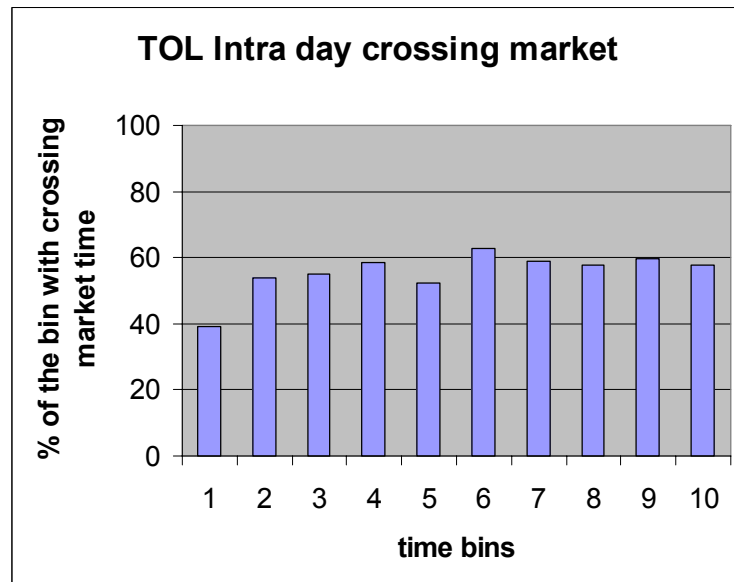
Figure 3. *Percentage of time that a crossing market existed for TOL over 10 equal time buckets over the day (averaged over 45 trading days).*

7.3 Empirical analysis of under execution risk due to undisclosed orders

Analysis of the trading data from Nov 2005 shows that on average 9.75% of securities contained undisclosed orders, the average fraction of the trading day when an undisclosed order appeared in the book was 2.36% (estimated as ½ of the time shown in Table 3, when undisclosed orders appearance on both bid and ask were counted), and if an undisclosed order was present at best ask/bid price then on average it represented between 3.04% and 6.08% of all depth at this price level. Therefore the probability of having an undisclosed order can be estimated as 0.23% and the difference between the observed and true full depth at the best price was below 6%. Therefore, the risk of under execution due to hidden liquidity is currently very low.

	% names	% of day	% of depth	% of order
1-Nov	8.37	6.19	4.31	0.20
2-Nov	5.42	5.37	2.36	0.08
3-Nov	6.15	1.40	1.30	0.10
4-Nov	11.17	3.07	4.15	0.14
7-Nov	8.86	3.76	3.00	0.13
8-Nov	11.88	6.12	3.08	0.14
9-Nov	11.76	5.09	3.10	0.19
11-Nov	3.19	6.39	2.36	0.35
14-Nov	11.50	3.48	0.94	0.12
15-Nov	12.38	8.86	3.07	0.13
16-Nov	10.99	3.29	3.32	0.10
17-Nov	8.42	6.32	4.85	0.13
18-Nov	10.84	9.31	3.76	0.14
22-Nov	15.00	3.59	3.84	0.12
24-Nov	11.00	2.45	2.44	0.10
25-Nov	9.95	3.61	2.85	0.21
28-Nov	10.14	5.26	4.13	0.20
30-Nov	8.50	1.39	1.89	0.12
average	**9.75**	**4.72**	**3.04**	**0.15**

Table 3. % of securities where undisclosed orders where used during normal trading. % of the normal trading time when undisclosed orders appear in the book (for these names), undisclosed % of total depth at the best bid and best ask levels, % of undisclosed orders among all limit orders

While the use of undisclosed order within the ASX market is currently insignificant for the transaction of crossings, the advent of the iceberg order type with the new ITS trading system may change that should it gain greater acceptance.. Iceberg orders can be considerably smaller (minimum 1000 shares compared to $200,000 order value for undisclosed orders). Given previous experiences on the ASX with undisclosed orders (see section 5.1), there may become significant from the crossing perspective. Furthermore, the iceberg order presents additional problems over and above those of undisclosed orders because the market does not publicly identify iceberg orders as such. However, once an iceberg order has exhausted its visible quantity and this visible quantity been replenished for the first time, it is possible to identify the order as an iceberg order.

7.4 Transaction Cost of Crossing

Orders entered into the market are charged $0.20 per order plus GST, all further modifications of the order including deletion, are free. Executed volume is charged at the same rate as orders executed against other brokers, namely, $2.00 per $100,000 plus GST (both sides pay this fee) capped at $20 plus GST.

Currently, it is no cheaper to transact a crossing on the ASX than it is execute against another broker in the market. However, as part of the ASX full pricing review as part of the CLICK migration, this may change in future.

In addition to the costs of executing the crossing, there are additional costs of auxiliary order entry for the purpose of creating the crossing market and appearing at the crossing price. This can be exacerbated if other participants hit these orders and force the broker to re-try.

7.5 Time and depth estimate. Stocks gaining most from crossing at best bid/ask price and those which gain most from crossing away from it.

The reduction in time from using crossing can be estimated as the average time a limit order submitted into the best price step waits until it has time priority (that is, when it is first) minus 10 sec (see tables in the Appendix B and C). Alternatively, it can be estimated from the average depth in the limit book, measured in terms of the average market orders hitting it (table in the Appendix D). The stocks with the largest depth at best price and with the longest waiting time would provide the largest benefit from crossing at best price level. Similarly, the stocks with small depth at best price may benefit more from deeper inside book crossing, required to fill the required amount.

Table 4 shows the stocks with the smallest fraction of liquidity in the book appearing at best price. Thus, these are securities where liquidity depth in the book is distributed further away from the bid and ask. Here market order whose volume exceeds the best depth can expect to walk up the book at least one price step incurring price impact of the order of average minimal price steps (last column in Table 4). If orders volume exceeds the volume on two best prices then walk up will include at least one more level, etc. For example, suppose DMA client submits market order to trade parcel of stocks of RIO 1.5 size of average market order. One can expect here that $79.33\% = \dfrac{100*(1.19)}{1.5}$ to be traded at best bid/ask and

$20.67\% = \dfrac{100*(1.5-1.19)}{1.5}$ with be transacted with premium of 3.09 minimal price steps. If liquidity

pool has available volume, and cross is transacted one minimal step worse than the best price, then the DMA order would reduce price impact for 20.67% of its volume from 3.09 minimal price steps to 1 minimal price step.

Securities, listed in Table 5, have the largest depth at best price level (measured in terms of average market order size). Here the maximal potential benefit in terms of waiting time saving goes to the limit order side of the crossing. For example, if DMA market order to trade CPA arrives then crossing it against limit pool order would save for the limit order side sitting in the book waiting until 13 market orders hit the book.

It worth noting that crossing allows the broker to keep time priority if further liquidity is behind.

	N_ORDER	best depth%	best depth/ord	best2 depth%	tot depth	min_steps
RIO	957.19	2.13	1.19	4.49	56	3.09
VSL	82.32	2.13	2.67	5.19	126	2.33
RCD	201.91	2.12	2.04	4.69	96	2.51
BNB	334.91	2.09	1.77	4.27	85	3.05
GUD	133.95	2.05	2.26	4.51	110	2.51
SUN	392.32	2.01	1.99	4.25	99	2.47
PTD	93.83	2.00	3.62	4.71	181	1.91
CBA	1295.25	1.94	1.61	4.20	83	2.31
STO	467.33	1.92	1.79	3.94	93	2.14
FMG	101.62	1.92	1.88	4.41	98	3.62
BSL	952.68	1.88	3.31	4.08	176	1.64
BHP	2010.65	1.88	2.79	4.24	148	1.60
ALN	264.45	1.81	2.29	3.88	127	2.51
BOQ	181.74	1.80	2.38	3.74	132	2.88
IOH	70.00	1.69	0.82	3.49	48	3.47
WES	705.73	1.67	1.58	3.39	95	2.90
MBL	813.46	1.57	1.29	3.34	82	4.33
CSL	446.71	1.52	1.29	3.14	85	4.12
SMS	287.62	1.52	1.38	3.10	91	2.46
WPL	821.73	1.49	1.31	3.09	88	2.82
PDN	240.64	1.44	2.79	3.79	194	1.85
NAB	1137.78	1.33	1.64	2.84	123	2.00
VCR	133.06	0.98	2.97	2.58	304	1.80
BTA	765.60	0.65	1.73	1.82	268	1.84

Table 4. Securities with smallest best (relative) best price depth. Column 2 – the average number of market orders, column 3, the average size of best depth (on one side of the book) as a % of total depth, column 3- the average size of best depth measured in average market orders, column 3 – the average depth of 2 best price levels in the book as % total depth, the total depth measured in average market orders, number of minimal steps between 2 best prices.

7.6 Potential for crossing between price steps

Clearly, the larger is the number of minimal price steps between the two best prices on the same side of the limit order book the large is the potential benefits that can be negotiated between the market and the limit sides of the cross. For example, consider PPT stock that on average has 9.58 minimal price steps between two best bids or ask (see Tables in Appendix D and E). Market order that transacts more volume than is available in the book at the best price will incur a large price impact. Limit order submitted between two best prices may never get executed. Cross at the price between two best prices (say, giving two minimal price steps premium to the limit order side) allows the market side to reduce its price impact and the limit side to obtain immediacy, non-disclosure and substantial liquidity premium on top of the spread.

8. Automated Strategies for Pricing Liquidity Pool Orders

The use of Liquidity Pool to facilitate crossing of DMA orders cannot be done manually due to the above-described time constraints. It requires an automated decision making about the fraction of the pool offered for crossing at any particular point in time and about its current pricing. This section is looking at better ways of pricing liquidity.

One strategy is to change the price on the liquidity pool order in line with changes in the security's market spread. An example is to automatically price it a given number of price steps away from the best price. This could be implemented as an automated strategy under the control of the sales traders.

Using such a strategy solves the problem of the market price moving, thereby leaving the liquidity exposed at an unfavourable price. However, this is very simplistic approach and on statistics gathered, leaves the liquidity order out of the money unless the liquidity order was priced at the 0 price steps away from the best price .Furthermore, it tells nothing about manage the volume of the liquidity order side of the cross.

	N MAR ORD	best	best %	best2 %
TLS	1570	30.28	7.15	17.12
THG	57	16.22	8.50	17.96
BPC	173	14.07	8.31	18.61
CPA	157	12.46	16.62	29.30
MOF	134	12.27	11.93	28.64
ENV	65	11.68	6.28	15.58
DUE	132	11.41	10.91	16.98
IPG	182	10.61	19.98	32.73
CEUCA	101	10.35	7.40	14.43
GSA	81	9.61	25.67	45.33
CEU	104	9.47	17.10	33.01
MPR	92	9.14	9.71	21.71
MAP	415	9.01	4.80	9.93
OXR	425	8.82	4.84	11.35
HDF	71	8.68	7.21	16.02
HGI	137	8.30	7.43	15.40
QAN	357	7.99	6.50	14.37
DRT	178	7.59	18.07	34.27
IIF	119	7.40	21.28	39.86
FKP	102	7.16	4.62	12.87
TSO	87	6.95	21.62	40.24
BJT	88	6.91	9.08	17.53
IOF	96	6.88	9.80	18.17
GAS	91	6.61	5.92	13.08
LHG	392	6.52	4.68	10.15
MDT	103	6.47	15.31	30.14
HVN	163	6.37	10.12	17.41
BCA	98	6.31	16.99	42.84
VPG	69	6.20	14.49	29.68
OMP	79	6.07	5.24	13.54
DJS	183	5.81	6.02	12.54
RIC	76	5.69	6.02	12.75
MIG	429	5.62	6.30	12.38
SDG	64	5.61	4.09	7.81
SGN	92	5.49	6.16	13.02
APA	80	5.43	5.88	11.48

Table 5. Securities with largest best price depth. Column 2 – the average number of market orders, Column 3 - the average size of best depth measured in average market orders, the average best price depth (on one side of the book) as a % of total depth, column 4 – the average depth of 2 best price levels in the book as % total depth.

An attractive approach would be to employ a VWAP-like pricing algorithm for the Liquidity Pool which would automatically set and quantity available.

9. Crossing Strategy Refinements. Crossing at fractions of a Price Step

Trading on the ASX is currently constrained to occur at discrete prices determined by the price step interval for a security. These price steps are determined by a combination of the security type as well as the price at which the security is currently trading[2]. This can add significantly to the cost of trading as it causes orders wishing to trade to cross a wider spread.

It is possible to trade inside a single price step spread. Suppose the spread between the current bid price B and current ask price A is equal to the minimal price step Δ. Suppose broker has two complementary (one buy one sell) orders to trade N shares. It turns out that he can trade them at any price on a much finer than minimal price grid with $\dfrac{\Delta}{N}$ step. This can be achieved by transacting two crosses – first for N_1 shares with crossing price equal bid price B (N_1 is any integer from [0,N] interval) and the second for N_2 shares ($N_2 = N - N_1$) with crossing price equal ask price A. The effective price delivered to the original buy and sell orders will be $C = A + \dfrac{\Delta}{N} N_1$. The higher is the size of the order N the smaller will be the minimal price step available to transacting.

From an operational perspective, this approach does involve a slight increase in complexity because two crossings need to be carried out, and also slightly greater risk of the crossing being frustrated by the market. However, the transactional costs of the crossing are only slightly greater (to account for the submission of additional crossing order) but this would be more than offset by the gains.

12. Conclusions

The key conclusions that can be drawn from the preceding results and analyses fall into several categories.

Firstly, the paper provides a solid foundation for the understanding of the benefits, risks and costs associated with the use of the crossing. It demonstrates that crossing in the high cap securities is generally very low risk on the ASX, mainly because the crossing markets tend to exist for these securities for most of the day (banking stocks are an exception). Crossing is slightly more risky in the period after market open due to market volatility. The acceleration of the execution of Liquidity Pool orders due to reuse of crossed orders can also be significant.

The study also demonstrates that additional benefit could be derived from the systematic use of crossing orders in automated trading including possibility to extend the space of feasible trade into inter-spread fine grid, increasing the incentives to trade by removing the need to cross the spread.

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[2] It is possible to transact off-market trades at average prices but these are out of scope for this discussion as they only apply to large parcels of stock.

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Appendix A: Detailed Results: Percentage of Trading Day when Crossing Market Exists

	average	stdev	asx100				
				AMC	81.567	11.408	Y
TSO	98.699	1.665	N	PPX	81.65	11.872	Y
MAP	97.128	2.086	Y	CML	79.868	10.329	Y
LHG	96.578	1.931	Y	CCL	80.511	11.066	Y
DRT	96.712	2.196	Y	CGF	82.259	13.247	Y
BPC	96.893	4.327	N	AXA	79.46	10.563	Y
QAN	95.395	2.961	Y	TEL	79.34	11.43	Y
MYP	93.762	2.843	Y	GTP	81.558	13.968	N
MOF	94.804	4.034	Y	IIF	88.127	22.08	Y
PBG	94.591	4.414	Y	CPU	76.404	11.339	Y
CPA	94.709	4.848	Y	IOF	84.293	19.5	Y
MXG	93.131	3.557	Y	ROC	80.509	15.804	N
FGL	93.539	4.664	Y	HDR	83.338	19.469	N
IAG	92.428	3.665	Y	ORG	73.858	10.49	Y
CSR	93.344	5.312	Y	MCW	79.929	16.766	Y
AMP	91.741	4.114	Y	TAP	80.102	17.336	N
OSH	92.224	5.221	Y	CEY	73.69	12.892	N
TEN	92.932	6.211	Y	API	76.394	15.948	N
OST	91.501	6.198	Y	WBC	69.172	8.741	Y
OXR	93.292	8.462	Y	ALZ	79.771	19.356	N
MPR	93.027	8.862	N	WOW	69.958	9.663	Y
GNS	89.735	6.169	N	PDN	79.691	19.925	N
PMN	90.361	7.198	Y	HDF	72.943	14.263	N
DJS	90.937	7.981	N	CNP	74.113	15.737	Y
DVC	89.844	7.013	Y	ABC	74.803	17.181	N
CEU	89.752	7.749	N	ENV	79.751	22.13	N
MIG	91.82	10.994	Y	GWT	70.692	13.188	N
TLS	94.632	14.454	Y	KIM	73.985	16.488	N
MGR	88.223	8.477	Y	CDO	74.148	17.647	N
FCL	88.287	9.005	Y	MGW	73.355	16.987	N
DUE	88.416	9.358	N	EXL	69.515	13.355	N
JST	89.338	10.846	N	ABS	69.335	13.66	N
SSX	88.812	10.54	N	ANZ	65.455	9.893	Y
SDL	88.664	11.003	N	ARQ	70.757	15.375	N
SGP	85.992	8.701	Y	VPG	74.584	19.303	N
MTS	88.475	11.272	Y	WDC	67.872	13.265	Y
BBI	86.863	9.84	N	AWB	66.516	12.575	Y
BIL	83.753	7.15	Y	SIP	75.048	21.19	Y
AWC	84.167	7.582	Y	QBE	63.033	9.471	Y
ZFX	85.535	8.988	Y	WYL	72.249	18.945	N
GPT	87.209	11.266	Y	AUW	76.402	23.289	N
AIX	86.818	11.966	N	SGN	71.959	19.236	N
AWE	88.047	13.465	N	HSP	72.372	20.057	N
BSL	84.512	10.39	Y	TAH	64.732	12.587	Y
TCL	82.17	8.316	Y	BLD	65.189	13.337	Y
PRK	83.922	11.072	Y	RIN	63.817	11.971	Y
MGQ	83.529	10.881	Y	MCG	67.295	15.629	Y
GAN	86.437	14.423	Y	PTD	65.267	14.221	N
HVN	85.024	13.045	Y	APN	69.193	19.153	Y
BHP	78.874	6.972	Y	COA	67.365	17.468	N
CSM	82.142	10.426	N	BTA	66.038	16.67	N
MAY	78.771	7.431	N	PMP	68.038	19.122	N
SYB	78.508	7.751	Y	NAB	58.793	9.905	Y
FXJ	84.063	13.57	Y	ENE	62.511	14.288	N
HGI	84.654	14.45	N	MRE	68.597	20.589	N

TWR	69.735	22.875	N	SGB	39.556	12.463	Y
JBH	63.468	16.921	N	ALS	45.059	17.99	N
SEK	66.354	20.338	N	BNB	40.621	14.183	Y
RMD	63.63	18.514	Y	SEV	45.252	18.858	N
RIC	68.887	24.023	N	FMG	42.291	16.259	N
DOW	58.663	14.294	Y	RHC	42.23	16.543	N
RCL	65.494	21.205	N	NCM	38.082	13.502	Y
GDR	61.449	17.177	N	UGL	40.272	15.747	N
AGL	57.025	12.888	Y	IRE	45.898	21.438	N
TIM	68.678	24.637	N	ADZ	49.579	25.558	N
BJT	64.519	20.688	N	BOQ	41.368	17.465	N
OMP	70.595	26.847	N	SFE	41.344	17.714	N
NWS	55.583	12.04	N	LEI	38.088	15.108	Y
VCR	64.704	21.485	N	WPL	33.627	10.928	Y
MCC	59.286	16.269	N	APA	45.924	23.552	N
ALN	57.828	14.88	Y	UTB	40.659	18.636	Y
ILU	56.704	15.513	Y	TSE	37.162	15.234	N
PBL	56.205	15.106	Y	CTX	36.763	14.948	Y
ALL	54.375	13.464	Y	ANN	38.875	17.253	Y
IPG	69.996	29.177	Y	BEN	34.623	14.859	N
GRD	64.769	24.222	N	CSL	29.914	11.126	Y
GAS	61.974	22.094	N	ASX	30.482	12.077	Y
LLC	54.478	14.729	Y	WOR	35.418	17.161	N
TOL	55.426	15.726	Y	RIO	28.604	11.299	Y
LNN	61.427	21.969	Y	SPT	37.023	19.724	N
CBA	49.19	10.766	Y	SDG	38.849	21.982	N
BCA	61.192	23.24	N	SGM	29.651	13.045	Y
SUN	52.771	14.826	Y	SMS	36.455	19.934	N
CIY	58.004	20.123	N	LSG	47.684	32.062	N
STO	52.909	15.142	Y	CRG	29.499	16.372	N
WAN	53.817	16.644	Y	NUF	31.404	18.336	N
JHX	50.587	13.791	Y	MBL	22.534	9.696	Y
CER	64.678	28.137	N	IFL	35.102	23.302	N
BWP	60.882	24.831	N	AEO	33.346	22.303	N
RCD	53.117	17.068	N	NRT	30.023	19.014	N
JBM	51.502	15.529	N	SBC	28.138	17.303	N
FWD	52.305	16.616	N	CXP	29.205	18.405	N
GUD	52.97	17.444	N	FLT	27.992	18.268	N
CDR	60.202	25.104	N	PBB	44.194	35.16	N
TPI	55.227	21.333	N	COH	20.374	12.03	Y
KCN	53.245	19.535	N	AQP	22.721	15.207	N
ADB	49.322	15.655	N	FOA	22.969	16.04	N
HIL	51.132	18.17	N	PPT	13.166	9.266	Y
THG	62.082	29.14	N				
IVC	52.641	21.517	N				
SHL	45.292	14.429	Y				
BBG	47.561	17.754	Y				
SIG	52.304	22.541	N				
FKP	49.89	20.606	N				
VSL	51.435	22.263	N				
BKN	47.014	18.016	N				
WES	40.184	12.654	Y				
MYO	50.281	22.86	N				
NWSLV	39.19	11.878	N				
ORI	42.275	15.017	Y				

Appendix B: Average waiting time (in seconds) for a limit order submitted into best bid price step

	average						
	average	CXP	420.79	TEL	249.62	ORIR	150.30
SSI	4421.75	JST	415.92	MTS	244.95	DOW	149.76
HDF	1244.44	ARQ	414.44	UTB	243.55	JBM	148.99
NHC	1102.86	API	411.64	TSE	240.10	BNB	142.28
APA	906.96	KCN	410.33	QAN	238.44	CCL	141.27
CIY	870.43	TEN	402.11	CSR	236.75	BTA	140.35
LSG	832.95	TIM	396.31	ALS	236.70	AMC	137.05
BWP	754.02	BBI	393.43	MAP	235.59	TOL	136.70
SGN	753.20	SSX	392.74	ADB	234.00	CML	136.65
DRT	706.06	IIF	389.68	PMN	226.82	JHX	132.71
CER	699.86	GAN	388.58	OXR	225.57	COH	131.28
VCR	698.45	GTP	387.16	HSP	223.62	BIL	131.28
AIX	683.90	MOF	387.10	NUF	222.89	AMP	126.93
MPR	678.44	AEO	382.88	PRK	221.42	NWS	125.46
SDG	669.95	AQP	379.99	CRG	220.41	LLC	121.20
GRD	661.04	DJS	369.75	SGP	219.88	LEI	117.46
FKP	654.61	FMG	366.96	SEV	218.82	WOR	117.44
BJT	644.60	FOA	363.69	AXA	215.80	ANN	114.96
MCW	643.42	BCA	362.53	ENE	210.64	ALL	114.02
MGX	636.60	LHG	361.24	AWB	210.31	BSL	107.41
JBH	626.31	IRE	360.58	FLT	209.90	SHL	103.76
MDT	625.78	GWT	358.17	SIG	209.06	PBL	103.45
FWD	621.37	WYL	356.48	DVC	208.35	SUN	101.43
AUW	615.40	PMP	355.43	UGL	206.82	STO	96.80
SEK	614.40	MGQ	348.95	PPX	206.25	CTX	96.61
RCL	590.18	GUD	348.90	RHC	204.87	ASX	95.77
CEU	586.70	BPC	346.09	OST	204.61	AGL	95.31
IOF	586.04	ALZ	337.61	WAN	196.89	TLS	94.45
GSA	579.33	SBC	337.26	MCC	196.54	ORI	88.45
GAS	555.68	CDO	333.59	FXJ	195.95	TAH	85.51
PTD	553.12	GPT	333.56	CEY	195.69	WDC	84.95
CPA	527.25	ROC	327.10	RCD	187.56	WOW	83.25
OMP	523.16	HVN	322.45	BOQ	182.87	SGB	82.46
UCL	504.69	PBG	321.83	AWC	179.36	QBE	79.72
IFL	504.28	MGW	316.95	ZFX	178.08	RIN	77.78
MYO	499.22	SPT	314.99	MCG	177.17	WES	66.83
CEUCA	493.71	CNP	309.33	EXL	174.89	NCM	64.88
VSL	493.24	MXG	307.09	CPU	172.27	CSL	60.94
ENV	492.10	PDN	299.61	SGM	172.27	WBC	60.73
THG	489.97	PBB	296.01	MAY	166.33	WPL	52.22
ABC	487.10	COA	287.98	MIG	165.84	ANZ	52.13
MRE	485.12	TPI	286.72	BBG	165.49	RIO	47.96
HIL	478.34	GNS	284.35	ABS	165.32	NAB	47.32
VPG	477.67	BEN	282.10	OSH	165.18	CBA	46.62
HGI	473.10	APN	280.57	ILU	159.91	MBL	45.54
IVC	469.02	CGF	278.40	IAG	159.61	BHP	37.96
DUE	464.16	KIM	277.38	PPT	158.84		
NRT	457.98	FCL	275.45	LNN	157.47		
CDR	449.26	BKN	271.18	BLD	156.75		
RIC	445.92	MGR	267.16	SFE	155.99		
TSO	443.81	IPG	266.27	SYB	155.90		
TWR	442.57	RMD	263.91	ORG	155.75		
TAP	442.39	HDR	260.61	FGL	155.63		
AWE	428.00	CSM	255.58	ALN	150.63		
ADZ	424.19	MYP	253.30	TCL	150.51		

Appendix C: Average waiting time (in seconds) for a limit order submitted into best ask price step

	average						
	average	VCR	455.56	SEV	257.92	LNN	164.07
SLV	3680.83	BCA	449.57	CSR	256.86	DOW	163.70
SSI	2100.33	ALZ	438.33	AWB	254.37	BIL	162.83
HDF	1628.02	OXR	437.53	MYO	252.92	ALN	162.27
CIY	1289.31	CNP	436.91	MCG	252.40	CPU	159.64
AZR	1243.33	AEO	436.33	MCC	250.20	PPT	158.03
AUW	1175.20	TWR	427.15	BEN	247.90	TOL	151.98
APA	1124.71	DUE	422.19	AXA	246.72	AWC	151.52
PBB	962.83	PDN	419.83	FOA	243.62	SYB	146.87
BJT	944.63	RMD	419.51	UCL	243.33	SFE	145.44
FKP	927.10	TIM	413.46	QAN	242.27	BLD	140.64
TFS	918.67	IRE	411.69	BOQ	241.95	JHX	140.03
CER	900.68	ALS	406.21	FLT	241.40	CML	137.17
MDT	891.74	BKN	402.98	PMN	238.78	SHL	130.86
SEK	879.60	FMG	401.73	IPG	238.44	ALL	128.26
FWD	842.42	DRT	398.88	RCD	235.90	BNB	126.31
VSL	823.27	ROC	397.10	MGR	235.64	QBE	125.83
CDR	795.61	WYL	392.81	SSX	235.33	SUN	125.70
CPA	787.45	ABC	388.12	HSP	234.92	TLS	123.54
OMP	756.04	AWE	378.49	FXJ	233.20	BSL	121.13
RIC	729.18	NRT	373.53	MAP	231.97	AMP	119.91
MPR	718.28	MGQ	370.28	PRK	231.01	NWS	119.33
ENV	702.49	SPT	362.78	NUF	230.93	AGL	119.01
TSO	695.23	BPC	360.94	ZFX	223.64	ASX	117.52
IOF	691.74	CDO	356.47	WOR	222.86	LLC	115.23
GRD	686.81	KCN	356.27	CGF	218.07	PBL	114.75
CEU	663.09	KIM	351.73	SGP	217.77	TAH	113.10
AIX	657.73	MXG	344.20	WAN	213.13	COH	109.77
GSA	651.98	FCL	344.09	PBG	211.15	SGB	105.26
ADZ	649.80	JST	339.95	LHG	209.96	ORI	104.50
HIL	628.82	DVC	335.65	CRG	206.63	LEI	102.51
GAS	627.15	TPI	333.42	MIG	203.18	CTX	99.53
TEN	622.04	MOF	326.38	EXL	199.88	STO	96.41
THG	609.39	GAN	313.24	UGL	199.19	RIN	85.80
BWP	605.65	TAP	310.59	CEY	194.20	CSL	84.85
API	592.03	SBC	302.07	OST	191.54	WOW	83.26
RCL	590.31	TEL	301.78	MAY	190.65	WDC	81.89
AQP	585.02	PPX	301.49	FGL	189.88	BTA	78.42
JBH	583.72	GNS	298.41	BBG	189.40	WES	68.17
GTP	576.09	GPT	298.26	SIG	187.29	NCM	63.13
MCW	574.59	CSM	296.08	ADB	186.53	WBC	61.34
IVC	562.92	MTS	294.76	UTB	183.80	CBA	54.03
MGW	557.56	HGI	294.74	ILU	181.97	WPL	53.79
ARQ	557.34	GWT	283.59	AMC	181.36	ANZ	51.50
LSG	555.46	RHC	280.73	ABS	180.91	RIO	51.09
IFL	542.24	GUD	279.04	SGM	178.89	NAB	46.61
VPG	527.73	HVN	277.90	TCL	178.43	MBL	44.42
CEUCA	486.79	IIF	277.15	JBM	178.39	BHP	41.31
PTD	481.51	DJS	271.00	CCL	176.46		
SGN	474.34	MRE	270.73	OSH	175.32		
MGX	470.20	COA	265.03	ANN	174.16		
BBI	465.31	MYP	264.72	IAG	173.79		
CXP	458.68	APN	261.78	ORG	173.51		
ORIR	457.33	SDG	258.63	HDR	172.84		
PMP	456.76	ENE	258.63	TSE	169.35		

Appendix D: Average number of market orders and the time-average size of the depth at best bid/ ask divided on the average size of market

	MARK	depth									
			IVC	104	4.2	BHP	2011	2.8	LNN	211	2.0
TLS	1570	30.3	AXA	211	4.2	PDN	241	2.8	TOL	293	1.9
THG	57	16.2	GWT	103	4.1	ZFX	310	2.8	ILU	232	1.9
BPC	173	14.1	CIY	49	4.1	CDR	84	2.8	FMG	102	1.9
CPA	157	12.5	PMP	158	4.0	WYL	112	2.7	BBG	220	1.8
MOF	134	12.3	DVC	219	4.0	MRE	122	2.7	STO	467	1.8
ENV	65	11.7	PBG	200	4.0	FLT	179	2.7	QBE	522	1.8
DUE	132	11.4	MXG	263	3.9	BKN	97	2.7	NUF	126	1.8
IPG	182	10.6	OST	259	3.9	VSL	82	2.7	BNB	335	1.8
CEUCA	101	10.3	GPT	229	3.9	AMC	361	2.6	NWSLV	312	1.8
GSA	81	9.6	FCL	177	3.9	ARQ	161	2.6	SGB	544	1.7
CEU	104	9.5	CSR	270	3.9	TEL	166	2.6	WDC	661	1.7
MPR	92	9.1	MGW	124	3.9	MTS	196	2.6	UGL	178	1.7
MAP	415	9.0	PPX	274	3.8	PRK	330	2.5	BTA	766	1.7
OXR	425	8.8	GNS	222	3.8	CPU	253	2.5	ALL	335	1.7
HDF	71	8.7	TIM	125	3.8	CCL	361	2.5	WOR	159	1.7
HGI	137	8.3	TEN	162	3.8	MAY	264	2.5	JHX	262	1.7
QAN	357	8.0	TCL	393	3.7	HWI	83	2.5	SPT	112	1.7
DRT	178	7.6	RCL	97	3.6	BIL	523	2.5	TSE	126	1.7
IIF	119	7.4	PTD	94	3.6	EXL	272	2.4	SHL	289	1.7
FKP	102	7.2	WAN	166	3.6	NRT	101	2.4	NAB	1138	1.6
TSO	87	6.9	BBI	168	3.6	NWS	633	2.4	LLC	303	1.6
BJT	88	6.9	AWE	187	3.6	WOW	634	2.4	LEI	278	1.6
IOF	96	6.9	ROC	145	3.5	BOQ	182	2.4	SGM	195	1.6
GAS	91	6.6	ANN	210	3.5	COA	158	2.4	CBA	1295	1.6
LHG	392	6.5	ADZ	95	3.4	PBB	129	2.4	UTB	223	1.6
MDT	103	6.5	CML	542	3.4	MCW	125	2.3	RIN	604	1.6
HVN	163	6.4	HIL	86	3.4	FWD	102	2.3	CRG	153	1.6
BCA	98	6.3	SGP	254	3.4	ADB	201	2.3	TPI	132	1.6
VPG	69	6.2	PMN	262	3.4	CXP	85	2.3	PPT	174	1.6
OMP	79	6.1	CSM	285	3.4	HSP	185	2.3	WES	706	1.6
DJS	183	5.8	JBH	104	3.3	ALN	264	2.3	SYB	273	1.6
RIC	76	5.7	API	119	3.3	MCC	224	2.3	SFE	248	1.6
MIG	429	5.6	BSL	953	3.3	DOW	216	2.3	ASX	289	1.5
SDG	64	5.6	GRD	96	3.2	GUD	134	2.3	NCM	622	1.5
SGN	92	5.5	KCN	129	3.2	MGX	68	2.3	COH	271	1.5
APA	80	5.4	TWR	137	3.2	SIG	193	2.2	PBL	380	1.5
BWP	78	5.4	IFL	62	3.1	IRE	80	2.2	MYP	221	1.5
GAN	141	5.3	CEY	286	3.1	JBM	290	2.2	ORI	328	1.5
AIX	124	5.3	FXJ	264	3.1	BEN	143	2.2	SMS	288	1.4
AEO	76	5.2	SEV	113	3.1	CNP	169	2.2	CTX	360	1.3
MYO	79	5.2	CGF	182	3.1	TAH	581	2.1	WPL	822	1.3
IAG	495	5.0	AWB	190	3.1	ENE	155	2.1	MBL	813	1.3
HDR	344	4.9	ORG	349	3.0	AGL	419	2.1	CSL	447	1.3
SSX	158	4.9	MGQ	179	3.0	APN	145	2.1	RIO	957	1.2
AQP	73	4.9	JST	129	3.0	ALS	150	2.1	FOA	125	1.2
AUW	81	4.9	TAP	144	3.0	ABS	255	2.1	IOH	70	0.8
CER	66	4.8	KIM	119	3.0	RMD	162	2.1			
LSG	78	4.8	CDO	151	3.0	RHC	157	2.1			
FGL	418	4.7	VCR	133	3.0	RCD	202	2.0			
AMP	655	4.7	ABC	106	3.0	MCG	200	2.0			
MGR	242	4.7	GTP	180	3.0	ANZ	1184	2.0			
ALZ	138	4.7	SGT	371	2.9	SUN	392	2.0			
OSH	360	4.6	AWC	401	2.9	SBC	112	2.0			
SEK	81	4.6	WBC	1210	2.9	BLD	318	2.0			

Appendix D: Time-weighted average number of minimal price steps between 2 best ask prices

ASK_12	AVERAGE	BKN	1.92	AWB	1.41	AMC	1.15
SLF	61.53	NRT	1.90	ABC	1.39	SGP	1.15
PPR	14.33	ADZ	1.89	STO	1.38	HGI	1.14
PPT	9.58	LLC	1.88	SYB	1.38	PMN	1.13
SLV	4.74	LSG	1.86	ORG	1.37	GSA	1.13
SSI	4.73	FKP	1.85	KIM	1.37	PBG	1.12
AQP	4.64	RCL	1.84	JBM	1.35	CML	1.10
CRG	4.57	ALN	1.83	CEU	1.34	MAY	1.10
COH	4.10	DOW	1.83	BWP	1.34	CSM	1.10
SBC	3.60	WPL	1.82	BCA	1.33	ZFX	1.10
FOA	3.10	MCG	1.81	ALZ	1.33	UCL	1.10
MBL	3.07	BJT	1.75	RMD	1.32	AUW	1.10
CSL	3.04	NHC	1.75	COA	1.32	BTA	1.10
ASX	2.87	RCD	1.73	API	1.32	AWC	1.09
UGL	2.74	PBL	1.73	CDO	1.31	PPX	1.08
SGM	2.71	FWD	1.71	BBI	1.31	HVN	1.08
CXP	2.66	HIL	1.70	NAB	1.30	MXG	1.08
TPI	2.62	ORIR	1.70	MCW	1.30	JST	1.08
IFL	2.54	KCN	1.68	WOW	1.29	CEY	1.07
TFS	2.52	HSP	1.68	BIL	1.29	NWS	1.07
SPT	2.51	AGL	1.67	IPG	1.29	FGL	1.07
FLT	2.51	BOQ	1.67	CER	1.29	MGR	1.07
ANN	2.47	QBE	1.67	MRE	1.28	BHP	1.07
TSE	2.46	VPG	1.66	DVC	1.27	IOF	1.06
NUF	2.40	VSL	1.66	WBC	1.27	OST	1.06
SDG	2.38	CNP	1.65	CCL	1.26	FXJ	1.06
BBG	2.37	SGB	1.65	WDC	1.26	TEN	1.06
WOR	2.36	TOL	1.64	CPU	1.26	CSR	1.05
CTX	2.36	NCM	1.64	AWE	1.26	DJS	1.05
SIG	2.34	ALL	1.63	PRK	1.25	GPT	1.05
UTB	2.33	BLD	1.63	JBH	1.25	ENV	1.05
RHC	2.32	SUN	1.62	SSX	1.25	DRT	1.05
AEO	2.31	SGN	1.61	MTS	1.25	BSL	1.05
BNB	2.30	TSO	1.61	TCL	1.25	MDT	1.04
WES	2.26	ENE	1.60	TEL	1.25	GNS	1.04
FMG	2.23	GAS	1.55	ANZ	1.24	TLS	1.03
JHX	2.20	MCC	1.55	AXA	1.24	GTP	1.03
BEN	2.18	TAH	1.54	ROC	1.24	OSH	1.03
RIO	2.17	CBA	1.53	CGF	1.23	AIX	1.02
SHL	2.16	MYO	1.53	FCL	1.23	MPR	1.02
ALS	2.16	ARQ	1.52	PTD	1.22	IAG	1.02
LNN	2.15	APA	1.52	IIF	1.22	OXR	1.02
IRE	2.15	MYP	1.51	MGQ	1.22	MAP	1.01
LEI	2.12	GRD	1.48	SEK	1.22	BPC	1.01
GUD	2.06	PMP	1.47	TWR	1.21	AMP	1.01
SEV	2.05	MGW	1.46	VCR	1.21	MOF	1.01
ADB	2.04	GWT	1.46	TAP	1.20	MIG	1.01
ILU	2.01	WYL	1.45	CIY	1.20	CPA	1.00
BMN	2.00	APN	1.45	HDF	1.20	QAN	1.00
PBB	2.00	ABS	1.45	PDN	1.20	AZR	1.00
WAN	1.97	RIN	1.45	LHG	1.20	CEUCA	1.00
ORI	1.96	RIC	1.44	THG	1.19	PRR	1.00
CDR	1.95	EXL	1.44	HDR	1.17	MGX	1.00
SFE	1.95	GAN	1.42	OMP	1.16	EPT	1.00
DUE	1.94	IVC	1.42	TIM	1.16		

Appendix E: Time-weighted average number of minimal price steps between 2 best bid prices

	average		DOW	1.83	APN	1.34	VCR	1.13
SLF	12.66	SHL	1.83	WOW	1.34	CML	1.11
PPT	8.01	FWD	1.82	FCL	1.34	SEK	1.11
TFS	7.57	WPL	1.80	APA	1.34	CER	1.11
CRG	5.94	BKN	1.79	AXA	1.33	DRT	1.11
FOA	5.79	TPI	1.77	ORIR	1.32	BBI	1.10
BMN	4.98	RCD	1.74	MCW	1.31	DJS	1.10
SSI	4.72	NCM	1.72	GWT	1.31	PMN	1.09
SBC	3.55	CBA	1.72	PMP	1.31	TCL	1.09
RIO	3.40	TOL	1.72	WDC	1.31	GTP	1.09
COH	3.25	FLT	1.71	EXL	1.30	ENV	1.09
AEO	3.25	WBC	1.71	TIM	1.30	IOF	1.09
AQP	3.09	ALL	1.71	MGQ	1.29	MXG	1.08
IFL	3.05	FKP	1.70	TEL	1.29	CEY	1.08
FMG	2.98	ALN	1.68	TAH	1.29	IPG	1.08
JHX	2.88	GUD	1.67	ARQ	1.28	FXJ	1.07
CXP	2.82	AUW	1.67	JBM	1.28	DVC	1.07
PBB	2.80	SDG	1.67	BWP	1.27	TLS	1.06
MBL	2.79	SLV	1.66	OMP	1.27	JST	1.06
ASX	2.75	PBL	1.65	NAB	1.26	UCL	1.06
SEV	2.73	CDR	1.65	PBG	1.25	HVN	1.06
ANN	2.69	QBE	1.64	ROC	1.25	DUE	1.06
RIC	2.55	BLD	1.63	CGF	1.25	LHG	1.05
IRE	2.53	IVC	1.61	ORG	1.25	AWE	1.05
CTX	2.47	AGL	1.60	IIF	1.24	MGR	1.05
NRT	2.47	WYL	1.60	AMC	1.24	TSO	1.04
CSL	2.43	GRD	1.60	TAP	1.24	BHP	1.04
SGM	2.41	ENE	1.59	PRK	1.23	HDR	1.04
LEI	2.39	SUN	1.57	MAY	1.23	CSR	1.03
SPT	2.36	VSL	1.57	SSX	1.22	IAG	1.03
BEN	2.33	HIL	1.56	ALZ	1.22	FGL	1.03
BJT	2.32	WES	1.56	API	1.22	BTA	1.03
NUF	2.30	LSG	1.55	GPT	1.22	QAN	1.02
RHC	2.27	MRE	1.51	MTS	1.21	OSH	1.02
MYO	2.21	JBH	1.50	MGW	1.21	GSA	1.02
TSE	2.19	RMD	1.50	ANZ	1.20	TEN	1.02
BCA	2.18	AWB	1.50	TWR	1.20	AIX	1.02
WOR	2.18	LNN	1.49	AWC	1.18	GNS	1.02
ALS	2.13	SGB	1.49	BIL	1.18	CSM	1.02
BOQ	2.11	THG	1.46	GAN	1.18	OXR	1.01
UGL	2.10	KIM	1.45	PDN	1.17	AMP	1.01
ORI	2.09	MCC	1.43	CCL	1.16	BPC	1.01
SIG	2.07	HSP	1.43	OST	1.16	BSL	1.01
BBG	2.05	ABS	1.43	HGI	1.16	MPR	1.01
ADZ	2.03	VPG	1.43	PPR	1.16	MIG	1.01
CNP	2.02	SYB	1.42	PTD	1.16	CPA	1.00
BNB	2.01	CDO	1.42	MYP	1.16	AZR	1.00
SFE	1.99	COA	1.40	SGN	1.16	MAP	1.00
LLC	1.97	ABC	1.40	CEU	1.15	MOF	1.00
NHC	1.95	CPU	1.37	SGP	1.15	CEUCA	1.00
UTB	1.94	MCG	1.37	RCL	1.15	MDT	1.00
KCN	1.89	STO	1.37	HDF	1.15	MGX	1.00
WAN	1.87	RIN	1.36	ZFX	1.14	EPT	1.00
ILU	1.86	CIY	1.35	PPX	1.13		
ADB	1.84	GAS	1.34	NWS	1.13		