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The Informativeness of the Limit Order Book in a Periodic Call Market

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Abstract

Using the intraday data on the Taiwan Stock Exchange (TWSE), we address the issue of the informativeness of the limit order book in the periodic call market. We find that the pre-call information variables, i.e., the market order and the radius of the limit order book, have significant impacts on the trade variables, i.e., the trading volume, the post-call bid-ask spread, and the trader surplus. Furthermore, we are able to show that the radius, as well as the market order, contains two differential forces in impacting on these trade variables.

JEL classification: G10; G20

Keywords: Bid-ask spread; Trading volume; Trader surplus; Heterogeneous information

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1. Introduction

The core of a limit order market is that it provides information about aggregate liquidity supply and trading interests. This is particularly true in an electronic limit order market without market makers (Glosten, 1994). Bagehot (1971) argues the necessity of the existence of the bid-ask spread due to information asymmetry in the market and the survivorship of the market maker. Copeland and Galai (1983) show that the market maker's bid-ask spread is to cover the cost of trading with informed traders. Glosten and Milgrom (1985) elaborate the characteristics of the bid-ask spread by showing the convergent nature of the bid and ask quotes as the number of trade getting large. Easley and O'Hara (1987) offer a model that the bid spread and the ask spread of the market maker may not be symmetric[2]. Their remark essentially show the complicated information nature in the bid-ask spread. But how are the above information theories related to the limit order book? As pointed out by Handa and Schwartz (1996), "[l]imit order traders resemble dealers in that they provide liquidity and immediacy to the market." This view is confirmed and enriched by the laboratory experiment of Bloomfield, O'Hara, and Saar (2005) that in a limit order market informed traders not only use more limit orders than do uninformed traders but also make and take liquidity in order to achieve round-trip trading in the market. Kaniel and Liu (2006) model that in equilibrium informed traders prefer limit orders to market orders and the probability of limit order preference is so high that makes the limit orders more informative than market orders. Handa and Schwartz (1996) offer a model that the choice between limit and market orders is based upon investors' beliefs whether they will encounter informed or uninformed traders. In Parlour (1998), an investor' choice between limit and market orders is based upon the current and the future states of the limit order book. Foucault (1999) tackles investors' order-type choice by introducing winner's curse problem for limit order traders of being picked-off. Foucault, Kadan, and Kandel (2005) address how traders' impatience has effects on order placement strategy. Goettler, Parlour, and Rajan (2005) model that low valuation traders tend to submit orders with ask prices lower than the consensus value of the asset. Similarly, high valuation traders tend to submit orders with bid prices higher than the consensus value. An implication of their model is that traders who submit market orders could benefit from negative transaction costs (i.e., they could buy below or sell above the consensus value). This implies that market

[2] Possibly the first theoretical structural claim of heterogeneous beliefs in a single bid-ask spread.

order[3] submitters can enjoy a higher degree of trader surplus. Foucault, Moinas, and Theissen (2007) claim that the status of limit orders itself contain volatility information because imbedded option features in limit orders. Goettler, Parlour, and Rajan (2009) claim that the characteristics of risky assets affect the way of information gathering, thus affect the trading strategy of investors, and hence affect the informativeness of the limit order book. As to empirical findings, Chung, Van Ness, and Van Ness (1999) find that on NYSE the main portion of bid and ask quotes is from the interests of limit order traders. Specialists are more likely to quote for low-volume stocks. Madhavan and Panchapagesan (2000) claim that it is a valuable privilege for market makers, such as specialists on NYSE, to access information regarding the evolution of the limit order book, and it is especially relevant at the market open. Griffiths, Smith, Turnbull, and White (2000) find that aggressive orders usually incur a larger price impacts but smaller opportunity costs. Furthermore, they find that when the bid-ask spreads are narrow and depth on the same (opposite) side of the book is thick (thin), aggressive orders tend to be recursive. Ranaldo (2004) shows that the aggressiveness of orders depends on the depths, the bid-ask spread and the change in volatility in the limit order book. Bae, Jang, and park (2003) find that limit order prevails market orders when the bid-ask spread is wider, the trade size is larger, and the market anticipates high volatility. By taking one step further in information asymmetry, Miller (1977) shows that with the short-sales constrains if investors have different valuations on the risky asset, the slope of the demand curve would be negative. The implication is that the market clearing price will be above the mean evaluation of all potential investors because of the combined effect of the short-sales constrains and the divergence of opinion[4]. Based up the theory of Miller (1977), Chen, Hong, and Stein (2002) form a framework in diversity of opinion with short-sales constraints by examining the breath of ownership in mutual funds. They find that there is a positive relation between the change in the breath and the subsequent returns. Hong, Scheinkman, and Xiong (2006) offer a bubble model that given heterogeneous beliefs with short-sell constrains, overconfident investors are willing to pay more than their evaluation because they believe that there are other investors who are willing to pay even more in the future. Kim, Lee, and Morck (2004) document that differential demand and supply schedules exist when investors having heterogeneous beliefs and the elasticities of these schedules react differently in financial crises. Bagwell (1992) find that heterogeneous beliefs exist in Dutch auction stock repurchases and the supply of these shares in the repurchasing programs

[3] This also implies that the size of the market order needs to be limited. Otherwise, it may “walk the book.”

[4] In this study, we use both divergence of opinion, heterogeneous beliefs or heterogeneous information, interchangeably.

are upward-sloping. Glosten (1994) models an electronic limit order book when there is an exogenous large supply of limit orders. He argues that due to the existence of informed trade, the slope of the supply schedule is positive, which reflects the discriminatory nature of the book. Kandel, Sarig, and Wohl (1999) find that the demand curves of 27 Israeli IPOs are elastic and downward-sloping. Kalay, Sade, and Wohl (2004) find an increasing pattern in the estimated mean quantity-adjusted elasticity of the excess demand during the trading day. That is, the lower the elasticity the larger the information asymmetry and vice versa. Their finding is consistent to the predictions that the information revealed during the trading day mitigates the severity of the adverse selection problem (Glosten and Milgrom, 1985). Kim, Lee, and Morck (2004) examine the differential changes in estimated demand and supply elasticities among different classes of investor around the financial crises in Asia. They find that the demand and supply curves of domestic institutions and foreign investors are more elastic than that of domestic individuals. Naes and Skjeltorp (2006) find that there are differential relationships between the slope and the number of trades in the book. That is, for the whole book there is a negative relationship between the mean slope and the number of trades, but a positive relationship if only focusing at the inner quotes. This phenomenon reflects differential information in different segments of the order book.

The above theoretical and empirical works are more focusing on the informativeness of the order book in a continuous market. That leads us to the purpose of this paper by addressing the following questions: In a periodic call market, does the limit order book contain information or even heterogeneous information? In particular, will the order strategy (market vs. limit orders) makes any difference in information revelation? Furthermore, will the number of the order price level in the book affect trade characteristics, such as the post-call spread, trading volume, or trader surplus? The significance is that in the call market to make a trade match it needs the full schedules of demand and supply, but it is barely the case in the continuous market. In our analysis, first, we offer an alternative interpretation on the post-call bid-ask spread in the periodic call market. Contrary to the conventional concept of the pre-trade spread in a continuous market, the post-call spread is to reflect the degree of information asymmetry resolved at the time of determining the market clearing price. In other words, the gap between the two post-call pricing schedules (demand and supply) is a realization of information symmetry and it should be considered as the degree of information symmetry achieved after the call. Furthermore, as an alternative to the slope of the order book (e.g., Kalay et al., 2004; Naes and Skjeltorp, 2006), we offer a pair of new information variables to measure the degree of heterogeneous beliefs. We call them the *radii* of the order book. The basic intuition is that the order (price and depth) at each order price level basically reflects differential information in the book (Glosten, 1994). However, the farther the order price is away from the best order price the less likely it will be considered in the game. Hence, we choose the number of the order price level between the best order price level and the most popular order price level that has the thickest depth in the book to be a proxy to reflect the degree of heterogeneous information in the book before a call. We find that there is a negative relationship between the radii of the order book and the post-call spread. These negative relations are consistent to the analyst underreaction hypothesis (Das, Levine, Sivaramakrishnan, 1998) and complement to the results of Park (2008) and Zhang (2006). These findings imply that the higher degree of heterogeneous beliefs in the pre-call environment, the less achievement of information symmetry in the post-call environment. However, in examining the liquidity characteristics of trading volume, we find that the market orders are positively and the radii of the order book are negatively correlated with the trading volume. By decomposing the radius of the order book into the lower radius (number of the matched order price level) and the upper radius (number of unmatched order price level), we find that the lower radii of the order book have a positive correlation[5] with the trading volume, but the upper radii, along with the market orders, have a negative correlation with the trading volume. Since the radius of the order flow represents the number of the order price level between the best order price level and the most popular order price level that has the thickest depth in the limit order book, the market order not only is a subset of the radius of the order flow, but, more precisely, it is a subset of the lower radius of the order flow. If the radius of the order book has contained all of information, what is the significance to introduce the variable of the market order? With respect to market liquidity (e.g., trading volume) the market order normally has two distinct characteristics: (1) low execution risk: pro trading volume, and (2) smaller size of depth: con trading volume (Table 1). The variable of the radius of the order book is only able to pick up the first characteristic of the market order. By simultaneously introducing the variable of the market order in the regression, we thus are able to extract the second characteristic of the market order.

Kalay et al. (2004) and Naes and Skjeltorp (2006) focus on the informativeness of the slope in the book. However, it is more intuitive that the slopes of the demand and supply schedules directly affect the surplus of the traders whose orders have been matched. Hence, it is relevant for us to ask: What is the relation between the trader

[5] The coefficient of the radius of the order book on the sell side is statistically insignificant (see Table 3).

surplus and the radius of the order book, which is a proxy of the degree of heterogeneous information? We find that the lower (upper) radii representing matched (unmatched) orders on both sides of the market have a positive (negative) contribution on the trading volume. Furthermore, the market order has a positive contribution on the trader surplus of the same side, but a negative contribution on the trader surplus of the opposite side. This phenomenon is consistent to the extension of the crowding out effect in Parlour (1998) that due to the time priority of the existing orders, depth at the best price on the same side of the book decreases the likelihood of incoming limit orders, while depth at the best price on the opposite side increases this probability. If so, for example, a thick depth of limit orders on sell side will increase the likelihood of market order submission on the same side, which in turn will decrease the probability of market order submission on the buy side. In short, an increase in market order on the sell side may cause a decrease in market order on the buy side. Hence, the crowding out effect in Parlour (1998) may explain our finding that there is a negative relation between the trader surplus of this side and the market order submitted from the opposite side.

The paper is organized in the following way. In section 2, we describe our sample data, including the rationale of the post-call bid-ask spread and the intuition of the radius of the order book and its formation. Section 3 presents the regression analyses of the post-call spread and the trading volume with respect to the slope and the radius of the order book. Also, we analyze the relation between the trader surplus and the radius of the order book. Section 4 concludes the paper.

2. Data and Methodology

2.1 Data

The sample intraday data that we choose are the constituent stocks in the TWSE Taiwan 50 Index[6] on the Taiwan Stock Exchange (TWSE) from January to May, 2005. Our sample includes the time-stamped trade related variables, such as market clearing price and volume, the time-stamped order related variables, such as the order prices and the order shares. This information is enough for us to reconstruct the demand and supply schedules with its intersection at the market clearing price and volume for each trade during the day. TWSE is an order-driven periodic call market. On a typical trading day, it opens at 9:00 a.m. and closes at 1:30 p.m. At 8:30 a.m., investors may start their order submissions. The second last trade of the day is at 1:25 p.m. After 1:25 p.m. and before 1:30 p.m., it only allows order accumulation.

[6] The TWSE Taiwan 50 Index, launched on October 29, 2002, was the first tradable index in Taiwan market. To be included in the Index, these firms must be ranked in the first fifty by market capitalization.

On TWSE, investors can only submit limit orders and there is no option of submitting conventional market orders. However, there are daily price limits, i.e., on a trading day, the price range of any stock is within $\pm 7\%$ of the previous closing price. Hence, by local convention, the "market order" on TWSE is an order with its limit price reaching its daily price limit, considering the tick size requirement. In Table 1, we present descriptive statistics on market capitalization, market clearing price, trade size, post-call spreads, limit and market order sizes, and the sizes of the radius in the order book. The mean market capitalization is about NT$184 billion with the mean price level of NT$39.54 and the mean trade size of 37.91 lot[7]. The mean (median) limit order sizes are 303 (215) lots and 406 (318) lots for the buy and sell sides, respectively. The mean (median) order sizes of the market order, however, are much smaller, i.e., 24 (15) lots and 33 (14) lots for the buy and sell sides, respectively. The mean lower radii of the order book on the buy and sell sides are 1.53 and 1.57, respectively, which are much smaller than those of upper radii, 5.87 and 7.08, respectively.

2.2 The rationale behind the post-call bid-ask spread

In theoretical work, such as, Glosten and Milgrom (1985), Easley and O'Hara (1987), one of the important elements in the bid-ask spread is the adverse-selection cost component. Glosten (1987) classifies this kind of adverse-selection cost component as an ex ante approach. In contrast, the ex post approach is that in the end the market maker will need to offset the loss to the informed traders by profiting from the liquidity traders. In the setting of the continuous market trading mechanism, the adverse-selection cost component in the quoted bid-ask spread is more geared to the description of the ex ante view, and the adverse-selection cost component in the realized bid-ask spread (e.g., Blume and Goldstein, 1992; Copeland and Galai, 1983; Lee, 1993; Petersen and Fiakowski, 1994;) is more geared to that of the ex post view. In the environment of the periodic call trading mechanism, such as the Taiwan Stock Exchange, immediately before a successful call, normally there is no bid-ask spread because the pricing schedules from both the demand and supply sides run across. Otherwise, for sure there will be no successful call. However, immediately after the call, normally there is a gap between these two pricing schedules in the limit order book. This gap may have a shape like the bid-ask spread in the continuous market but can carry a different meaning. That is, immediately before a successful call, the sections in the demand and supply schedules eventually cleared can be viewed as to reflect the degree of information asymmetry resolved at the market clearing price.

[7] On TWSE, a round lot is 1,000 shares.

To put it differently, the gap between the two post-call pricing schedules (demand and supply) is a realization of information symmetry from the pre-call to the post-call demand and supply pricing schedules. It is because the buy orders with limit prices higher than the call price and the sell orders with limit prices lower than then call price will for sure be completely cleared. Any remaining matched volume is determined and cleared at the call price. Hence, this post-call gap[8] between the two pricing schedules cannot be viewed as the bid-ask spread in the continuous market, but on the contrary it should be considered as the degree of information symmetry achieved after the call. We offer a more elaborated illustration of this idea in Appendix A.

2.3 The intuition and measure of the radius of the limit order book

Given the interpretation of the post-call bid-ask spread, the follow-up question then becomes: Given the existence of information asymmetry, what is the level of heterogeneous information[9] in the pre-call demand and supply pricing schedules? Naes and Skjeltorp (2006) claim that the slopes of the bid and ask pricing schedules reflect the degree of heterogeneous information[10]. They argue that the pricing schedules from both sides of the market contain differential information. Hence, there is a negative relation between the level of the disagreement among analysts and the average absolute slopes (i.e., a smaller $\left|\frac{\Delta Q}{\Delta P}\right|$) of the limit order book. Nonetheless, the measurement of slope (or elasticity) can be problematic as indicated in Kalay et al. (2004). Thus, this encourages us to explore another pair of proxy to measure heterogeneous information in the limit order book. If the above claim in Naes and Skjeltorp (2006) is correct, then it also implies that the pricing schedule on each side of the market should be more spread out the greater the disagreement among analysts. If this is true, there should be a positive relationship between heterogeneous information and the number of order price level in the limit order book. This point of view is also consistent to Figure 1 in Miller (1977): A steeper differential valuation schedule is caused by stronger heterogeneous information (i.e., divergence of opinion). Furthermore, Biais, Hillion, and Spatt (1995) empirically find that on Paris Bourse the depths are lower at the inside bid-ask quotes than those of away from the best quotes.

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[8] Any unsuccessful call often will have a gap between the demand and supply schedules. Our interpretation only goes to the gap after a successful call.

[9] As pointed out by Hong et al. (2006), there are several ways of having divergence in opinion (i.e., heterogeneous information) in the market, e.g., based upon the same piece of private information, but one group of investor is more confident than others or different groups of investor have different set of private information.

[10] Their data used are from a continuous trading environment.

In a theoretical framework, Seppi (1997) suggests that in the book the supply of limit orders beyond the inside bid-ask quotes are a source of liquidity for large orders from the opposite side. These above views imply that in the limit order book (1) the best quotes may not be the only source of private information, (2) quotes beyond the best quotes do carry differential information. Nonetheless, short-sales on Taiwan Stock Exchange (TWSE) are permitted. Does this meaning that the divergence of opinion will not work on TWSE? No, Miller (1977) only says that the co-existence of short-sales constrains and heterogeneous information will cause an over-valuation in market clearing prices. He is not saying that heterogeneous information could not exist without short-sales constrains. For example, Hong and Stein (2003) model market crash that is caused by the divergence of opinion without the consideration of the short-sales constrains but with a class of rational arbitrageurs.

Having established the line of reasoning that the number of order price level can be considered as a proxy for heterogeneous information in the book, we need to take a closer look at these order price levels. In the book on TWSE, orders with higher buy prices or lower sell prices have better chances to be cleared and orders far away from the best prices are less likely to be cleared and possibly remain in the book through out the whole trading day. From time-series point of view, these stale orders are simply a facade of the change in heterogeneous information in the book. Hence, the raw form of the order price level needs to be cultivated before suitable for our purpose. To get a feeling on the characteristic of these order price levels in the book, we plot the mean buy and sell order flows (depths) of the first eight order price levels in the book. On each side of the book, we first compute the mean order sizes of the market open, close, intraday 30-min (mean), and the whole trading day for each of the first eight order price levels[11] for each firm over the five month sample period (from January to May, 2005). Then, we compute the cross sectional means over all these constituent stocks in the TWSE Taiwan 50 Index. Except market open and close, in Figure 1 we observe that the depths vary significantly among different order price levels and present an inverse U-shaped pattern when they are away from the best order prices[12]. That is, the average depth at each order price level reaches its thickest point somewhere in the middle of the pricing schedule and then declines. In the book there is a most popular order price level[13] that has the thickest depth on each

[11] In our sample arrangement, we only consider the first eight price levels in our analysis, but we have examined the schedules of ten or twelve order price levels. They yield similar results.

[12] In the quote-driven continuous market, the lowest ask and the highest bid usually are called the inside quotes. In the order-driven periodic call market, we call the lowest ask and the highest bid in the limit order book as the best order prices mainly because these prices may run across each other.

[13] If there are more than one order price levels that have the thickest depth, then we shall choose the farthest order price level in the limit order book as our most popular order price level.

side of the market at each call in the book. Investors who eager to complete trades would consider to submitting orders with more aggressive features, such as market orders or orders with competitive prices. Investors who wish to minimize trading cost or maximize trading profit would consider to submitting orders with less aggressive features, such as limit orders with prices farther away from the best prices. Thus, the former investors may incur a higher trading cost and the latter may suffer a higher execution risk (i.e., the possibility of no trades). If weighing order submission by these two factors, investors can submit orders that are neither at the best price nor at the farthest order price level in the book, but somewhere in between as observed in our Figure 1, which is also consistent to Figure 1 in Naes and Skjeltorp (2006). Hence, for our purpose, we measure the number of the order price level between this most popular price level and the best order price level as the (buy or sell) proxy for the degree of heterogeneous information before a call in the pricing schedule. We call them the *radii* of the order book. Before, we have chosen the post-call bid-ask spread as the resolution of information asymmetry (or the achievement of information symmetry) after a call. Then now one may raise the question: What is the relationship between the pre-trade radius of the order price level and the post-call spread? Specifically, if a wider pre-trade radius of the order price level implies that a higher degree of heterogeneous information causes this archipelago-like pricing schedule, then when the pre-trade heterogeneous information is high, will the call trading mechanism on TWSE produce a narrower post-trade bid-ask spread (i.e., achieving a smaller degree of information symmetry) or a wider post-trade bid-ask spread (i.e., achieving a larger degree of information symmetry)? Stickel (1991), Gleason and Lee (2003), among others, demonstrate that the immediate stock price reaction to analysts' forecast revisions is incomplete, in that prices, on average, continue to drift in the same direction for at least three to nine months after the revision. Zhang (2005) and Jiang et al. (2005) document that information uncertainty is positively related to the post-analyst-revision drift. Zhang (2006) and Park (2008) further show that analysts underreact to new information and they underreact even more when there is higher information uncertainty. In short, analyst forecast rationality predicts zero ex ante forecast errors following good or bad news and provides no role for information uncertainty. However, analyst optimism tends to predict negative forecast errors. On average, more negative forecast errors the higher information uncertainty regardless of the nature of news (Das et al., 1998). The idea of heterogeneous information or the divergence of opinion in the literature, such as in Miller (1977), Bagwell (1992), Kandel et al. (1999), Chen et al. (2002), Hong and Stein (2003), Kim et al. (2004), and Hong et al. (2006), is actually information asymmetry among informed investors. This kind of complexity in information asymmetry may cause even more negative forecast errors in the sense of Das et al. (1998). Hence, for this modified analyst underreaction hypothesis we predict that there is a negative correlation between the pre-trade radius of the order price level that represents the degree of the pre-call heterogeneous information and the post-call bid-ask spread that represents the post-call achievement in information symmetry due to the call.

3. Empirical Results

The purpose of our empirical study has two folds: one is to examine the information content in the limit order book, and the other is to perform the comparison of the results between our model specification and the ones in the literature. In particular, Kalay et al. (2004) and Naes and Skjeltorp (2006) suggest that the slopes in the limit order book reflect the degree of information asymmetry. If so, information variables suggested in the theory, such as, the bid-ask spread and trading volume should be affected by the slope. However, the measure of the slope is problematic as indicated in Kalay et al. (2004, pp. 463). Thus, we choose the radii of the order book as the alternative information proxies in the limit order book.

3.1 The slopes and the radius of the limit order book

Naes and Skejeltorp (2006) claim that the slopes of the bid and ask pricing schedules reflect the degree of heterogeneous information[14]. They argue that the greater the disagreement among analysts, the flatter the average slope of the order book. However, there are two pricing schedules in the limit order book, one is on the demand side and the other one on the supply side. While the demand and supply pricing schedules reflect liquidity needs and heterogeneous information of their own side of the market, normally, the slope of the demand pricing schedule carries a negative sign and, however, that of the supply pricing schedule carries a positive sign. If the fundamental elements that determine the pricing schedule on each side of the market are different, then a simple average of these two pricing schedules' slopes may likely to obscure the information content in each of these two pricing schedules. Our rationale is straight forward that if there are two information proxies in the limit order book, why just use the net measure, even it is a combination[15] of the two proxies? A

[14] Their data are mainly in a continuous trading environment setting.

[15] Naes and Skejeltorp (2006) combine the slopes of demand and supply schedules by averaging the two slopes. Kalay et al. (2004) combine these two slopes by examining the slope of the excess demand (demand minus supply). However, in this fashion, the slope of the excess demand still presents the mixed features of the original slopes.

direct usage of these two information proxies, such as, the radii of the order book of the demand and supply pricing schedules, may yield not only two separate results but possibly differential and comparable results. We thus conduct a series of regression test to examine these two sets of information proxies in the limit order book. There are two aspects in this examination: (1) the relation between the post-call bid-ask spread (a proxy for the resolution of information asymmetry) and our information variables (i.e., the slopes and the radii of the book), (2) the relation between the trading volume and our information variables.

The candidates of the dependent variable are (a) the one-sided trading volume at each call, and (b) the post-call bid-ask percentage spread.

$$Dependent_t = \alpha + \beta_1 \cdot MktOdr\_buy_t + \beta_2 \cdot MktOdr\_sell_t + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t + \beta_5 \cdot Information\_buy_t + \beta_6 \cdot Information\_sell_t + \varepsilon_t .$$

We choose six independent microstructure variables for each regression model. $MktOdr\_buy_t$ ($MktOdr\_sell_t$) is an indicator variable that is equal to one, if the orders at the first level[16] of order price on the demand (supply) pricing schedule are the market order, i.e., their order prices reach the daily price limit $+7\%$ (-7%), with the consideration of the relevant tick size. Otherwise, it is equal to zero. The indicator variable $Open = +1$ (and $Close = +1$), if the call is at the market open (close). Otherwise, $Open = 0$ (and $Close = 0$). The independent variable of $Information\_buy_t$ ($Information\_sell_t$) is the information variable to proxy the heterogeneous information on the demand (supply) pricing schedule. In Kalay et al. (2004) and Naes and Skjeltorp (2006), they claim that the slope of the demand or supply pricing schedule reflects heterogeneous beliefs in the market. Hence, in regression models II and IV, we use the absolute slopes of the demand (supply) pricing schedule as the independent variable of $Information\_buy_t$ ($Information\_sell_t$). We, however, believe that the variables of the radii of the order book that measure the numbers of order price level between these most popular price levels and the best order price levels in the demand and supply pricing schedule actually contain better information. Thus, in regression models I and III we use the radius of the order book of the demand (supply) pricing schedule as the independent variable of $Information\_buy_t$ ($Information\_sell_t$). The sample data in our regression analyses are in the form of panel data, i.e., we stack up individual firms' intraday data one on the top of another. Hence, it may contain biased effects of

[16] If it is the market order (defined by the practice in the Taiwan stock market), then it has to be at the first level of the order book, buy or sell side, but not *vice versa*.

autocorrelation and heteroskedasticity in the error terms. We apply Newey and West (1987) consistent variance/covariance matrix to correct these biases for the t-statistics. In examining the post-call bid-ask percentage spread, in models I and II both market open and market close variables have positive contribution to the size of the spread. These results are consistent to the well-known findings in the literature, such as Lee, Mucklow, and Ready (1993) as well as theoretical work, such as Admati and Pfleiderer (1988) and Brock and Kleidon (1992) that a wider spread corresponds to an environment of higher information asymmetry or liquidity needs, such as market open and close. The coefficients of market orders from both sides of the market have negative signs. This result implies that in both models I and II the existence of market orders, either buy or sell, contribute less in the achievement of information symmetry than that of limit orders. The popular view in the literature indicates that informed traders tend to use market orders[17] because they are less patient or their private information has a higher decay rate. However, Bloomfield, O'Hara, and Saar (2005) show that informed and uninformed both will use market and limit orders, but only have a preference in timing when choosing the order types. Perhaps of this mixed order strategy, it makes market orders a less revealing vehicle than limit orders in achieving information symmetry. Alternatively, instead of market orders, if informed traders do predominately use limit orders, then market orders carry less information (Kaniel and Liu, 2006). Thus, the evidence of a negative relation between the market order and the post-call spread is consistent to the analyst underreaction hypothesis and the claim in Kaniel and Liu (2006) that the higher the degree of information asymmetry in a pre-trade environment, the less the degree of information symmetry achieved in the post-trade environment by using market orders.

Furthermore, if the hypothesis of the analyst forecast rationality that predicts zero ex ante forecast errors is correct, then we should observe no relation between the information variables (i.e., the slopes or the radius of the book) and the post-call bid-ask percentage spread. Alternatively, if the analyst underreaction hypothesis is correct, we should observe a negative relation between the information variables and the post-call bid-ask percentage spread. In model II, the information variables are the slopes of the demand and supply schedules, as studied in Kalay et al. (2004) and Naes and Skjeltorp (2006). The coefficient of the absolute slope on the demand side has a negative sign and the absolute slope on the supply side has a positive sign. This

[17] Glosten (1994) and Seppi (1997) explicitly incorporate informed traders into their models, but assume that they always enter market orders instead of limit orders. However, Chakravarty and Holden (1995) and Kaniel and Liu (2002) include both market and limit orders in informed traders' order preference.

empirical evidence from the absolute slopes offer mixed results on the modified analyst underreaction hypothesis. In model I, the information variables are the radii of the order book. Both of the coefficients of the radius carry a negative sign that supports the modified analyst underreaction hypothesis and complements to the results of Park (2008) and Zhang (2006). This finding from the radius of the book implies that the higher heterogeneous information in the pre-call environment, the less achievement in information symmetry in the post-call environment.

When examining the dependent variable trading volume, we find that the relationship between market orders and trading volume is positive in both models III and IV (Table 2). It implies that market orders have a positive contribution to trading volume. It is intuitively appealing that due to their price advantageous market orders enjoy a higher degree of matching opportunity than that of limit orders. But is this the only characteristic of the market order reflected in the book? Again, before addressing this question, we wish to examine the relation between the information variables and trading volume first. In model IV, the proxies for the information variables are the absolute slopes of the demand and supply that have a positive correlation with the trading volume. However, in model III, the proxies for the information variables are the radii of the order book that have a negative correlation with the trading volume. Ostensibly, these two results are contradicting to each other. The absolute slopes used in our regression models are the average absolute slopes between each pair of order price in the demand and supply schedules. The way we measure our radii of the order price level is to count the number of the order price level between the price level of the thickest depth and the best order price level in the buy and sell pricing schedules. These radii of the order price level thus could contain both matched and unmatched orders. The reason that the coefficients of the radii of the order book are negative is perhaps because the radii are predominantly occupied by unmatched orders. In other word, the information variables (the radii of the order book) that we choose may contain two distinct characteristics relative to the conventional information variables (i.e., the absolute slopes of the demand and supply schedules). To examine this double-featured characteristics in the radii of the order book, we further divide these radii into two portions[18]. That is, the portion that is cleared at the call price and the rest left in the book. We call the former the lower portion of the radius (i.e., the lower radius, see details in Appendix B) and the latter the upper portion of the radius (i.e., the upper radius) to reflect graphical presentation of the demand and supply schedules with price in the horizontal axis and the

[18] This radius decomposition paints a path for us to answer the previous question: Is this the only characteristic in the market order reflected in the relation with the trading volume?

cumulated order size in the vertical axis such as the one shown in Figure 1 of Mendelson (1982). Since we choose the radius of the order book as the information variable, thus, the upper and lower radii of the order price level must also contain information. If heterogeneous private information contains two parts, one that can be revealed[19] (i.e., becomes public information) and the other cannot be revealed in the trade, then the revealed[20] portion of heterogeneous private information most likely is due to the matched orders and the unrevealed portion of heterogeneous private information mostly likely is still withheld in the unmatched orders. Hence, our lower radius of the order price level is a proxy for the part of heterogeneous private information that has been revealed and our upper radius of the order price level is a proxy for the part of heterogeneous private information has not been revealed in the trade. In regression model VI: Trading volume, we find that the lower radii of the order price level have a positive correlation with the trading volume and the upper radii have a negative correlation with the trading volume. It implies that the upper radius of the order price level that contains the portion of unrevealed heterogeneous private information in the book checks the size of the trading volume. This also implies that given heterogeneous information traders with more precise information may submit more aggressive orders that are most likely to be cleared. Interestingly, Naes and Skjeltorp (2006, pp. 424) also find that “the parameter estimate switches sign and becomes more positive the closer they get to the inner quotes. That is, the slope at the inner quotes is positively related to the number of trades, while the average slope for the full book is negatively related to the number of trades. In other words, the order book slope seems to contain different information about trading activity depending on what subset of the order book we use to calculate the slope.”

Furthermore, we observe that the coefficients of market orders are negative, contrasting to the positive coefficients of the lower radii of the order price level that reflect the number of matched order price level in the pricing schedules. This finding touches our long delayed question: But is this the only characteristic of the market order reflected in the book? It is that the lower radii of the order price level may have contained part of the information in the market order variables. This information duplication is due to that the matched orders could be included in both the radii of the order book and the market order variables. However, there is another piece of information that is trapped in the market order variables but is not reflected in the radii of the order book. That is, the sizes of the market orders on both sides are

[19] There are numerous theoretical models discuss the private information revelation, such as Admati and Pfleiderer (1988), Easley and O’Hara (1987), Kyle (1985) and Glosten and Milgrom (1985).

[20] Here, the revealed portion of private information means that the part of private information is reflected in the trading volume and the market clearing price in a periodic call market.

on average smaller than that of limit orders (see Table 1). This is the reason that the coefficients of market orders are negative in our regression model VI: Trading volume. Similarly, in model V: Post-call spread, after controlling for market open and close[21], we find negative coefficients for the market order variables as well as for the upper radii. The coefficient of the lower radius on sell side is positive, but statistically insignificant. Overall, these findings enhance our belief that the radii of the order book are preferred information variables over the conventional measures, e.g., the absolute slopes of the demand and supply schedules.

In order to further addressing the previous question regarding the characteristics of the market order in relation to the trading volume, we regress the lower radii of the order price level on market orders of the both sides, controlling for market open and close. The basic notion is that for any successful call there is a positive trading volume. Market orders, if exist, must be taking part in this trading volume and so does the content in the lower radii (because they represent the number of order price level). Hence, there must be a common feature between market orders and the radii of the order book. That is,

$$LowerRadius_{Buy,i,t} = \alpha + \beta_1 \cdot MktOrder_{Buy,i,t} + \beta_2 \cdot MktOrder_{Sell,i,t} + \beta_3 \cdot Open_{i,t} + \beta_4 \cdot Close_{i,t} + \varepsilon_{i,t},$$
$$LowerRadius_{Sell,i,t} = \alpha + \beta_1 \cdot MktOrder_{Buy,i,t} + \beta_2 \cdot MktOrder_{Sell,i,t} + \beta_3 \cdot Open_{i,t} + \beta_4 \cdot Close_{i,t} + \upsilon_t.$$

$LowerRadius_{Buy,t}$ ($LowerRadius_{Sell,t}$) is the number of matched order price level on the buy (sell) side, $MktOrder_{Buy,t}$ ($MktOrder_{Sell,t}$) is the buy (sell) indicator variable that is equal to one if there is a market order and is equal to zero, otherwise. $Open_t$ ($Close_t$) is the indicator variable that is equal to one, if the trade is at market open (close), and zero, otherwise. ε_t and υ_t are regression error terms, respectively.

In Table 4, after controlling for the market open and close in both regression models, as we predicted there is a positive correlation between $LowerRadius_{Buy,t}$ ($LowerRadius_{Sell,t}$) and $MktOrder_{Buy,t}$ ($MktOrder_{Sell,t}$). Furthermore, there is also a

[21] We would expect a positive coefficient on the market close variable, but instead, we have a negative sign, only insignificant.

positive correlation between $LowerRadius_{Buy,t}$ ($LowerRadius_{Sell,t}$) and $MktOrder_{Sell,t}$ ($MktOrder_{Buy,t}$). This finding implies that the market order of the sell (buy) side can also have the positive contribution on the number of buy (sell) side matched order price level. This is likely because the market order from one side not only facilitates its own side of trade completion but also helps the other side matching possibility (Parlour, 1998; Bloomfield, O'Hara, Saar, 2005). However, by observing their adjusted R^2, we are also aware of that $LowerRadius_{Buy,t}$ ($LowerRadius_{Sell,t}$) and $MktOrder_{Buy,t}$ ($MktOrder_{Sell,t}$) are not two identical variables. Between them, they do share some common information, but at least one of them contains some differential information as we suggested in the previous section (e.g., Model VI, Table 3). We conjecture that the market order contains two salient features: the first feature is its aggressive price and the second feature is its relative smaller size (than that of limit orders). The former feature gives the market order a positive relation with the trading volume, but the latter feature contributes a negative relation with the trading volume. The market order shares its aggressive price feature with the lower radius that represents the number of matched order price level. This is the main reason that in Table 2 the coefficients of the market orders are positive but in Table 3 they are negative (due to the second feature of relatively smaller size) because the appearance of the lower radii of the order price level has reflected its first feature.

3.2 Trader Surplus and Information Asymmetry

As discussed in Kalay et al. (2004) and Naes and Skjeltorp (2006), the slopes in the limit order book summarize the level of heterogeneous information. However, it is more intuitive that the slopes of the demand and supply schedules should directly affect the surplus of the traders who submit orders; in particular, those traders whose orders are matched in the trades. Thus, it becomes relevant for us to know: What is the relation between the trader surplus and the level of heterogeneous information?

By placing the price on the horizontal axis and the quantity on the vertical axis as suggested in Mendelson (1982), in Figure 2 we observe that the flatter the demand (supply) curve, which implies a higher the degree of heterogeneous information and the larger the size of the trader surplus on the demand (supply) side. Recall our argument that as in Naes and Skjeltorp (2006) if the greater the disagreement among analysts, the more gentle the average absolute slopes[22] of the order book, then this also implies that on each side of the market, the greater the disagreement among analysts, the more spread out the pricing schedules, which leads to a larger size of the radii of the order book. Furthermore, by decomposing the radius of the order book into $LowerRadius$ and $UpperRadius$ of the buy and sell sides, respectively, given its trade match status, we expect that only $LowerRadius$ on each side of the market has the positive contribution to its corresponding trader surplus. However, $UpperRadius$ that represents the unmatched orders should have a negative contribution to the trader surplus. On the surface, it seems that $UpperRadius$ and $LowerRadius$ are the two components in the radius of the order book. The larger the size of one component will lead to a smaller size of the other component. However, as we explained before that the lower (upper) radius represents the revealed (unrevealed) portion of private heterogeneous information. Goettler et al. (2005) suggests that a trader willing to incur a high transaction cost has a large benefit (i.e., welfare gain) from trade. We thus predict a positive (negative) relation between the trader surplus and the lower (upper) radius of the order price level.

We regress the trader surplus of the demand and supply sides, respectively, on $UpperRadius$ and $LowerRadius$ of both sides of the market, controlling for the order types, and market open and close. That is,

$$\begin{aligned} Surplus_t = \alpha + \beta_1 \cdot MktOdr\_buy_t + \beta_2 \cdot MktOdr\_sell_t + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t \\ + \beta_5 \cdot UpperRadius\_buy_t + \beta_6 \cdot UpperRadius\_sell_t \\ + \beta_7 \cdot LowerRadius\_buy_t + \beta_8 \cdot LowerRadius\_sell_t + \xi_t . \end{aligned}$$

The candidates for the dependent variable are the trade surpluses on the demand and supply sides. $MktOrder_{Buy,t}$ ($MktOrder_{Sell,t}$) is the buy-(sell-) side indicator variable that is equal to one if there is a market order and is equal to zero, if there is no market orders, $Open_t$ ($Close_t$) is the indicator variable that is equal to one if the trade at market open (close), and ξ_t is the regression error term. $UpperRadius\_buy_t$ ($UpperRadius\_sell_t$) is to proxy heterogeneous information of the unmatched orders and $LowerRadius\_buy_t$ ($LowerRadius\_sell_t$) is to proxy heterogeneous information of the matched orders on the buy-side (sell-side) pricing schedule. From Table 5, we observe that the coefficients of market open and close

[22] To compute slope, we need at least two pairs of price and depth observations in the matched section or the entire pricing schedule. From time to time, however, there is only one pair off order price/depth in the matched section or even in the entire pricing schedule. This feature makes slope application limited than that of our radius of the order price level.

indicator variables are positive. This finding is consistent to the prediction in the literature that around market open and close the level of heterogeneous information and trading volume are higher (e.g., Admati and Pfleiderer, 1988; Brock and Kleidon, 1992). Thus, we should expect a higher trader surplus around market open and close. Furthermore, we find that:

- Negative coefficients of upper radii: buy and sell,
- Positive coefficients of lower radii: buy and sell,
- Positive coefficients of market order: the same side as the trader surplus.

As discussed above, the upper radii of the order price level represent unrevealed heterogeneous private information that should check the size of trading volume, and thus the trader surplus. Goettler et al. (2005) suggests that a trader willing to incur a high transaction cost has a large benefit (i.e., welfare gain) from trade. This can explain that the lower radii of the buy and sell sides both contribute the revelation of heterogeneous private information by pricing aggressively and thus should have a positive correlation with the trader surplus. However, there is a twist. The coefficient of the lower radii on the same side as that of the trader surplus is smaller than that of the opposite side. For instance, in the trader surplus of the demand side regression model, the coefficient of the lower radius on the buy side is 0.3076, which is smaller than the coefficient of the lower radius on the sell side, 0.9507. The reason is that the part of information in the lower radius on the buy side is also reflected in the buy market order variable (2.0227) that is on the same side as the trader surplus dependent variable. The submission of the buy market order increases the trader surplus of the buy side because their orders are aggressively priced. This is the reason on the surface that when regressing the trader surplus of the demand side, the size of the coefficient of the radius on the buy side is smaller than that of the radius on the sell side. But why the size of the coefficient (2.0227) of the market order on the buy side is greater than that of the radius on the buy side (0.3076)? All orders included in the lower radius are the matched orders because of aggressive pricing. Among them, the market orders[23] have the most aggressive prices and thus they should contribute the most in the trader surplus on the same side. A similar situation can be found in the trader surplus of supply side regression.

[23] Alternatively, market orders are aggressive orders that add weights on its own side of pricing schedule in determining the market clearing price. That is, if the size of the market order on the demand (supply) side is relatively larger, then the market clearing price determined tends to be higher (lower). Thus, the buy (sell) market order will increase the trader surplus on the demand (supply) side because of the aggressive price of the market order but it also will decreases the trader surplus because of a higher (lower) market clearing price. The net effect of the market order, thus, becomes an empirical issue.

Finally, we need to interpret the results of the opposite market order variable, i.e., $MktOrder_{Buy,t}$, if the dependent variable is the trader surplus on the supply side, and $MktOrder_{Sell,t}$, if the dependent variable is the trader surplus on the demand side. In the trader surplus of the demand side regression, the coefficient of $MktOrder_{Sell,t}$ is negative. We find a similar situation in the trader surplus of the supply side regression, i.e., the coefficient of $MktOrder_{Buy,t}$ is negative. Why? Why when the market order submitted from the opposite side of the trader surplus, their relationship is negative? Parlour (1998) shows that the state of the limit order book will affect trade decision. The time priority of orders already in the book may arise crowding out effect. Parlour's model predicts that depth at the best price on the same side of the book decreases the likelihood of submitting a limit order, while depth at the best price on the opposite side of the book increases this probability. If so, it implies that while the likelihood of submitting a market order on one side increases, the likelihood of submitting a limit order on the other side also increases. Perhaps, this is the reason that we observe negative signs on the coefficients of the opposite-side market orders in our trader surplus regressions. That is, the more market orders submitted from the other side, the less market orders and the more limit orders will be submitted from this side. The consequence is less trader surplus will be achieved on this side because of less aggressive orders submitted from the same side.

Nonetheless, the trading environment described in Parlour (1998) is in a continuous market setting. In our analysis the sample data employed are from the TWSE, which is a periodic call market. Thus, it is necessary for us to verify whether the order submitting strategy on the TWSE is consistent to the prediction in Parlour (1998). On both sides and for each stock, we first compute the two alternative percentage depths of market order by taking the ratio of the size of the market order over (1) the size of the radius depth, which is the total depth of the orders within the best order price level and the most popular (i.e., the deepest) order price level (2) the depth of the first twenty order levels in the limit order book. Then, we subtract these two percentage depths of the market order on the sell side, respectively, from that of the buy side and call it $Diff\%MktOrder_{i,t}$. We then regress $Diff\%MktOrder_{i,t}$ on the indicator variables of market order (buy and sell sides), controlling for the market open and close. That is,

$$Diff\,\%MktOrder_{i,t} = \alpha + \beta_1 \cdot Open_{i,t} + \beta_2 \cdot Close_{i,t} + \beta_3 \cdot MktOrder_{i,t}^{Buy} + \beta_4 \cdot MktOrder_{i,t}^{Sell} + \nu_{i,t},$$

where $Open_t$ ($Close_t$) is the indicator variable that is equal to one if the trade at market open (close), and is equal to zero, otherwise, and $\nu_{i,t}$ is the regression error term.

From Table 6, we observe that after controlling for the market open and close, there is a negative relation between $Diff\,\%MktOrder_{i,t}$ and the sell side market order indicator variable. This finding is consistent to the prediction in Parlour (1998) that the likelihood of limit order submission on one side increases as the depth of the opposite side increases and that in term increases the likelihood of the market order submission on the latter side. Furthermore, this finding supports our conjecture to the question raised by ourselves: Why do we observe a smaller trader surplus when the market order is submitted from the opposite side of the market in Table 5? That is, the submission of the market order from the opposite side decreases the likelihood of the market order submission of this side. A decrease in the market order submission means less aggressive orders in price dimension, which in term reduces the size of the trader surplus for the matched orders of this side.

4. Conclusion

The issue of whether the limit order book contains information is a popular topic in the academic literature. Nonetheless, the research along this line is more geared to the continuous market setting, but not so much in a periodic call market setting. By employing the intraday data on the Taiwan Stock Exchange, we address the issue of the informativeness of the limit order book in the periodic call market. Contrasting to the conventional notion of the continuous market pre-trade bid-ask spread that contains the level of information asymmetry, we interpret the periodic call market post-call bid-ask spread as the achievement of information symmetry after a call. We find that both the market order and the radius (a proxy of heterogeneous information) of the order book are negatively correlated with the post-call bid-ask spread. It implies that the higher the pre-call heterogeneous information, the lower the post-call information symmetry achieved, which is consistent to the analyst underreaction hypothesis. However, in examining the liquidity characteristics of trading volume, we find that the radii of the order book on both sides of the market are negatively correlated with the trading volume. By decomposing the radii into the lower (matched orders) and the upper (unmatched orders) radii of the order book, the former has a positive and the latter has a negative correlation with trading volume. Our result complements to the finding in Naes et al. (2006) that the slope at the inner quotes is positively but the average slope for the full book is negatively related to the number of trades. As the slope, it seems that the radius of the order book also contains two different sets of information about trading activity, i.e., one set is in the matched orders and the other one is in unmatched orders.

It is intuitively appealing that the slopes of the demand and supply schedules directly affect the surplus of the traders who submit orders. If so, it is interesting to know what is the relation between the trader surplus and the radius of the order book, which is a proxy of the level of heterogeneous information? We find that the lower (upper) radii representing matched (unmatched) orders on both sides of the market have a positive (negative) contribution to the trader surplus. Furthermore, the market order has a positive contribution on the trader surplus of the same side, but a negative contribution on the trader surplus of the opposite side. This phenomenon is consistent to the extension of the crowding out effect in Parlour (1998). We perform further test to show that this effect could also occur in a periodic call market, such as TWSE.

Appendix A

Table A1(a): The limit order book in a periodic call market

Buy (sell) orders are the sum of buy (sell) orders in shares at the same limit price. Demand (supply) is the demand (supply) schedule that aggregates all order shares at and above (below) the limit price. Excess is the excess demand by subtracting supply from demand.

Supply	Sell orders	Price	Buy orders	Demand	Excess
100	100	$34.50	100	500	400
200	100	34.60	100	400	200
300	100	34.70	200	300	0
400	100	34.80	100	100	(300)

Table A1(b): The limit order book in a periodic call market

Buy (sell) orders are the sum of buy (sell) orders in shares at the same limit price. Demand (supply) is the demand (supply) schedule that aggregates all order shares at and above (below) the limit price. Excess is the excess demand by subtracting supply from demand.

Supply	Sell orders	Price	Buy orders	Demand	Excess
100	100	$34.50	100	600	500
200	100	34.60	100	500	300
300	100	34.70	300	400	100
400	100	34.80	100	100	(300)

In Table A1(a), the market clearing price is $34.70 and the trading volume is 300 shares. All sell (buy) orders with their limit prices below (above) the market clearing price will be cleared and all sell (buy) orders with their limit prices at the market clearing price at least one side will be cleared, if not both sides. In this case, at the market clearing price of $34.70, neither side has any order with a limit price of $34.70 left in the book. Thus, the post-call bid-ask spread is $0.20 (=$34.80-$34.60). In Table A1(b), the market clearing price is still $34.70 and the trading volume is 300 shares. All sell (buy) orders with their limit prices below (above) the market clearing price will be cleared and all sell (buy) orders with their limit prices at the market clearing price at least one side will be cleared, if not both sides. In this case, at the market clearing price of $34.70, the buy side has 100 order shares with a limit price of $34.70 left in the book. Thus, the post-call bid-ask spread is $0.10 (=$34.80-$34.70) that is smaller than that in Table 1(a). If applying the interpretation of the (pre-trade) bid-ask spread in the continuous market, holding the order-processing and the inventory-carrying cost components constant, one would conclude that the bid-ask spread of $0.10 in the case of Table A1(b) contains a smaller adverse-selection cost component, but the bid-ask spread of $0.20 in the case of Table A1(a) has a larger adverse-selection cost component. However, in the case of Table A1(a), the layout of the order submission from both sides makes it actually clear a higher proportion of the total order shares submitted, i.e., in the demand side 300 shares out of 500 shares, contrasts to 300 shares out of 600 shares in the case of Table A1(b). We thus claim that the post-call bid-ask spread in the periodic call market should carry a different meaning than the pre-trade bid-ask spread in the continuous market. Indeed, the post-call bid-ask spread in the periodic call market should imply the size of the resolution of information asymmetry from the pre-call to the post-call environment. It represents the achievement of information symmetry after the call.

Appendix B

To illustrate the idea of decomposing the radius of the order book, we need to offer two examples. We define the lower radius of the order book is equal to the number of matched order price level and the upper radius is equal to the difference between the radius of the order book and the lower radius. For instance, on the buy side, the radius of the order book is equal to three and the number of the matched buy order is equal to two, then the lower radius is equal to two and the upper radius is equal to 1 (= 3-2). The lower radius represents the part of heterogeneous information that can be reconciled, but the upper radius represents the part of heterogeneous information that cannot be reconciled. Indeed, the radius of the order book is always greater than zero. However, it is possible equal to one, if the order price level that has the thickest depth is the best ask or bid and if the number of the matched order on the same side is more than one, by defining the lower radius is equal to the number of the matched order, then the upper radius can be a negative number. For instance, on the buy side, the radius of the order book is equal to one and the number of the matched buy order is equal to 3, then the lower radius is equal to 3 and the upper radius is equal to -2 (=1 – 3). Again, the lower radius of 3 implies that the reconcilable part of heterogeneous information is greater than the radius of the order book (one). The upper radius of implies that the non-reconcilable part of heterogeneous information now is negative. In this sense, the lower radius can go beyond the level of the radius of the order book up to the number of the matched order price level in the book. At the same time, to reflect the expanded reconcilable part of heterogeneous information in the lower radius, the upper radius can go below zero by showing the retreat of the non-reconcilable part of heterogeneous information.

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Figure 1a: Buy orderflow schedule (8 order price levels)
Buy orders are arranged from the highest limit price to the lowest limit price in the limit order book. At the same limit price the order sizes are aggregated.

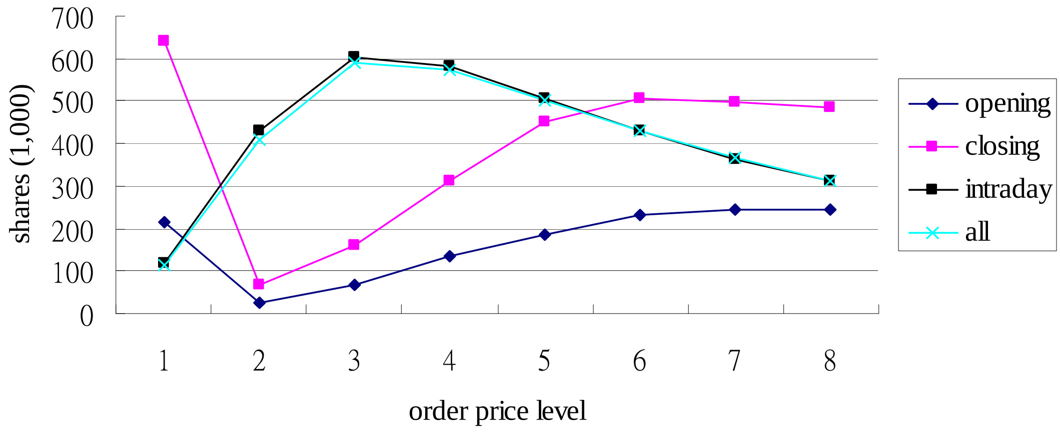

Figure 1b: Sell orderflow schedule (8 order price levels)
Sell orders are arranged from the lowest limit price to the highest limit price in the limit order book. At the same limit price the order sizes are aggregated.

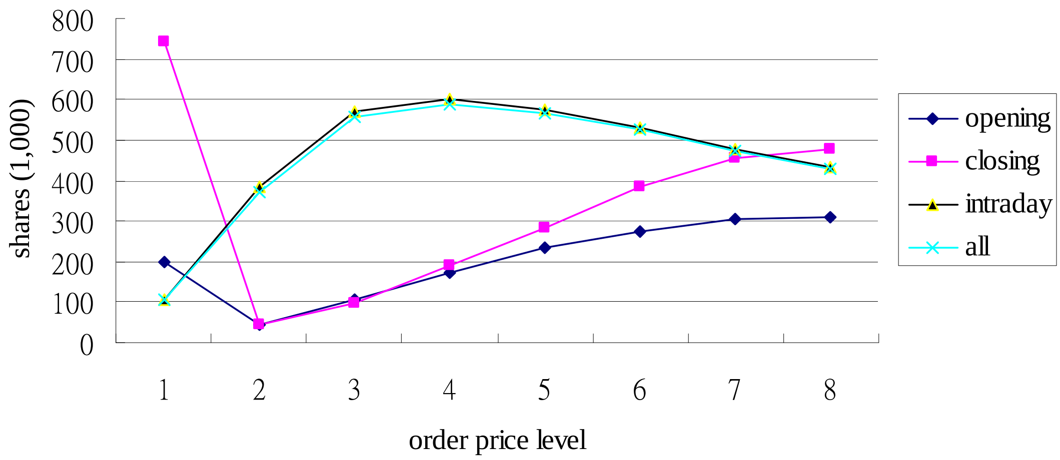

Table 1: Descriptive statistics on market capitalization, price, trade size, post-call spreads, order sizes, and market order sizes. First for each firm, we compute their five-month averages of these variables in interest. Then we compute the cross-sectional means by averaging these means across firm. To compute the market capitalization, we use the trade price multiplying the number of shares outstanding that is from the Taiwan Economic Journal database. The rest of the variable data are from the intraday data (the order and the trade files) of the Taiwan Stock Exchange. The dollar spread is the post-call $(best\ ask - best\ bid)$. The percentage spread is $\frac{the\ dollar\ spread}{(best\ ask + best\ bid)/2}$. On TWSE, the market order is the limit order with its price reaching the daily limit of $\pm 7\%$ of the previous closing price, considering the appropriate tick size. Our sample data contain constituent stocks in the TWSE Taiwan 50 Index from January to May, 2005.

Variables \ Statistics	Mean	Median	Maximum	Minimum	Standard deviation	Standard error
Mean market capitalization (millions)	183972.78	98285.73	1208906.32	44520.17	201992.34	28566.03
Mean market clearing price	39.54	30.57	227.29	10.87	35.20	4.93
Mean trade size (1000shares)	37.91	29.83	127.38	7.39	26.76	3.75
Mean post-call dollar spread	0.1226	0.0702	0.6866	0.0394	0.1185	0.0166
Mean post-call percentage Spread	0.3109%	0.3079%	0.4769%	0.1489%	0.0861%	0.0121%
Mean limit order size: Buy(1000shares)	302.87	215.44	1222.54	41.45	231.67	32.44
Mean limit order size: Sell(1000shares)	406.43	318.29	1579.43	45.65	318.50	44.60
Mean market order size: Buy(1000shares)	23.73	15.47	244.46	5.62	34.99	4.90
Mean market order size: Sell(1000shares)	32.77	14.42	730.24	5.25	100.58	14.08
Mean radius of order price level: buy	6.90	6.74	10.39	4.68	1.32	0.18
Mean radius of order price level: sell	8.19	7.83	11.83	5.70	1.49	0.21
Mean lower radius of order price level: buy	1.53	1.47	2.73	1.11	0.32	0.04
Mean lower radius of order price level:sell	1.57	1.48	2.99	1.13	0.37	0.05
Mean upper radius of order price level: buy	5.87	5.72	9.34	3.90	1.23	0.17
Mean upper radius of order price level: sell	7.08	6.79	9.62	4.90	1.33	0.19

Table 2: The comparison of the explanatory power between two sets of information variables in the post-call spread and trading volume.

$$Dependent_t = \alpha + \beta_1 \cdot MktOdr\_buy_t + \beta_2 \cdot MktOdr\_sell_t + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t + \beta_5 \cdot Information\_buy_t + \beta_6 \cdot Information\_sell_t + \varepsilon_t .$$

The candidates for the dependent variable are the post-call percentage bid-ask spread and the trading volume. $MktOrder_{Buy,t}$ is the indicator variable that is equal to one if there is a market order and is equal to zero, if there is no market orders, $Open_t$ ($Close_t$) is the indicator variable that is equal to one if the trade at market open (close), ε_t is the regression error term. $Information\_buy_t$ ($Information\_sell_t$) is the information variable to proxy the heterogeneous information on the demand (supply) pricing schedule. The candidates of information variable are the absolute slopes and the radii of the pricing schedules on the demand and the supply side. The t-statistics corrected by the variance-covariance consistent matrix (Newey and West, 1987) are reported in the parentheses. Our sample data contain constituent stocks in the TWSE Taiwan 50 Index from January to May, 2005.

Dependent / Independent	Model I: Post-call Spread	Model II: Post-call Spread	Model III: Trade volume	Model IV: Trade Volume
Intercept	0.004797 (364.93)	0.00324 (388.04)	25.23908 (56.57)	5.442903 (16.71)
MktOrder: buy	-0.0003 (-58.99)	-0.00061 (-105.46)	25.95905 (64.66)	20.3654 (56.48)
MktOrder: sell	-0.00023 (-45.88)	-0.00050 (-88.52)	23.39799 (67.05)	16.5691 (54.04)
Open	0.001537 (48.06)	0.00131 (39.82)	403.128 (26.34)	416.6354 (27.30)
Close	0.000757 (23.82)	0.000935 (30.09)	1136.356 (33.45)	1144.721 (33.73)
Abs. slope: Demand		-2.92E-8 (-27.48)		0.002197 (23.36)
Abs. slope: Supply		5.791E-8 (70.09)		0.001871 (27.43)
Radius: buy	-0.00011 (-132.96)		-0.43565 (-11.12)	
Radius: sell	-0.0001 (-121.26)		-0.14178 (-3.67)	
Adj. R^2	0.2025	0.0688	0.1283	0.1420

Table 3: The explanatory power of the decomposed information variables in the post-call spread, trading volume, and volatility.

$$Dependent_t = \alpha + \beta_1 \cdot MktOdr\_buy_t + \beta_2 \cdot MktOdr\_sell_t + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t + \beta_5 \cdot UpperRadius\_buy_t + \beta_6 \cdot UpperRadius\_sell_t + \beta_7 \cdot LowerRadius\_buy_t + \beta_8 \cdot LowerRadius\_sell_t + \varepsilon_t.$$

The candidates for the dependent variable are the post-call percentage bid-ask spread, the trading volume, and the volatility proxy (i.e., the absolute value of percentage change in market clearing price). $MktOrder_{Buy,t}$ is the indicator variable that is equal to one if there is a market order and is equal to zero, if there is no market orders, $Open_t\,(Close_t)$ is the indicator variable that is equal to one if the trade at market open (close), ε_t is the regression error term. $UpperRadius\_buy_t\,(UpperRadius\_sell_t)$ is to proxy the heterogeneous information of unmatched orders and $LowerRadius\_buy_t\,(LowerRadius\_sell_t)$ is to proxy the heterogeneous information of matched orders on the buy-side (sell-side) pricing schedule. The t-statistics corrected by the variance-covariance consistent matrix (Newey and West, 1987) are reported in the parentheses. Our sample data contain constituent stocks in the TWSE Taiwan 50 Index from January to May, 2005.

Independent \ Dependent	Model V: Post-call spread	Model VI: Trading volume
Intercept	0.004647 (330.89)	-57.0064 (-50.97)
MktOrder-buy	-0.00045 (-74.42)	-16.7134 (-26.56)
MktOrder-sell	-0.00034 (-60.52)	-16.4145 (-28.94)
Open	0.000775 (21.49)	156.9328 (11.07)
Close	-3.34E-6 (-0.09)	884.3734 (26.86)
Upper radius: buy	-0.00011 (-135.10)	-1.39395 (-35.94)
Upper radius: sell	-0.0001 (-123.96)	-0.96765 (-27.85)
Lower radius: buy	0.000027 (8.05)	36.7539 (48.29)
Lower radius: sell	1.951E-6 (0.64)	39.52631 (53.41)
Adj. R^2	0.2090	0.1963

Table 4: Regressions: the number of matched order price level and the market orders

We present the relationship between the number of matched order ($LowerRadius_{Buy}$ and $LowerRadius_{Sell}$) and the market orders, after controlling for the market open and close.

$$LowerRadius_{Buy,t} = \alpha + \beta_1 \cdot MktOrder_{Buy,t} + \beta_2 \cdot MktOrder_{Sell,t} + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t + \varepsilon_t,$$
$$LowerRadius_{Sell,t} = \alpha + \beta_1 \cdot MktOrder_{Buy,t} + \beta_2 \cdot MktOrder_{Sell,t} + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t + \upsilon_t.$$

$LowerRadius_{Buy,t}$ $(LowerRadius_{Buy,t})$ is the number of matched order price level on the buy (sell) side, $MktOrder_{Buy,t}$ $(MktOrder_{Sell,t})$ is the buy- (sell-) side indicator variable that is equal to one if there is a market order and is equal to zero, if there is no market orders, $Open_t$ $(Close_t)$ is the indicator variable that is equal to one if the trade at market open (close), ε_t and υ_t are regression error terms. The t-statistics corrected by the variance-covariance consistent matrix (Newey and West, 1987) are reported in the parentheses. Our sample data contain constituent stocks in the TWSE Taiwan 50 Index from January to May, 2005.

	Intercept	MktOrder:buy	MktOrder:sell	Open	Close	Adj. R^2
Lower Radius: Buy	1.215593 (921.09)	0.804949 (355.79)	0.265989 (136.02)	3.414436 (80.67)	2.942596 (81.55)	0.3232
Lower Radius: Sell	1.212012 (773.08)	0.351866 (128.96)	0.781537 (306.06)	2.939954 (76.29)	3.43504 (95.88)	0.2939

Table 5: The explanatory power of the decomposed information variables on the trade surpluses

$$SurplusDemand_t = \alpha + \beta_1 \cdot MktOdr\_buy_t + \beta_2 \cdot MktOdr\_sell_t + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t$$
$$+ \beta_5 \cdot UpperRadius\_buy_t + \beta_6 \cdot UpperRadius\_sell_t$$
$$+ \beta_7 \cdot LowerRadius\_buy_t + \beta_8 \cdot LowerRadius\_sell_t + \xi_t.$$
$$SurplusSupply_t = \alpha + \beta_1 \cdot MktOdr\_buy_t + \beta_2 \cdot MktOdr\_sell_t + \beta_3 \cdot Open_t + \beta_4 \cdot Close_t$$
$$+ \beta_5 \cdot UpperRadius\_buy_t + \beta_6 \cdot UpperRadius\_sell_t$$
$$+ \beta_7 \cdot LowerRadius\_buy_t + \beta_8 \cdot LowerRadius\_sell_t + \psi_t.$$

The candidates for the dependent variable are the trade surpluses on the demand and supply sides. $MktOrder_{Buy,t}$ ($MktOrder_{sell,t}$) is the buy- (sell-) side indicator variable that is equal to one if there is a market order and is equal to zero, if there is no market orders, $Open_t$ ($Close_t$) is the indicator variable that is equal to one if the trade at market open (close), and is equal to zero, otherwise. ξ_t and ψ_t are the regression error terms. $UpperRadius\_buy_t$ ($UpperRadius\_sell_t$) is to proxy the heterogeneous information of unmatched orders and $LowerRadius\_buy_t$ ($LowerRadius\_sell_t$) is to proxy the heterogeneous information of matched orders on the buy-side (sell-side) pricing schedule. The t-statistics corrected by the variance-covariance consistent matrix (Newey and West, 1987) are reported in the parentheses. Our sample data contain constituent stocks in the TWSE Taiwan 50 Index from January to May, 2005.

	Model X	Model XI
	Surplus: Demand	Surplus: Supply
Intercept	0.1294 (27.97)	0.1268 (28.50)
MktOrder: buy	2.0227 (394.59)	-0.5580 (-142.29)
MktOrder: sell	-0.5664 (-148.12)	1.9541 (413.57)
Open	1.8211 (78.63)	1.3916 (62.76)
Close	2.7335 (100.56)	2.8606 (120.97)
Upper radius: Buy	-0.0604 (-30.86)	-0.0465 (-24.24)
Upper radius: Sell	-0.0686 (-34.18)	-0.0767 (-38.87)
Lower radius: Buy	0.3076 (50.54)	0.9697 (210.95)
Lower radius: Sell	0.9507 (191.78)	0.5065 (84.69)
Adj. R^2	0.5016	0.5185

Table 6: Regressions: the percentage depth of market order

On both sides, we first compute the percentage depth of the market order by taking the ratio of the size of the market order over (1) the size of the radius depth, which is the total depth of the orders within the best order price level and the most popular (i.e., the deepest) order price level (2) the depth of the first twenty order levels in the limit order book. Then, we subtract the percentage depth of the market order on the sell side from that of the buy side and name it $Diff\,\%MktOrder_t$. We regress $Diff\,\%MktOrder_t$ on the indicator variables of the market order (buy and sell sides), controlling for the market open and close.

$$Diff\,\%MktOrder_t = \alpha + \beta_1 \cdot Open_t + \beta_2 \cdot Close_t + \beta_3 \cdot MktOrder_t^{Buy} + \beta_4 \cdot MktOrder_t^{Sell} + \nu_t,$$

$MktOrder_t^{Buy}$ ($MktOrder_t^{Sell}$) is the buy- (sell-) side indicator variable that is equal to one if there is a market order and zero, otherwise. $Open_t$ ($Close_t$) is the indicator variable that is equal to one if the trade at market open (close) and zero, otherwise. ν_t is the regression error terms. The t-statistics corrected by the variance-covariance consistent matrix (Newey and West, 1987) are reported in the parentheses. Our sample data contain constituent stocks in the TWSE Taiwan 50 Index from January to May, 2005.

Independent / Dependent	Intercept	Open	Close	MktOrder: buy	MktOrder: Sell	Adj. R^2
$Diff\,\%MktOrder_t$: the radius depth	-0.00016 (-4.85)	0.0270 (7.25)	-0.0505 (-8.86)	0.0079 (45.74)	-0.0067 (-38.46)	0.0165
$Diff\,\%MktOrder_t$: 20 order level depth	-0.00008 (-3.99)	0.0124 (10.38)	-0.0191 (-10.78)	0.0040 (38.11)	-0.0037 (-30.42)	0.0144