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金融市場微結構之探討：升降單位與流動性議題之分析

Essays on the Microstructure Issues of Tick Size and Equity Liquidity

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中文摘要

本研究主要在於探討兩個金融市場微結構的重要議題。第一個議題是在分析美國證券市場在實施小數化制度（Decimalization）之後，也就是交易升降單位由十六分之一調整成百分之一的措施，對於期貨市場與現貨市場之間的套利關係之影響。研究結果發現小數化制度的施行，對於套利者而言，會因為執行風險的提高而降低其套利意願，進而降低期貨與現貨市場之間的定價效率。由於套利者對於可套利交易的價格偏離程度之要求變大，因此在分量迴歸（Quantile Regression）的分析中，可以得到較大的定價誤差會在小數化制度實行後具有顯著改善的結果。第二個議題則是在分析公司治理（Corporate Governance）與股票流動性（Equity Liquidity）之間的關係。藉由內部與外部公司治理指標的討論，研究結果顯示公司治理程度與其股票流動性高低具有顯著的相關性，而此意味著公司治理程度較弱的企業，可能會因為較高的資訊不對稱成本（Asymmetric Information Costs）而使其股票流動性變差。

關鍵詞：升降單位、套利、小數化制度、電子盤期貨、指數股票型基金、定價效率、分量迴歸、公司治理，透明度與資訊揭露、資訊不對稱成本、流動性、反購併條款

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ABSTRACT

This dissertation consists of two separate essays. The first essay investigates the impact of decimalization (penny pricing) on the arbitrage relationship between index exchange-traded funds (ETFs) and E-mini index futures. The empirical results show that the overall pricing efficiency has deteriorated in the post-decimalization period; however, the pricing efficiency is improved only when an extreme large mispricing signal is observed, implying that the introduction of decimalization has in general resulted in weakening the ability and willingness of arbitrageurs to initiate arbitrage trades. The second essay examines the effects of internal and external corporate governance mechanisms on equity liquidity. The empirical results reveal that both internal and external governance measures have significant relationships with the liquidity measures, implying that the economic costs of equity liquidity are greater for those companies with poor corporate governance.

Keywords: Tick Size; Arbitrage; Decimalization; E-mini futures; ETFs; Pricing Efficiency; Quantile Regression; Corporate Governance; Transparency and Disclosure; Asymmetric Information Costs; Liquidity; Anti-takeove Provisions

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CHAPTER 1. INTRODUCTION

The phrase "market microstructure" is conceived by Garman (1976) as the title of his study about market marking and inventory costs. Later, the phrase evolved into a descriptive title for the investigation of the economic forces affecting trades, quotes and prices. Naturally, market microstructure can also be viewed as the branch of financial economics that investigates trading and organization of markets. About the previous studies on market microstructure issues, Biais et al. (2005) provide an excellent review of the literature by surveying topics about price formation and trading process, and the consequences of market organization for price discovery and welfare.

The organization of the market can be seen as the extensive form of the game played by investors and traders. It determines the way in which the private information and strategic behavior of the traders affect the market outcome. Like auction design or mechanism design, market microstructure analyzes how the rules of the game can be designed to minimize frictions and thus optimize the efficiency of the market outcome.

The rate of change in financial markets has accelerated in recent years, with an unprecedented proliferation of new markets and instruments. The goals of this research in microstructure are to improve the understanding of how markets work and to design well functioning markets. This dissertation focuses on several important issues in market microstructure, including tick size, arbitrage efficiency and market liquidity.

The first issue in this dissertation is to discuss the influences of tick size on arbitrage efficiency among markets. Tick size is the minimum price variation allowed for quoting and trading in financial assets, and refers to the smallest amount by which a trader may improve a price. For a considerable time, stocks on the New York Stock Exchange (NYSE) had been quoted in eighths of a dollar; however, on June 24, 1997, the NYSE reduced the tick size from one eighth to one sixteenth. Starting from January 29, 2001, all stocks traded on the NYSE and on the American Stock Exchange (AMEX) have been subsequently quoted in decimals (i.e., penny pricing or decimalization). The decimalization of the stock markets represents an important issue for market participants because it had potentially significant influences on market efficiency and market liquidity, and therefore, the overall functioning of the financial markets.

After decimalization, arbitrageurs face higher execution risk because of the lower quoted depth and slower execution speed in the spot market. The financial issue that pricing efficiency and arbitrage opportunities between index futures and their underlying index surrounding decimalization will be important for market participants, since a structural change within one market may have significant impacts on the derivatives markets.

The second issue examined in this dissertation is the relationship between corporate governance and equity liquidity. Corporate governance is an extremely important issue for all investors. Within those firms where poor corporate governance is adopted, managers are more likely to use their information advantage to pursue a private benefit of control, which will ultimately lead to an increase in the agency costs faced by shareholders. As the agency problem worsens, insiders (such as executives or controlling owners) can easily exploit the wealth and the rights of small shareholders; it is for this reason that poor corporate governance is associated with all investors.

The information asymmetry component is a compensation arising from the asymmetric information risk faced by liquidity providers. Since it is difficult to determine who the informed traders are, the providers of liquidity cannot prevent the losses incurred when they actually trade with an informed trader. Effective spread must therefore include an appropriate information asymmetry component in order to compensate for this risk of loss, thereby enabling liquidity providers to maintain their operations against informed trading activities.

Poor disclosure practice and weak shareholders rights within a firm is accompanied by poor corporate governance and higher levels of asymmetric information risk; as a result, liquidity providers will tend to broaden the equity spread of those firms exhibiting poor corporate governance, since such price-protection action will have the effect of reducing the market liquidity of the stock. The effects of internal and external corporate governance mechanisms on equity liquidity, by using the S&P T&D rankings and governance index (entrenchment index) as proxies for internal and external corporate governance respectively, will reveal the importance of corporate governance to market participants.

All in all, the essays of this dissertation provide some insights into the issues of market microstructure, emphasize on the importance of tick size and corporate governance on financial markets. With these points in mind, the research results will furnish us with the empirical evidences to comprehend the occasion of some distinctive phenomena in financial markets.

Chapter 1 Introduction

CHAPTER 2. DECIMALIZATION AND THE ETFS AND FUTURES PRICING EFFICIENCY

1. INTRODUCTION

Tick size is the minimum price variation allowed for quoting and trading in financial assets, and refers to the smallest amount by which a trader may improve a price.[1] For some considerable time, stocks on the New York Stock Exchange (NYSE) had been quoted in eighths of a dollar; however, on June 24, 1997, the NYSE reduced the tick size from one eighth to one sixteenth. Starting from January 29, 2001, all stocks traded on the NYSE and on the American Stock Exchange (AMEX) were subsequently quoted in decimals (i.e., penny pricing or decimalization).[2] The decimalization of the stock markets represents an important issue for market participants because it had potentially significant influences on market efficiency and market liquidity, and therefore, the overall functioning of the financial markets.

The decimalization of the US stock markets has attracted considerable research attention, albeit producing rather mixed results. Proponents of penny pricing argue that the reduction in tick size would improve market quality and liquidity. They suggest that a smaller tick size would benefit liquidity demanders as competition between liquidity providers increases, which would induce a reduction in overall bid-ask spreads (Bollen and Whaley, 1998; Ronen and Weaver, 2001; Henker and Martens, 2005). Bessembinder (2003) finds that not only small traders placing market orders have benefited, those traders executing large trades are also enjoying reductions in their average execution costs. Furfine (2003) also finds that after

[1] The tick size is normally set by exchange regulations.

[2] The NYSE lowered the tick size to a penny for seven securities on August 28, 2000, for a further 57 securities on September 25, 2000, and an additional 94 securities on December 5, 2000. All remaining securities began trading in decimals on January 29, 2001. NASDAQ began converting to decimal pricing on March 12, 2001, and completed the process on April 9, 2001.

decimalization, actively-traded stocks generally experience an increase in liquidity. Furthermore, Zhao and Chung (2006) find that decimal pricing led to a significant increase in the probability of information-based trading (PIN), arguing that decimal pricing increased the value of private information and raised the informational efficiency of asset price.

Opponents of penny pricing nevertheless argue that while such a change may have benefited certain liquidity demanders, this is to the detriment of liquidity providers. The increase in the costs of providing liquidity would lead to a decline in their willingness to provide liquidity (Harris, 1994; Glodstein and Kavajecz, 2000; Jones and Lipson, 2001; Bollen and Busse, 2006).

Graham et al. (2003) find that while the reduction in spreads reduces the trading costs for small trades, it has no effects on the trading costs for large trades, since the reduction in spreads is accompanied by a simultaneous reduction in depth. Chakravarty et al. (2004) argue that for institutional investors, the influence of penny pricing on trading costs is unclear, since their trades are typically large and require significant inroads into the limit order book, and/or the presence of other suppliers of liquidity, typically in the upstairs market. Furthermore, Bollen and Busse (2006) find that following the switch to decimals, actively-managed mutual funds experience an increase in trading costs.

Regarding the efficiency of the cash/futures pricing system, proponents of decimalization also argue that the lower transaction costs should result in a general reduction in index futures mispricing errors (which provide the trigger for arbitrage trading), because the finer increments of stock prices benefit investors as the pricing increment dictates the smallest possible bid-ask spread for a given stock. However, this particular viewpoint ignores the importance of possible reductions in liquidity due to penny pricing. Not only does decimalization lead to smaller spreads, but it can also cause a reduction in depth, which induces ambiguous changes in market quality.

As noted by Kumar and Seppi (1994), arbitrage activities may be affected by liquidity.

Therefore, in order for an arbitrage trade to be profitable, the required positions taken by arbitrageurs are usually large, and thus, will normally require a deep market. Roll et al. (2005) argue that an illiquidity shock may have a lasting effect on arbitrage opportunities as arbitrageurs struggle to close the gap. They empirically demonstrate that market liquidity enhances the efficiency of the futures/cash pricing system.

In their study of the impact of decimalization on institutional traders, Chakravarty et al. (2005) find that decimalization appears to have benefited those institutions with greater patience, whereas it may have hurt those seeking quick execution of trades. Since arbitrageurs require quick execution of their submitted orders, and since they must also be well capitalized, this implies that arbitrageurs are more likely to be institutional investors that demand quick execution of their trades.[3] Further, in order to cover transaction costs and make sufficient profits, arbitrageurs tend to take on large positions, which require a deep market. We therefore argue that after decimalization, the benefits obtained by the arbitrageurs, due to the reduction in the bid-ask spread, may have been more than offset by their losses stemming from the reduction in market depth, which may ultimately affect the ability and willingness of arbitrageurs to initiate arbitrage trades.

In this paper, we analyze market pricing efficiency in the pre- and post-decimalization periods by examining the arbitrage relationship between exchange-traded funds (ETFs) and index futures. There are three possible explanations from the literature as to why arbitrageurs' profits may have suffered as a result of decimalization, as follows.

First of all, arbitrageurs require a deep market when engaging in arbitrage activities. They would be affected by the fall in liquidity if liquidity providers are less willing to provide it due to lowered profitability of supplying liquidity following the move to penny pricing (Anshuman and Kalay, 1998). Furthermore, arbitrageurs are essentially market makers who

[3] Attari et al. (2005) note that if arbitrageurs were not well capitalized, capital constraints would make their trades predictable.

simultaneously connect buyers (sellers) in one market, with sellers (buyers) in another market, so they could also be viewed as porters of liquidity. Under normal circumstances, well-capitalized arbitrageurs act as suppliers of liquidity, with their presence being vital to the smooth functioning of the markets. Therefore, if market depth drops subsequent to penny pricing, it would impair the capabilities of arbitrageurs as suppliers or porters of liquidity in the markets.

Second, the execution risk would likely rise due to the reductions in average execution speed. A successful arbitrage trade carries almost no risk except for execution risks. Harris (1991) notes that a smaller tick size leads to an increase in the number of possible prices at which traders can trade, thereby complicating the negotiation process, and reducing the average speed of execution, which results in increased execution risk for arbitrageurs.

Third, a reduction in tick size may weaken the priority rules in the limit order book (Harris, 1994, 1996; Angel, 1997; Seppi, 1997). It lowers the cost of jumping ahead of existing orders in the book and gaining priority. It is likely that this activity, referred to as "front running", would discourage investors from placing limit orders.[4] Front-running tends to reduce the profits of informed traders.[5] Harris (2003) argues that the long-run effect of front-running is to make prices less informative. Since front running limit orders placed by arbitrageurs became easier after decimalization, fewer arbitrageurs could consequently make profitable trades and they would have gradually withdrawn from the markets, which would ultimately make the market prices less informative. This implies that market efficiency would be impaired by decimalization.

After decimalization, arbitrageurs face higher execution risk because of decreased quoted depth and slower execution speed in the ETF market. We conjecture that the pricing efficiency

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[4] Investors wary of front-runners would be more likely to conceal their true trading interest (depth) in a market with a lower minimum price variation. Harris (1996) argues that the minimum price increment should be economically significant in order to protect liquidity providers from quote matchers.

[5] Harris (2003) defines informed traders as value traders, news traders, information-oriented technical traders and arbitrageurs.

on average may have deteriorated in the post-decimalization period. Arbitragers will only participate in trading only when it is profitable to do so, meaning that only when the mispricing signal is large enough to compensate for the increased execution risk. Therefore, the pricing efficiency is likely to be improved when extreme mispricing signals occur. The purpose of this study is to examine pricing efficiency and arbitrage opportunities between index futures and their underlying index surrounding decimalization. Although many studies have been undertaken on the influence of tick reductions on the equity markets, only a few studies have examined pricing efficiency across related markets following tick reductions (see, for example, Henker and Martens, 2005; Chou and Chung, 2006). This is, however, an important topic, since a structural change within one market may have significant impacts on another.

As has been demonstrated in a number of the prior studies, penny pricing is likely to benefit certain traders while simultaneously hurting certain others. Our paper provides additional evidence on the merits of decimalization from the perspective of the efficacy of the cash/futures pricing system. We use ETFs as the index proxies, which include both the S&P 500 Depositary Receipts (SPDRs) and the NASDAQ 100 Index Tracking Stocks (QQQs).[6] The sample index futures include the E-mini versions of the S&P 500 and NASDAQ 100 index futures.

Our study differs from the extant literature in the following ways. First of all, we analyze the influences of penny pricing on pricing efficiency across closely related markets; this is an area which has received relatively little attention in the literature. Examining the pre- and post-decimalization transmission of information between ETFs and index futures, Chou and Chung (2006) find that ETFs began to lead index futures in the price discovery process, and

[6] On November 9, 2004, NASDAQ and the AMEX announced that the NASDAQ 100 Index Tracking Stock (listed under the symbol "QQQ"), would be transferred from the AMEX to NASDAQ effective from December 1, 2004, where it would trade under the new symbol "QQQQ". In this study, we use the old symbol "QQQ", because our sample period covers the time when the old symbol was in effect.

that there was also a tendency towards an increase in the information shares of ETFs after decimalization. However, they provide no evidence on the ways in which decimalization may have affected pricing efficiency from the perspective of arbitrage opportunities.

Secondly, our paper differs from Henker and Martens (2005), who study the spot-futures arbitrage during the pre- and post-introduction of sixteenths on the NYSE. Their focus is on the examination of the size of the theoretical mispricing signals (i.e., the ex-post arbitrage trading profits) with no consideration of either the transaction costs or the time lag involved in initiating arbitrage trades. Our study explicitly considers transaction costs while also measuring the profits from ex-ante arbitrage trading.

After observing a mispricing signal, arbitrageurs can only trade at the next available prices of ETFs and index futures; thus, when we refer to ex-ante arbitrage trading, we measure the arbitrage profits using the prices immediately after a mispricing signal is observed, as opposed to measuring the profit by the size of the mispricing signal. We believe that our analyses will more closely represent arbitrage profits in the real world and that they will provide valuable evidence on the changes in price efficiency as a result of penny pricing.

Finally, we analyze the regression of average pricing efficiency by the method of ordinary least squares (OLS), as well as the pricing efficiency of the entire distribution of mispricing sizes by the quantile regression. By controlling for the influence of the market characteristics on pricing efficiency, the OLS method would show the change in degree of mispricing on average; however, the quantile regression method could show the change in mispricing under various quantiles. Therefore, the quantile regression is particularly useful when we want to observe the change in pricing efficiency of the entire distribution of mispricing signals.

The remainder of this paper is organized as follows. Section 2 describes the data and discusses the research methodology. Section 3 presents the empirical results on the efficiency of the cash/futures pricing system between ETFs and E-mini futures by the ex-ante arbitrage and the regression analyses. Finally, the conclusions are presented in Section 4.

2. DATA AND METHODOLOGY

2.1. The Data

Our analysis focuses on the arbitrage relationship between index ETFs and E-mini futures. ETFs are tradable instruments on the spot index, which makes arbitrage between the spot index and its underlying futures both simple and feasible. The sample ETFs include SPDRs and QQQs, and the sample E-mini futures include S&P 500 and NASDAQ 100 E-mini futures. The ETFs prices are usually scaled down in order to make them comparable to stock prices. The prices of SPDRs are 1/10th of the S&P 500 index level and the prices of QQQs are 1/40th of the NASDAQ 100 index level.[7]

The respective contract sizes of S&P 500 and NASDAQ 100 E-mini futures are $50 multiplied by the S&P 500 index level, and $20 multiplied by the NASDAQ 100 index level. Thus, for an arbitrage trade with a long or short position in one contract of S&P 500 E-mini futures (NASDAQ 100 E-mini futures), the required offsetting position in SPDRs (QQQs) is 500 (800) shares.

The sample covers the period July 27, 2000 to July 30, 2001, a period which spans six months prior to, and six months after, the date of decimalization.[8] The data on ETFs, which include the tick-by-tick quote and trade prices, trading volume and quoted depth, are obtained from the NYSE Trade and Quote (TAQ) database. Only regular AMEX quote and trade prices are used for ETFs. The corresponding data on E-mini futures, which include trade prices and

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[7] On February 14, 2000, NASDAQ announced that the Board of Directors of NASDAQ Investment Product Services, Inc. (the sponsors of QQQs) had approved a two-for-one stock split. The payment date for the stock split was March 17, 2000, payable to all stockholders held on record as at February 28 2000. Therefore, the prices of QQQs became 1/40th of the index level form 1/20th at this date of split.

[8] On 31 July 2001, the NYSE began trading the DIAs, QQQs and SPDRs listed on the AMEX on the unlisted trading privileges (UTP) basis. Boehmer and Boehmer (2003) showed that the introduction of UTP leads to an improvement in liquidity. In order to avoid any confounding effect, we confine our sample period up to this date.

number of trades, are obtained from the intraday database of Tick Data Inc..[9] The ETF dividend data are obtained from the University of Chicago's Center for Research in Security Prices database (CRSP). The three-month T-Bill rates on the secondary market, obtained from the web-based Federal Reserve Board database, are used as the risk-free rate (as a proxy for the opportunity costs of arbitrage trades).[10] For the intraday analyses, we transform the daily T-Bill rates into continuous compounded rates, assuming constant rates within a day.

In order to ensure the accuracy of our sample data, we delete all trades and quotes that are out of time sequence. We also omit quotes that meet the following three conditions: (i) either the bid or the ask price is equal to, or less than, zero; (ii) either the bid or the ask depth is equal to, or less than, zero; and (iii) either the price or volume is equal to, or less than, zero.

Following Huang and Stoll (1996), we further minimize data errors by eliminating trades and quotes meeting the following additional criteria: (i) all quotes with negative bid-ask spreads, or with bid-ask spreads greater than US$4; (ii) all trades and quotes which took place either before the market opened or after it closed; (iii) all trade, bid and ask prices with consecutive absolute relative changes (i.e., absolute returns) of more than 10%.

The futures prices and ETF quotes are synchronized using the MINSPAN procedure suggested by Harris et al. (1995). We match every reported quote for an ETF with the trading price of an E-mini future so as to form trading pairs. If there is a futures trade at the exact time of the reported ETF quote, then a pair is formed; if there is no futures trade at the exact time of the reported ETF quote, the futures trades within the previous and subsequent seven seconds are then considered. When only one futures trade meets this criterion, a pair is formed. If both leading and lagging futures trades are obtained, the closer of the two trades is used to form the pair with the other trade being discarded.

Although, on each trading day, futures contracts continue to trade until 4:15 p.m. Eastern

[9] The quote data for index futures are unavailable, as is the case in most futures studies.
[10] The T-Bill rate data are obtained from website: www.federalreserve.gov/releases/h15/data.htm.

Standard Time (EST), the trading pairs are only formed until 4:00 p.m. The number of matches equals the minimum total number of index futures trades and the minimum total number of ETF quotes. For SPDRs and S&P 500 E-mini futures, there are 301,018 observations in the pre-decimalization period and 322,524 in the post-decimalization period. For QQQs and NASDAQ 100 E-mini futures, there are 387,404 observations in the pre-decimalization period and 463,823 in the post-decimalization period.

2.2. Research Methodology

Using the cost-of-carry model, we establish the ex-post and ex-ante no arbitrage conditions between ETFs and E-mini futures. The focus of the ex-post tests is on the frequency and persistence of boundary violations, while the ex-ante tests calculate the arbitrage profits by explicitly considering the arbitrage trading lags and transaction costs. In a perfect market, the theoretical prices of index futures can be described by the cost-of-carry model, as follows:

$$F(t) = [S(t) - Div(t)]e^{r(T-t)} \tag{1}$$

where $F(t)$ is the theoretical futures price at time t for a contract expiring at time T; $S(t)$ is the spot price of the underlying index at time t; r is the risk-free interest rate; and $Div(t)$ is the present value of the dividend for holding the underlying index from time t to time T. In a perfect market, if prices deviate from Equation (1), then arbitrageurs will simultaneously sell the overpriced instrument and buy the underpriced one. This will ultimately bring the prices back to equilibrium.

The impact of transaction costs is to permit futures prices to fluctuate within a band around the theoretical price in Equation (1) without triggering profitable arbitrage opportunities, with the width of the band being dependent upon both the amount of the round-trip commission of trading spot and futures, and the size of the market impact of arbitrage trades. Most studies view such commission as a fixed cost; however, fees vary by types of traders as well as by order size. The market impact costs can be measured by bid-ask spread and market depth. Taking transaction costs into consideration, Equation (2) describes the no-arbitrage band for the futures prices:

$$\{[S(t)-Div(t)]e^{r(T-t)}\}(1-C_c-C_m)<F(t)<\{[S(t)-Div(t)]e^{r(T-t)}\}(1+C_c+C_m) \quad (2)$$

where C_c and C_m represent commissions and market impact costs, respectively. If the futures price penetrates the upper bound, a long arbitrage trade will simultaneously buy the spot and short the futures. If the futures price drops below the lower bound, a short arbitrage will make the reverse transactions.

2.2.1 Ex-Post Mispricing Analyses

We use ETFs as the cash proxy and E-mini futures as the sample futures contract. As argued by previous studies (Kurov and Lasser, 2002; Chu and Hsieh, 2002), the introduction of ETFs has provided index futures arbitrageurs with an easy way of taking advantage of arbitrage opportunities, and hence, has also improved price efficiency.

Assume that an arbitrage trade is placed at time t and lifted at the futures expiration date T. With commissions and spread costs (proxy for the market impact costs), the no-arbitrage bands between SPDRs and S&P 500 E-mini futures (ES) are as shown in Equations (3) and (4):

$$\{10\times[SPDR(t)_{bid}-SDiv(t)]e^{r(T-t)}\}(1-C_c)<ES(t)_{ask} \quad (3)$$

$$\{10\times[SPDR(t)_{ask}-SDiv(t)]e^{r(T-t)}\}(1+C_c)>ES(t)_{bid} \quad (4)$$

and the no-arbitrage band between QQQs and NASDAQ 100 E-mini futures (NQ) is as shown in Equations (5) and (6):

$$\{40\times[QQQ(t)_{bid}-QDiv(t)]e^{r(T-t)}\}(1-C_c)<NQ(t)_{ask} \quad (5)$$

$$\{40 \times [QQQ(t)_{ask} - QDiv(t)]e^{r(T-t)}\}(1 + C_c) > NQ(t)_{bid} \tag{6}$$

where $SPDR(t)_{bid}$ is the SPDR bid price, and $SPDR(t)_{ask}$ is the SPDR ask price, at time t. $QQQ(t)_{bid}$ is the QQQ bid price, and $QQQ(t)_{ask}$ is the QQQ ask price, at time t.

However, the bid and ask quotes for E-mini futures are unavailable. Kurov and Zabotina (2005) demonstrate the minimum E-mini futures bid-ask spread is binding. They estimate effective spreads for the E-mini futures using an average opposite direction absolute price change. We thus use the futures trade prices minus and plus one minimum tick size to proxy for the bid and ask prices of E-mini futures, respectively. Thus, $ES(t)_{bid}$ is the S&P 500 E-mini bid price, and $ES(t)_{ask}$ is the S&P 500 E-mini ask price, at time t. $NQ(t)_{bid}$ is the NASDAQ 100 E-mini bid price and $NQ(t)_{ask}$ is the NASDAQ 100 E-mini ask price, at time t. $SDiv(t)$ and $QDiv(t)$ are the respective present values of the dividends of SPDRs and QQQs, from time t to time T. As previously explained, since ETF prices are usually scaled down to make them comparable to those of stocks, adjusting factors of 10 and 40 are added.

We use the bid and ask prices to gauge the market impact costs, assuming that when trading in ETFs and E-mini futures, arbitrageurs can buy at the ask prices and sell at the bid prices. Thus, market impact costs are explicitly considered by the bid-ask spread. The transaction costs, C_c, in Equations (3), (4), (5) and (6) comprise of trading commissions only. We adopt an approach similar to that of Chung (1991) and Chu and Hsieh (2002), in which several levels of commission are assumed when measuring the arbitrage profits. The levels of one-way transaction costs are set as from 0.05% to 0.5% of the theoretical futures price, with 0.05% increments.[11]

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[11] Stoll and Whaley (1987) estimate that transaction costs are approximately 0.50-0.75% of the underlying index value. Chung (1991) uses round-trip transaction costs ranging from 0.5 to 1.0% for MMI index arbitrages. Given a reasonable range of the index level, Klemkosky and Lee (1991) calculate that for S&P 500 index arbitrage, the transaction costs are about 0.14% for member firms and 0.24% for institutional investors. Sofianos (1993) assumes that round-trip transaction costs are roughly 0.4%. Neal (1996) estimates the average round-trip cost at 0.31% for buy programs and 0.32% for sell programs. Following Chu and Hsieh (2002) and Kurov and Lasser (2002), our specification of transaction costs covers most of these ranges.

2.2.2 Ex-Ant Arbitrage Profit Analyses

We further assume that arbitrageurs can trade at the next available ETF quote and futures trade prices immediately after observing a mispricing signal, which would yield more reasonable estimates of the profits that arbitrageurs are expected to make *ex-ante*. The respective ex-ante profits of long ($ESAP_L$) and short ($ESAP_S$) arbitrage trades, between SPDRs and S&P 500 E-mini futures, are measured by Equations (7) and (8). Similarly, Equations (9) and (10) measure the ex-ante profits of long ($NQAP_L$) and short ($NQAP_S$) arbitrage between QQQs and NASDAQ 100 E-mini futures.

$$ESAP_L = ES(t^+)_{bid} - \left\{10 \times \left[SPDR(t^+)_{ask} - SDiv(t)\right] e^{r(T-t^+)}\right\}(1 + C_c) \tag{7}$$

$$ESAP_S = \left\{10 \times \left[SPDR(t^+)_{bid} - SDiv(t)\right] e^{r(T-t^+)}\right\}(1 - C_c) - ES(t^+)_{ask} \tag{8}$$

$$NQAP_L = NQ(t^+)_{bid} - \left\{40 \times \left[QQQ(t^+)_{ask} - QDiv(t)\right] e^{r(T-t^+)}\right\}(1 + C_c) \tag{9}$$

$$NQAP_S = \left\{40 \times \left[QQQ(t^+)_{bid} - QDiv(t)\right] e^{r(T-t^+)}\right\}(1 - C_c) - NQ(t^+)_{ask} \tag{10}$$

where t^+ indicates the time of the first quote (trade) price of ETFs (E-mini futures) immediately after the mispricing signal is observed, and all other variables are defined similarly as those in Equations (3) through (6).

2.2.3 Regression Analyses

Our empirical methodologies up to now focus on the ex-ante mispricing errors, which can be seen as univariate analyses. However, the changes in pricing efficiency can be affected by the changes in market factors other than decimalization. We thus follow Chung (1991) and Kurov and Lasser (2002) to control for other possible factors that are also likely to affect the market pricing efficiency. The simple version of the cost-of-carry model defined in Equation (1) is used to calculate the mispricing series. The mispricing series are calculated for every

5-minute interval.

We consider the change in average futures mispricing after the introduction of decimalization by using an autoregressive regression model, as defined in the following equation:

$$\begin{aligned}|MPE_t| &= \beta_0 + \beta_1 D_t^{decimal} + \beta_2 D_t^{open} + \beta_3 D_t^{close} \\ &+ \beta_4 Vol_t + \beta_5 NT_t + \beta_6 ET_t + \sum_{i=1}^{\tau} \varphi_i |MPE_{t-i}| + \varepsilon_t\end{aligned} \tag{11}$$

where t denotes the 5-minute time interval. $|MPE_t|$ is the average absolute pricing errors during time period t, defined similar to that in Kurov and Lasser (2002):

$$|MPE_t| = \frac{1}{n}\sum_{k=1}^{n}\left|\frac{F_{t,k} - F_{t,k}^*}{ETF_{t,k} \times f}\right| \tag{12}$$

where k denotes the kth price data within n observations in t time interval. $F_{t,k}$ is the actual futures price, $F_{t,k}^*$ is the theoretical value from the cost-of-carry model, and f is the adjusting factor for $ETF_{t,k}$ prices. $D_t^{decimal}$ is a dummy variable that equals 0 for the pre-decimalization period and 1 afterward; D_t^{open} and D_t^{close} are dummy variables indicating the opening and closing 5-minute intervals. Vol_t is the Parkinson (1980) extreme value estimator to proxy for ETF volatility, defined as:

$$Vol_t = \sqrt{\frac{1}{4\log 2}\left(\log\frac{H_t}{L_t}\right)^2} \tag{13}$$

where H_t and L_t denote the high and low prices of ETFs during time period t, respectively. NT_t is the number of ETFs trades during time period t and ET_t is the annualized time to expiration of the futures contract during time period t.

The dummy variable, $D_t^{decimal}$, is included in the regression to test for the structural shift in mispricing after decimalization. A negative and significant coefficient of the dummy variable will indicate a decrease in average absolute mispricing and vise versa. The dummy variables D_t^{open} and D_t^{close} are included in the regression to test whether mispricing is larger during the open and close intervals. The variables, Vol_t, ET_t, and NT_t, are used to control for factors likely to affect pricing errors. The number of lagged error terms, τ, is equal to 6 and 8 periods for SPDRs and QQQs, respectively.[12]

Market volatility is an important factor affecting the mispricing of futures. Yadav and Pope (1994) show that futures' mispricing tends to be higher during periods of high spot volatility. They argue that higher volatility makes arbitrage riskier by increasing uncertainty of arbitrage profits. Furthermore, Kurov and Lasser (2002) point out that when market risk is high enough, arbitrage trades will not be initiated even when they appear profitable, as arbitrageurs wait for even larger mispricing that serves as a "buffer" against risk. Chan and Chung (1993) demonstrate that increases in futures mispricing are followed by increases in volatility of spot and futures prices and the mispricing subsequently declines. Therefore, we expect a significant positive relation between volatility and pricing errors. Moreover, changes in spot trading volume may also affect the spot-futures pricing relation. Jones et al. (1994) show that number of trades contains most of the important information for describing trading activity. We conjecture that there is a significant negative relation between number of trades and average mispricing, as number of trades is a proxy for information arrivals.

In addition to the OLS method, to analyze the entire distribution of mispricing, we estimate Equation (11) by a linear quantile regression model proposed by Koenker and Bassett (1978). This approach permits estimating various quantile functions of a conditional distribution, among them, the median (0.5th quantile) function is a special case.[13] Each

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12 We use the Durbin's alternative statistic to test for the serial correlation problem. The test results indicate that there are no first, second and third order serial correlation presented when the number of lag periods is set to 6 and 8 periods for SPDRs and QQQs, respectively.

13 An introduction of quantile regression is brief illustrated in Appendix. A detailed explanation of the estimation

quantile regression characterizes a particular (center or tail) point of a conditional distribution.[14] The results from different quantile regressions provide a more complete description of the underlying conditional distribution of pricing errors.[15]

3. EMPIRICAL RESULTS

3.1. Summary Statistics

Table 1 reports the summary statistics, including quote depth, close price, trading volume, number of trades, days to maturity, bid-ask spread, market quality index, pricing error, and volatility. As expected, after decimalization, there are decreases in bid-ask spreads and quoted depth, and these is an increase in the average daily trading volume for SPDRs and QQQs. This result is consistent with those found in the prior studies (for example, Gibson et al., 2003; Chou and Chung, 2006). As argued above, a smaller spread size may not necessarily be advantageous to arbitragers, who are likely to act as providers or porters of liquidity in the market.

procedure is provided in Koenker (2005).

[14] We estimate two extreme quantiles, 0.01 and 0.99 quantiles, as well as 0.05 to 0.95 quantiles, with a 0.05 increment.

[15] Koenker and Hallock (2001) mention a faulty notion that quantile regression could be achieved by segmenting the response variable into subsets according to its unconditional distribution and then doing least squares fitting on these subsets. They indicate that this form of "truncation on the dependent variable" would yield disastrous results. In general, such strategies are doomed to failure for all the reasons so carefully laid out in Heckman's (1979) work on sample selection.

Table 1 Summary statistics

The table shows summary statistics for ETFs and their underlying E-mini futures. Quoted depth is calculated as (Q_{ask} + Q_{bid}), and bid-ask spread is calculated as ($P_{ask} - P_{bid}$), where P_{ask} is the ask price, P_{bid} is the bid price, Q_{ask} is the depth at ask and Q_{bid} is the depth at bid. The market quality index (MQI) is calculated as $[(Q_{ask} + Q_{bid})/10000/2]/[(P_{ask} - P_{bid})/[(P_{ask} + P_{bid})/2] \times 100]$ and the absolute mispricing error is calculated as $|F_M - F_T|/(ETF \times f)$, where f is the adjusting factor for ETF prices, F_M is the futures market price, and F_T is the futures theoretical price. Figures in parentheses are standard deviation.

	Pre-Decimalization (Jul 27, 2000-Jan 28, 2001)	Post-Decimalization (Jan 29, 2001-Jul 30, 2001)	Entire Period (Jul 27, 2000-Jul 30, 2001)
Panel A: SPDRs and S&P 500 E-mini			
No. of trading days	127	127	254
No. of Obs. (ETF-futures trades pairs)	131,049	205,971	337,020
No. of Obs. (ETF-futures quotes pairs)	301,018	322,524	623,542
Average absolute mispricing errors (%)	0.0942 (0.0787)	0.0842 (0.0560)	0.0881 (0.0660)
A1. SPDRs			
Average bid-ask spread	0.1366 (0.0323)	0.1216 (0.0443)	0.1287 (0.0398)
Average quoted depth (100 shares)	3,283 (2,434)	1,526 (2,244)	2,358 (2,495)
Average daily trading volume (100 shares)	54,605 (22,287)	72,454 (26,433)	63,530 (25,987)
Average No. of trades per 5-min	13.74 (7.75)	21.66 (10.54)	17.70 (10.06)
Average daily close price	140.26	123.80	132.03
Annualized Std. Dev. of daily return (%)	22.19	22.53	22.28
Market quality index (MQI)	166.80	76.75	119.15
A2. S&P 500 E-mini			
Average days to maturity	54.42 (26.10)	56.60 (27.94)	55.51 (27.01)
Average No. of trades per 5-min	333.35 (168.65)	443.15 (223.66)	388.19 (205.51)
Panel B: QQQs and NASDAQ 100 E-mini			
No. of trading days	127	127	254
No. of Obs. (ETF-futures trades pairs)	358,905	408,859	767,764
No. of Obs. (ETF-futures quotes pairs)	387,404	463,823	851,227
Average absolute mispricing errors (%)	0.3349 (0.1534)	0.3910 (0.1187)	0.3648 (0.1389)
B1. QQQs			
Average bid-ask spread	0.1151 (0.0697)	0.0615 (0.0417)	0.0853 (0.0619)
Average quoted depth (100 shares)	132 (162)	108 (201)	119 (185)
Average daily trading volume (100 shares)	254,978 (116,058)	344,598 (112,590)	299,788 (122,626)
Average No. of trades per 5-min	39.52 (10.44)	45.65 (12.13)	42.58 (11.72)
Average daily close price	79.07	46.33	62.70
Annualized Std. Dev. of daily return (%)	63.33	55.98	59.59
Market quality index (MQI)	4.37	4.01	4.18
B2. NASDAQ 100 E-mini			
Average days to maturity	54.41 (26.10)	56.59 (27.95)	55.50 (27.01)
Average No. of trades per 5-min	458.32 (243.01)	630.32 (312.98)	544.26 (293.06)

Previous studies on equity securities have demonstrated that there is a general reduction in the quoted depth after decimalization, and we also find this to be the case for both SPDRs and QQQs. Such reduction in market depth is likely to harm arbitrageurs, who usually trade large positions in order to realize the arbitrage profits. Even though the average quoted depth for both ETFs seem to be large, the standard deviation of quoted depth indicates that the quoted depth is quite volatile. Thus, it is very likely that arbitragers will experience times when the market depth is low and thus face high execution risk. This prompts us to empirically examine the arbitrage opportunity between ETFs and E-mini futures.

From Table 1, we find decrease (increase) in the average absolute mispricing errors for QQQs (SPDRs) after decimalization. From the summary statistics of pricing errors, it seems that no definite conclusions can be made regarding the cash/futures pricing efficiency after decimalization, which might be caused by failing to control for changes in other market factors, an issue will be addressed later by the method of OLS and quantile regressions. We further gauge the overall market quality by adopting a market quality index (MQI) similar to that proposed by Bollen and Whaley (1998). We define MQI in this study as the ratio between the half quoted depth of the prevailing bid-ask quotes and the percentage quoted spread. As can be seen from Table 1, there is a significant deterioration in market quality after decimalization, as measured by the MQI.

3.2. Ex-Post Mispricing Analyses

The mispricing signals are identified by Equations (3) and (4) for SPDRs and Equations (5) and (6) for QQQs with various levels of transaction costs based on the theoretical futures prices. The total number of violations, the number of violations as percentage of number of observations, the average mispricing signal, the standard deviation of signals, and the statistics of violation within a 5-minute interval, are summarized in Table 2 (for SPDRs), and Table 3 (for QQQs), for both the pre- and post-decimalization periods. As the tables show, an increase in transaction costs tends to lead to reductions in the number of violations and the percentage of violations.

For SPDRs, comparing Panel A and Panel B of Table 2, we can see that after decimalization there is a substantial decrease in number of violations and the percentage of violations. In contrast, from Table 3, the number of violations and the percentage of violations generally increase for QQQs. As a result, no general conclusions regarding pricing efficiency can be made from the number and frequency of pricing errors.

The ex-post profit (i.e., the average mispricing signal) is defined as the difference between the futures quoted price and the appropriate upper or lower boundary when an mispricing signal is observed. When comparing the mispricing signal sizes in the pre- and post-decimalization periods, we find that the average signal sizes are generally smaller after penny pricing than before for both ETFs. It appears that the smaller mispricing signals indicate an improvement in pricing efficiency, but it is also likely that the somewhat smaller average signal sizes in the post-decimalization period are partially attributable to a reduction in the bid-ask spread. More importantly, a decreased mispricing size also implies that the potential arbitrage profits are smaller after decimalization, which may weaken arbitragers' incentive to participate in trading.

Table 2 and Table 3 also show that most of the boundary violations before and after penny pricing are clustered. From Panel B in Table 2, for the case with transaction cost of 0.5%, although the total number of violations is only 17, the maximum number of violations in a 5-minute interval is as high as 10.[16] Similar results are also obtained with various levels of transaction costs for both ETFs. This result supports the argument proposed by Chung (1991) that mispricing signals tend to occur in clusters.

[16] Note that the average number of violations in 5-minute intervals, the average percentage of violations in 5-minute intervals and the percentage of violations in clusters of 5 or more in 5-minute intervals are calculated based on those 5-minute intervals with mispricing signals observed.

Table 2 Ex-post boundary violations of SPDRs and S&P 500 E-mini futures

The ex-post tests refer to the frequency and persistence of boundary violations. No-arbitrage boundaries are constructed with the SPDR and S&P 500 E-mini (ES) prices, which are defined as:

$$\left\{10\times\left[SPDR(t)_{bid}-SDiv(t)\right]e^{r(T-t)}\right\}(1-C_c)<ES(t)_{ask}\quad\text{or}\quad\left\{10\times\left[SPDR(t)_{ask}-SDiv(t)\right]e^{r(T-t)}\right\}(1+C_c)>ES(t)_{bid}$$

where $SPDR(t)_{bid}$ is the SPDR bid price and $SPDR(t)_{ask}$ is the SPDR ask price at time t; $ES(t)_{bid}$ is the S&P 500 E-minis bid price and $ES(t)_{ask}$ is the S&P 500 E-minis ask price at time t; $SDiv(t)$ refers to the present value of the SPDR dividend from time t to time T; and C_c is the trade commission. Since SPDR prices are 1/10th of the index level, an adjustment factor of 10 is applied. Transaction costs are measured as a percentage of the theoretical futures value under the cost-of-carry model.

Number of Observations	Transaction Costs	Number of Violations	Number of Violations as % of Number of Observations	Average Mispricing Signal	Standard Deviation of Mispricing Signal	Average Number of Violations in 5-min Intervals	Maximum Number of Violations in 5-min Intervals	Average % of Violations in 5-min Intervals	% of Violations in Clusters of 5 or More in 5-min Intervals
Panel A: Pre-Decimalization (Jul 27, 2000 ~ Jan 28, 2001)									
301,018	0.05%	97,094	32.26%	0.8677	0.7290	17.01	90	52.59%	74.55%
	0.10%	51,057	16.96%	0.6287	0.6971	14.08	75	44.30%	70.27%
	0.15%	17,548	5.83%	0.4812	0.9150	8.82	55	27.57%	52.96%
	0.20%	3,253	1.08%	0.6285	1.8620	4.80	42	13.61%	31.86%
	0.25%	542	0.18%	1.9077	4.0091	3.52	25	9.10%	22.73%
	0.30%	207	0.07%	3.9332	5.5026	5.31	23	14.83%	35.90%
	0.35%	127	0.04%	5.5617	5.9675	6.05	22	18.65%	33.33%
	0.40%	111	0.04%	5.6452	6.0114	6.17	21	19.61%	38.89%
	0.45%	100	0.03%	5.5595	6.0471	7.69	21	25.10%	53.85%
	0.50%	78	0.03%	6.3624	6.0732	8.67	21	25.24%	66.67%
Panel B: Post-Decimalization (Jan 29, 2001 ~ Jul 30, 2001)									
322,524	0.05%	81,276	25.20%	0.4357	0.3587	12.01	74	39.50%	69.95%
	0.10%	20,191	6.26%	0.2900	0.3467	5.86	46	18.82%	43.78%
	0.15%	1,889	0.59%	0.3217	0.7478	2.79	26	8.01%	16.42%
	0.20%	191	0.06%	1.0461	1.8296	2.65	15	7.84%	16.67%
	0.25%	63	0.02%	2.1201	2.4242	3.32	15	10.62%	15.79%
	0.30%	36	0.01%	2.8677	2.4379	3.60	14	11.94%	10.00%
	0.35%	28	0.01%	3.0061	2.2491	3.11	11	10.33%	11.11%
	0.40%	25	0.01%	2.7175	2.1589	3.57	11	12.30%	14.29%
	0.45%	21	0.01%	2.5454	2.0751	3.50	11	11.02%	16.67%
	0.50%	17	0.01%	2.4601	1.9545	3.40	10	10.59%	20.00%

Table 3 Ex-post boundary violations of QQQs and NASDAQ 100 E-mini futures

The ex-post tests refer to the frequency and persistence of boundary violations. No-arbitrage boundaries are constructed with the QQQ and NASDAQ E-mini (NQ) prices, which are defined as:

$$\{40 \times [QQQ(t)_{bid} - QDiv(t)]e^{r(T-t)}\}(1 - C_c) < NQ(t)_{ask} \quad \text{or} \quad \{40 \times [QQQ(t)_{ask} - QDiv(t)]e^{r(T-t)}\}(1 + C_c) > NQ(t)_{bid}$$

where $QQQ(t)_{bid}$ is the QQQ bid price and $QQQ(t)_{ask}$ is the QQQ ask price at time t; $NQ(t)_{bid}$ is the NASDAQ 100 E-minis bid price and $NQ(t)_{ask}$ is the NASDAQ 100 E-minis ask price at time t; $QDiv(t)$ refers to the present value of the QQQ dividend from time t to time T; and C_c is the trade commission. Since QQQ prices are 1/40th of the index level, an adjusting factor of 40 is applied. Transaction costs are measured as a percentage of the theoretical futures value under the cost-of-carry model.

Number of Observations	Transaction Costs	Number of Violations	Number of Violations as % of Number of Observations	Average Mispricing Signal	Standard Deviation of Mispricing Signal	Average Number of Violations in 5-min Intervals	Maximum Number of Violations in 5-min Intervals	Average % of Violations in 5-min Intervals	% of Violations in Clusters of 5 or More in 5-min Intervals
Panel A: Pre-Decimalization (Jul 27, 2000 ~ Jan 28, 2001)									
387,404	0.05%	353,223	91.18%	6.4106	3.5484	35.83	91	90.22%	99.74%
	0.10%	324,534	83.77%	5.2944	3.3139	32.92	87	82.60%	99.46%
	0.15%	279,216	72.07%	4.4244	3.0485	28.40	82	70.80%	97.78%
	0.20%	223,167	57.61%	3.7663	2.7842	23.28	77	57.65%	91.76%
	0.25%	167,663	43.28%	3.2216	2.5649	19.03	74	46.95%	84.74%
	0.30%	116,970	30.19%	2.7936	2.4157	14.97	70	37.07%	78.20%
	0.35%	75,116	19.39%	2.4987	2.3512	11.19	67	27.99%	67.43%
	0.40%	44,979	11.61%	2.3259	2.3774	8.47	65	21.56%	55.06%
	0.45%	26,017	6.72%	2.2219	2.4984	6.91	62	17.93%	45.82%
	0.50%	14,840	3.83%	2.1575	2.7302	5.89	60	15.72%	39.63%
Panel B: Post-Decimalization (Jan 29, 2001 ~ Jul 30, 2001)									
463,823	0.05%	446,738	96.32%	4.6321	1.9584	45.35	94	95.79%	99.92%
	0.10%	432,965	93.35%	3.8367	1.8440	43.95	94	92.64%	99.88%
	0.15%	408,899	88.16%	3.1089	1.7089	41.51	94	87.31%	99.74%
	0.20%	368,032	79.35%	2.4795	1.5548	37.39	93	78.48%	99.36%
	0.25%	306,891	66.17%	1.9640	1.3998	31.25	90	65.46%	97.60%
	0.30%	228,580	49.28%	1.5732	1.2650	23.64	81	49.49%	92.33%
	0.35%	148,055	31.92%	1.2963	1.1750	16.38	77	34.29%	82.66%
	0.40%	82,171	17.72%	1.1203	1.1588	10.70	67	22.47%	68.34%
	0.45%	39,956	8.61%	1.0193	1.2532	7.11	54	15.13%	52.80%
	0.50%	17,511	3.78%	0.9904	1.5169	4.99	43	10.92%	38.73%

Table 4 Ex-ante arbitrage analyses for SPDRs and S&P 500 E-mini futures

The ex-ante tests impose an execution lag for trading in SPDRs and S&P 500 E-mini futures, and thus the ex-ante mean profits are arbitrage profits after considering the transaction lag. A long arbitrage ($ESAP_L$), triggered by futures overpricing, buys 500 SPDR shares and shorts an S&P 500 E-mini futures contract after observing an upper-boundary violation, whereas a short arbitrage ($ESAP_S$), triggered by futures underpricing, executes the reverse transactions. Profits for long and short arbitrage are measured as:

$$ESAP_L = ES(t^+)_{bid} - \{10 \times [SPDR(t^+)_{ask} - SDiv(t^+)]e^{r(T-t^+)}\}(1+C_c) \text{ and } ESAP_S = \{10 \times [SPDR(t^+)_{bid} - SDiv(t^+)]e^{r(T-t^+)}\}(1-C_c) - ES(t^+)_{ask}$$

where t^+ indicates the time of the first quote (trade) price of ETFs (E-minis) immediately after observation of the mispricing signal. $SPDR(t^+)_{bid}$ is the SPDR bid price and $SPDR(t^+)_{ask}$ is the SPDR ask price at time t^+. $ES(t^+)_{bid}$ is the S&P 500 E-mini futures bid price and $ES(t^+)_{ask}$ is the S&P 500 E-mini futures ask price at time t^+; $SDiv(t^+)$ refers to the present value of the SPDR dividend from time t^+ to time T; and C_c is the trade commission. Since SPDR prices are 1/10th of the index level, an adjustment factor of 10 is applied.

Transaction Costs	Number of Trades	Profitable Trades	Profitable Trades as % of All Trades	Average Signal	Standard Deviation of Signal	Average Profit	Standard Deviation of Profit	Correlation of Signal and Profit	*p*-value
Panel A: Pre-Decimalization (Jul 27, 2000 ~ Jan 28, 2001)									
0.05%	97,052	85,723	88.33%	0.8676	0.7289	0.8001	0.8058	0.8477	(<.0001)
0.10%	51,030	42,690	83.66%	0.6286	0.6972	0.5370	0.7749	0.8227	(<.0001)
0.15%	17,532	12,908	73.63%	0.4812	0.9153	0.3335	0.9883	0.8478	(<.0001)
0.20%	3,250	2,003	61.63%	0.6288	1.8628	0.3544	1.9405	0.8937	(<.0001)
0.25%	542	334	61.62%	1.9077	4.0091	1.3899	4.2122	0.9028	(<.0001)
0.30%	207	157	75.85%	3.9332	5.5026	3.2152	5.9267	0.8888	(<.0001)
0.35%	127	98	77.17%	5.5617	5.9675	4.5763	6.7278	0.8749	(<.0001)
0.40%	111	91	81.98%	5.6452	6.0114	4.6436	6.8690	0.8644	(<.0001)
0.45%	100	85	85.00%	5.5595	6.0471	4.4905	7.0124	0.8603	(<.0001)
0.50%	78	64	82.05%	6.3624	6.0732	5.2624	7.1859	0.8467	(<.0001)
Panel B: Post-Decimalization (Jan 29, 2001 ~ Jul 30, 2001)									
0.05%	81,250	64,508	79.39%	0.4357	0.3587	0.3302	0.4674	0.6229	(<.0001)
0.10%	20,182	12,674	62.80%	0.2900	0.3468	0.0971	0.4848	0.5271	(<.0001)
0.15%	1889	866	45.84%	0.3217	0.7478	-0.0283	0.8924	0.5750	(<.0001)
0.20%	191	89	46.60%	1.0461	1.8296	0.3226	2.2563	0.5388	(<.0001)
0.25%	63	37	58.73%	2.1201	2.4242	1.0092	3.4439	0.4122	(0.0008)
0.30%	36	23	63.89%	2.8677	2.4379	1.3992	4.1028	0.2765	(0.1026)
0.35%	28	16	57.14%	3.0061	2.2491	0.7249	4.4831	0.3790	(0.0467)
0.40%	25	16	64.00%	2.7175	2.1589	0.3362	4.6920	0.3537	(0.0828)
0.45%	21	13	61.90%	2.5454	2.0751	0.1274	4.8240	0.3142	(0.1654)
0.50%	17	10	58.82%	2.4601	1.9545	-0.3359	5.1468	0.3478	(0.1713)

Table 5 Ex-ante arbitrage analyses for QQQs and NASDAQ 100 E-mini futures

The ex-ante tests impose an execution lag for trading QQQs and NASDAQ 100 E-mini futures, and thus the ex-ante mean profits are arbitrage profits after considering the transaction lag. A long arbitrage ($NQAP_L$), triggered by futures overpricing, buys 800 QQQ shares and shorts a NASDAQ 100 E-mini futures contract after the observation of an upper-boundary violation, whereas a short arbitrage ($NQAP_S$), triggered by futures underpricing, executes the reverse transactions. Profits for the long and short arbitrage are measured as:

$$NQAP_L = NQ(t^+)_{bid} - \{40 \times [QQQ(t^+)_{ask} - QDiv(t^+)]e^{r(T-t^+)}\}(1+C_c) \text{ and } NQAP_S = \{40 \times [QQQ(t^+)_{bid} - QDiv(t^+)]e^{r(T-t^+)}\}(1-C_c) - NQ(t^+)_{ask}$$

where t^+ indicates the time of the first quote (trade) price of ETFs (E-minis) immediately after observation of the mispricing signal. $QQQ(t^+)_{bid}$ is the QQQ bid price and $QQQ(t^+)_{ask}$ is the QQQ ask price at time t^+. $NQ(t^+)_{bid}$ is the NASDAQ 100 E-mini futures bid price and $NQ(t^+)_{ask}$ is the NASDAQ 100 E-mini futures ask price at time t^+; $QDiv(t^+)$ refers to the present value of the QQQ dividend from time t^+ to time T; and C_c is the trade commission. Since QQQ prices are 1/40th of the index level, an adjustment factor of 40 is applied.

Transaction Costs	Number of Trades	Profitable Trades	Profitable Trades as % of All Trades	Average Signal	Standard Deviation of Signal	Average Profit	Standard Deviation of Profit	Correlation of Signal and Profit	*p*-value
Panel A: Pre-Decimalization (Jul 27, 2000 ~ Jan 28, 2001)									
0.05%	353,120	341,812	96.80%	6.4107	3.5484	6.2775	3.7377	0.8204	(<.0001)
0.10%	324,440	306,998	94.62%	5.2944	3.3139	5.0962	3.5671	0.8046	(<.0001)
0.15%	279,138	255,802	91.64%	4.4244	3.0485	4.1420	3.3820	0.7783	(<.0001)
0.20%	223,104	197,362	88.46%	3.7663	2.7843	3.3872	3.2056	0.7413	(<.0001)
0.25%	167,616	142,501	85.02%	3.2216	2.5650	2.7361	3.0725	0.6998	(<.0001)
0.30%	116,932	94,684	80.97%	2.7937	2.4158	2.1832	3.0194	0.6566	(<.0001)
0.35%	75,093	57,474	76.54%	2.4989	2.3514	1.7402	3.0558	0.6183	(<.0001)
0.40%	44,967	32,573	72.44%	2.3261	2.3776	1.4054	3.1803	0.5855	(<.0001)
0.45%	26,012	18,078	69.50%	2.2221	2.4986	1.1553	3.3699	0.5556	(<.0001)
0.50%	14,839	9,875	66.55%	2.1576	2.7303	0.9230	3.6393	0.5355	(<.0001)
Panel B: Post-Decimalization (Jan 29, 2001 ~ Jul 30, 2001)									
0.05%	446,619	440,968	98.73%	4.6321	1.9583	4.5937	2.0357	0.8076	(<.0001)
0.10%	432,848	423,466	97.83%	3.8367	1.8439	3.7794	1.9445	0.7943	(<.0001)
0.15%	408,791	393,736	96.32%	3.1089	1.7088	3.0250	1.8400	0.7738	(<.0001)
0.20%	367,937	345,420	93.88%	2.4794	1.5547	2.3574	1.7246	0.7432	(<.0001)
0.25%	306,812	276,950	90.27%	1.9639	1.3997	1.7887	1.6120	0.7030	(<.0001)
0.30%	228,519	195,022	85.34%	1.5732	1.2649	1.3277	1.5373	0.6441	(<.0001)
0.35%	148,013	117,837	79.61%	1.2963	1.1748	0.9618	1.5139	0.5709	(<.0001)
0.40%	82,145	59,928	72.95%	1.1202	1.1585	0.6655	1.5792	0.4905	(<.0001)
0.45%	39,947	26,428	66.16%	1.0192	1.2529	0.4090	1.7637	0.4145	(<.0001)
0.50%	17,507	10,394	59.37%	0.9901	1.5165	0.1695	2.1472	0.3546	(<.0001)

3.3. Ex-Ante Arbitrage Profit Analyses

In this section, we report the results of the ex-ante analyses under the assumption that arbitragers can only transact at the next available futures trade price and ETF quote price after observing a mispricing signal.[17] Table 4 and Table 5 present the results for SPDRs and QQQs surrounding decimalization, respectively. As Table 4 shows, under different levels of transaction costs, there are significant decreases in the number and percentage of profitable trades for SPDRs after decimalization. Table 5, on the contrary, shows substantial increases in the number and percentage of profitable trades for QQQs after decimalization.

It would seem, therefore, that there are no consistent results in the frequencies of profitable trades after the reduction in tick size. Nevertheless, from Table 4 and Table 5, it is seen that the ex-ante mean arbitrage profits decrease for both SPDRs and QQQs, and the correlation of signal and profit is lower after penny pricing. Interestingly, the decreases in mean arbitrage profits are relatively more significant at higher levels of transaction costs, when the required mispricing signals are large. This indicates that pricing efficiency changes are likely to be different for mispricing signals of different sizes.

These seem to indicate that the efficiency of market pricing may have been improved as a result of decimalization. However, the decrease in minimum tick size makes the boundary conditions to be tighter and tends to make smaller mispricing signals, thus a decrease in mispricing signals also implies that the mean arbitrage profits after decimalization are lower and this does not necessarily indicate an improvement in pricing efficiency. We suggest that the decreases in mispricing signals and mean arbitrage profits are caused, at least partially, by the narrower spreads of ETFs in the post-decimalization period. However, due to the simultaneous reduction in quoted depth, and the increase in execution risk, it is much more

[17] The assumption of trading at the next available quotes should be reasonable because the average time span between the tick-by-tick trades are about 9.46 and 6.94 seconds for SPDRs and QQQs, respectively, which would be sufficient for arbitragers that closely monitor the market conditions to react to the mispricing signals.

difficult for arbitrageurs to initiate profitable arbitrage trades when they observe small mispricing signals.

Therefore, arbitragers will only participate in trading when there is sufficient profit to be made, i.e., when the mispricing signal is large enough to cover the increased execution risk. We argue that the pricing efficiency may be improved only when the mispricing signal is sufficiently large. The overall pricing efficiency might actually deteriorate after decimalization. In order to test this assertion, we now turn to the analyses of the changes in the entire distribution of mispricing signals surrounding decimalization by the quantile regression.

3.4. Regression Analyses of Mispricing

Following previous studies (Kurov and Lasser, 2002; Henker and Martens, 2005), inferences on improvements in the cash/futures pricing efficiency after decimalization could be affected by changes in market conditions over the sample period. We employ the decimal dummy, open dummy, close dummy, volatility, number of ETFs trades and time to maturity as independent variables to explain the degree of mispricing in the 5-minute intervals. Let θ denote quantile for which the relation between mispricing and explanatory variables is estimated. We estimate coefficients of quantile regression at θ from 0.05 to 0.95, with a 0.05 increment. We also consider two additional extreme percentiles, i.e., θ = 0.99 and 0.01, to observe the changes in pricing efficiency when large arbitrage opportunities are present, i.e., when the mispricing signal is extremely large. The statistical inferences of the quantile regression coefficients are drawn by the bootstrapping method.[18]

We estimate the regression using the method of OLS first, which is used to examine change in degree of average mispricing. As demonstrated in Table 6 and Table 7, the

[18] We compute the empirical variance-covariance matrix of realizations and construct confidence intervals using the bootstrapping method and the number of replications is set to 1,000. For details, see Eforn (1982), De Angelis et al. (1993), and Andrews and Buchinsky (2000, 2001).

positively significant OLS coefficients of decimal dummy indicate higher pricing errors after decimalization and imply that the pricing efficiency of the cash/futures system has become significantly worse on average after decimalization, after controlling for changes in other market factors. We next perform the quantile regression to analyze the entire distribution of mispricing size in the post-decimalization period.

Quantile methods provide support for our argument in that the coefficients on decimal dummy in the pooled quantile regressions became negative for quantiles greater than 65% for SPDRs and 85% for QQQs. The coefficients further become significantly negative for quantiles over 70% and 85% for SPDRs and QQQs, respectively. These results show that the improvement in the pricing efficiency occurs only when large mispricing signals occur, because larger profits help arbitrageurs against latent risk when executing arbitrage trades. For the other control variables, quantile regression estimates are also quite similar to the OLS estimates in high quantiles and the sings and significances of the OLS coefficient are generally consistent with those in Kurove and Lasser (2002). Finally, the finding that QQQs pricing efficiency improves in more extreme quantiles than those of SPDRs implies that the execution risk of QQQs may be greater than that of SPDRs.

Overall, these results show that after penny pricing, the general pricing efficiency of the cash/futures pricing system does not seem to improve. We show that arbitrageurs require larger mispricing signals to be engaged in arbitrage trading, as pricing efficiency is found to be improved only at higher quantiles of mispricing signals. In other words, due to increased execution risk after decimalization, such as reduction in market depth and lower average arbitrage profits, arbitragers would wait for the occurrences of large mispricing size to be compensated for the increased risk of arbitrage trades. Therefore, the overall pricing efficiency between ETF and E-mini futures become worse after decimalization except for when the mispricing signals are large enough.

Table 6 Mispricing analyses for the relationship between SPDRs and S&P 500 E-mini futures using OLS and quantile regression

As a preliminary test, this study considers the change in average futures mispricing after the introduction of decimalization by using an autoregressive model with six lags defined in the following equation:

$$|MPE_t| = \beta_0 + \beta_1 D_t^{decimal} + \beta_2 D_t^{open} + \beta_3 D_t^{close} + \beta_4 Vol_t + \beta_5 NT_t + \beta_6 ET_t + \sum_{i=1}^{6} \varphi_i |MPE_{t-i}| + \varepsilon_t$$

where t denotes one of the five minutes time periods. $|MPE_t|$ is the average absolute mispricing errors during time period t; $D_t^{decimal}$ is a dummy variable that equals 0 during the pre-decimalization period and 1 afterward; D_t^{open} and D_t^{close} are (0,1) dummy variables which respectively control for the open and close interval effects; Vol_t is the Parkinson (1980) extreme value estimator which is used to be a proxy for volatility; NT_t is the number of SPDRs trades during time period t; and ET_t is time to expiration of the S&P 500 E-mini futures contract during time period t. In addition, six lags of the dependent variable in the regression model are employed to eliminate autocorrelation in the regression residuals. We adopt OLS method and a linear quantile regression model proposed by Koenker and Bassett (1978) to estimate this equation. The total number of time periods is 19,632. Figures in parentheses are p-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

		Quantile Regression (θ = 0.99, 0.95, 0.9, 0.85, 0.8, 0.75, 0.7)						
Variable	OLS	0.99	0.95	0.9	0.85	0.8	0.75	0.7
$D^{decimal}$	0.025***	-0.040*	-0.053***	-0.039***	-0.027***	-0.019***	-0.015***	-0.008**
	(<.001)	(0.070)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.035)
D^{open}	0.114***	0.832	0.629***	0.480***	0.351***	0.316***	0.262***	0.218***
	(<.001)	(0.151)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
D^{close}	0.044***	0.045	0.043*	0.030	0.033*	0.039***	0.036**	0.033**
	(0.002)	(0.294)	(0.067)	(0.179)	(0.064)	(0.009)	(0.024)	(0.040)
Vol	0.921***	2.950***	1.422***	1.004***	0.815***	0.669***	0.540***	0.462***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
NT	-0.063***	-0.177***	-0.080***	-0.061***	-0.053***	-0.044***	-0.035***	-0.029***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
ET	0.028***	0.062	0.008	0.018	0.042	0.038	0.036	0.031
	(0.203)	(0.505)	(0.868)	(0.564)	(0.106)	(0.135)	(0.128)	(0.150)
$\|MPE_{t-1}\|$	0.405***	0.595***	0.397***	0.358***	0.344***	0.339***	0.329***	0.324***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-2}\|$	0.156***	0.181***	0.218***	0.202***	0.199***	0.202***	0.206***	0.205***
	(<.001)	(0.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-3}\|$	0.108***	0.122***	0.149***	0.143***	0.150***	0.149***	0.150***	0.149***
	(<.001)	(0.003)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-4}\|$	0.079***	0.018	0.084***	0.123***	0.123***	0.125***	0.117***	0.116***
	(<.001)	(0.658)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-5}\|$	0.094***	0.160***	0.141***	0.126***	0.129***	0.125***	0.111***	0.117***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-6}\|$	0.109***	0.060	0.085***	0.098***	0.093***	0.088***	0.104***	0.100***
	(<.001)	(0.252)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
Constant	0.088***	0.529***	0.304***	0.236***	0.192***	0.153***	0.123***	0.092***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.8088	0.6268	0.6548	0.6630	0.6653	0.6659	0.6645	0.6620

Table 6 (Continued)

	Quantile Regression (θ = 0.65, 0.6, 0.55, 0.5, 0.45, 0.4, 0.35)						
Variable	0.65	0.6	0.55	0.5	0.45	0.4	0.35
$D^{decimal}$	-0.001	0.001	0.003	0.007**	0.010***	0.014***	0.017***
	(0.686)	(0.854)	(0.314)	(0.034)	(0.003)	(<.001)	(<.001)
D^{open}	0.198***	0.160***	0.146***	0.133***	0.108***	0.102***	0.069**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.030)
D^{close}	0.021	0.019	0.016	0.012	0.012	0.013	0.017
	(0.162)	(0.176)	(0.264)	(0.305)	(0.271)	(0.257)	(0.169)
Vol	0.419***	0.361***	0.305***	0.245***	0.208***	0.146***	0.097***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.006)
NT	-0.026***	-0.021***	-0.017***	-0.012***	-0.010***	-0.002	0.002
	(<.001)	(<.001)	(<.001)	(<.001)	(0.005)	(0.500)	(0.570)
ET	0.033*	0.023	0.016	0.011	0.001	0.005	0.020
	(0.091)	(0.225)	(0.437)	(0.579)	(0.962)	(0.785)	(0.295)
$\|MPE_{t-1}\|$	0.325***	0.328***	0.328***	0.330***	0.325***	0.319***	0.312***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-2}\|$	0.193***	0.189***	0.188***	0.179***	0.175***	0.174***	0.175***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-3}\|$	0.148***	0.151***	0.152***	0.149***	0.148***	0.146***	0.144***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-4}\|$	0.118***	0.119***	0.115***	0.112***	0.113***	0.112***	0.109***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-5}\|$	0.117***	0.111***	0.110***	0.113***	0.110***	0.112***	0.115***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-6}\|$	0.104***	0.101***	0.098***	0.101***	0.103***	0.102***	0.101***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
Constant	0.067***	0.046***	0.027***	0.006	-0.008	-0.036***	-0.060***
	(<.001)	(<.001)	(0.001)	(0.449)	(0.284)	(<.001)	(<.001)
R^2	0.6588	0.6543	0.6479	0.6397	0.6295	0.6174	0.6034

Table 6 (Continued)

	Quantile Regression (θ = 0.3, 0.25, 0.2, 0.15, 0.1, 0.05, 0.01)						
Variable	0.3	0.25	0.2	0.15	0.1	0.05	0.01
$D^{decimal}$	0.022***	0.024***	0.029***	0.037***	0.044***	0.047***	0.038***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)
D^{open}	0.031	0.024	-0.020	-0.047	-0.157	-0.459***	-0.315***
	(0.281)	(0.439)	(0.610)	(0.277)	(0.153)	(<.001)	(<.001)
D^{close}	0.015	0.018*	0.022**	0.024	0.004	0.000	-0.011
	(0.201)	(0.086)	(0.043)	(0.151)	(0.813)	(0.998)	(0.756)
Vol	0.070**	0.021	-0.050	-0.130***	-0.170***	-0.266***	-0.070
	(0.049)	(0.587)	(0.216)	(0.002)	(0.001)	(<.001)	(0.564)
NT	0.003	0.005	0.012***	0.017***	0.023***	0.036***	0.052***
	(0.365)	(0.181)	(0.005)	(<.001)	(<.001)	(<.001)	(<.001)
ET	0.016	0.001	-0.018	-0.031	-0.049	-0.052	-0.038
	(0.443)	(0.961)	(0.442)	(0.227)	(0.113)	(0.180)	(0.575)
$\lvert MPE_{t-1}\rvert$	0.303***	0.310***	0.311***	0.303***	0.296***	0.296***	0.267***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-2}\rvert$	0.179***	0.175***	0.170***	0.170***	0.165***	0.147***	0.101***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.007)
$\lvert MPE_{t-3}\rvert$	0.143***	0.132***	0.126***	0.124***	0.116***	0.084***	0.028
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.551)
$\lvert MPE_{t-4}\rvert$	0.105***	0.100***	0.100***	0.101***	0.098***	0.108***	0.045
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.291)
$\lvert MPE_{t-5}\rvert$	0.115***	0.115***	0.107***	0.104***	0.094***	0.076**	0.021
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.014)	(0.651)
$\lvert MPE_{t-6}\rvert$	0.101***	0.101***	0.104***	0.095***	0.087***	0.076***	0.064*
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.006)	(0.060)
Constant	-0.074***	-0.085***	-0.109***	-0.128***	-0.148***	-0.179***	-0.164***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.5868	0.5676	0.5446	0.5159	0.4762	0.4161	0.2962

Table 7 Mispricing analyses for the relationship between QQQs and NASDAQ 100 E-mini futures using OLS and quantile regression

As a preliminary test, this study considers the change in average futures mispricing after the introduction of decimalization by using an autoregressive model with eight lags defined in the following equation:

$$|MPE_t| = \beta_0 + \beta_1 D_t^{decimal} + \beta_2 D_t^{open} + \beta_3 D_t^{close} + \beta_4 Vol_t + \beta_5 NT_t + \beta_6 ET_t + \sum_{i=1}^{8} \varphi_i |MPE_{t-i}| + \varepsilon_t$$

where t denotes one of the five minutes time periods. $|MPE_t|$ is the average absolute mispricing errors during time period t; $D_t^{decimal}$ is a dummy variable that equals 0 during the pre-decimalization period and 1 afterward; D_t^{open} and D_t^{close} are (0,1) dummy variables which respectively control for the open and close interval effects; Vol_t is the Parkinson (1980) extreme value estimator which is used to be a proxy for volatility; NT_t is the number of QQQs trades during time period t; and ET_t is time to expiration of the NASDAQ 100 E-mini futures contract during time period t. In addition, eight lags of the dependent variable in the regression model are employed to eliminate autocorrelation in the regression residuals. We adopt OLS method and a linear quantile regression model proposed by Koenker and Bassett (1978) to estimate this equation. The total number of time periods is 19,713. Figures in parentheses are p-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

		Quantile Regression (θ = 0.99, 0.95, 0.9, 0.85, 0.8, 0.75, 0.7)						
Variable	OLS	0.99	0.95	0.9	0.85	0.8	0.75	0.7
$D^{decimal}$	0.105***	-0.123***	-0.036**	-0.029**	-0.016*	0.002	0.005	0.013
	(<.001)	(0.004)	(0.021)	(0.014)	(0.059)	(0.857)	(0.533)	(0.118)
D^{open}	0.087**	11.688*	0.751	0.048	0.019	-0.099**	-0.084***	-0.088*
	(0.015)	(0.083)	(0.278)	(0.636)	(0.843)	(0.030)	(0.005)	(0.075)
D^{close}	0.072**	0.048	0.182***	0.113**	0.126***	0.103**	0.091**	0.078**
	(0.042)	(0.605)	(<.001)	(0.016)	(<.001)	(0.016)	(0.012)	(0.021)
Vol	0.485***	2.367***	1.466***	1.092***	0.909***	0.717***	0.619***	0.500***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
NT	-0.099***	-0.330***	-0.178***	-0.148***	-0.125***	-0.100***	-0.089***	-0.072***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
ET	1.278***	0.340	0.607***	0.382***	0.413***	0.434***	0.492***	0.495***
	(<.001)	(0.382)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-1}\|$	0.370***	0.541***	0.268***	0.242***	0.226***	0.217***	0.203***	0.204***
	(<.001)	(0.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-2}\|$	0.017**	0.090	0.139***	0.161***	0.163***	0.165***	0.162***	0.160***
	(0.022)	(0.106)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-3}\|$	0.094***	0.086	0.122***	0.115***	0.116***	0.119***	0.130***	0.132***
	(<.001)	(0.184)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-4}\|$	0.077***	0.049	0.118***	0.124***	0.115***	0.122***	0.120***	0.117***
	(<.001)	(0.267)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-5}\|$	0.058***	0.056	0.075***	0.084***	0.089***	0.089***	0.090***	0.094***
	(<.001)	(0.257)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-6}\|$	0.091***	0.075	0.098***	0.098***	0.098***	0.095***	0.090***	0.092***
	(<.001)	(0.119)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-7}\|$	0.060***	0.052	0.064***	0.066***	0.081***	0.081***	0.085***	0.082***
	(<.001)	(0.285)	(0.002)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-8}\|$	0.084***	0.055	0.079***	0.080***	0.074***	0.068***	0.069***	0.065***
	(<.001)	(0.339)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
Constant	0.529***	1.591***	0.923***	0.770***	0.666***	0.561***	0.502***	0.425***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
R^2	0.7195	0.5326	0.5684	0.5883	0.5982	0.6046	0.6090	0.6119

Table 7 (Continued)

	Quantile Regression (θ = 0.65, 0.6, 0.55, 0.5, 0.45, 0.4, 0.35)						
Variable	0.65	0.6	0.55	0.5	0.45	0.4	0.35
$D^{decimal}$	0.020***	0.031***	0.041***	0.050***	0.062***	0.067***	0.080***
	(0.005)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
D^{open}	-0.148***	-0.133***	-0.132**	-0.211***	-0.229***	-0.249***	-0.263***
	(<.001)	(<.001)	(0.015)	(<.001)	(<.001)	(<.001)	(<.001)
D^{close}	0.066**	0.057**	0.053*	0.057**	0.041	0.038	0.051
	(0.029)	(0.029)	(0.054)	(0.040)	(0.131)	(0.133)	(0.116)
Vol	0.366***	0.245***	0.146***	0.038	-0.051	-0.193***	-0.298***
	(<.001)	(<.001)	(<.001)	(0.374)	(0.179)	(<.001)	(<.001)
NT	0.466***	-0.038***	0.536***	-0.007	0.603***	0.014	0.665***
	(<.001)	(0.001)	(<.001)	(0.529)	(<.001)	(0.197)	(<.001)
ET	-0.049***	0.497***	-0.020*	0.575***	-0.001	0.644***	0.030**
	(<.001)	(<.001)	(0.067)	(<.001)	(0.893)	(<.001)	(0.012)
$\lvert MPE_{t-1}\rvert$	0.207***	0.205***	0.194***	0.189***	0.187***	0.185***	0.182***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-2}\rvert$	0.156***	0.156***	0.162***	0.158***	0.153***	0.151***	0.148***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-3}\rvert$	0.132***	0.131***	0.137***	0.138***	0.138***	0.139***	0.138***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-4}\rvert$	0.117***	0.112***	0.112***	0.114***	0.114***	0.112***	0.112***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-5}\rvert$	0.094***	0.099***	0.097***	0.094***	0.094***	0.089***	0.085***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-6}\rvert$	0.093***	0.094***	0.094***	0.094***	0.096***	0.096***	0.097***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-7}\rvert$	0.083***	0.076***	0.071***	0.073***	0.070***	0.069***	0.074***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\lvert MPE_{t-8}\rvert$	0.062***	0.065***	0.066***	0.065***	0.069***	0.075***	0.074***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
Constant	0.338	0.292***	0.221	0.169***	0.137***	0.077**	0.011
	(0.000)	(<.001)	(0.000)	(<.001)	(<.001)	(0.041)	(0.790)
R^2	0.6144	0.6165	0.6176	0.6180	0.6176	0.6163	0.6146

Table 7 (Continued)

	Quantile Regression (θ = 0.3, 0.25, 0.2, 0.15, 0.1, 0.05, 0.01)						
Variable	0.3	0.25	0.2	0.15	0.1	0.05	0.01
$D^{decimal}$	0.086***	0.095***	0.108***	0.130***	0.169***	0.240***	0.573***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
D^{open}	-0.323***	-0.323***	-0.384***	-0.413***	-0.399***	-0.416***	-0.382
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.105)
D^{close}	0.024	0.011	0.033	0.031	0.037	0.081	-0.048
	(0.546)	(0.687)	(0.156)	(0.416)	(0.255)	(0.159)	(0.845)
Vol	-0.411***	-0.546***	-0.693***	-0.819***	-0.952***	-1.202***	-1.307***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
NT	0.051***	0.756***	0.073***	0.940***	0.104***	0.136***	0.192***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)
ET	0.698***	0.065***	0.823***	0.087***	1.201***	1.884***	4.166***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-1}\|$	0.180***	0.185***	0.198***	0.199***	0.203***	0.231***	0.197***
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)
$\|MPE_{t-2}\|$	0.152***	0.147***	0.140***	0.147***	0.140***	0.079**	0.000
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.044)	(0.994)
$\|MPE_{t-3}\|$	0.134***	0.124***	0.114***	0.105***	0.104***	0.070*	0.060**
	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.094)	(0.027)
$\|MPE_{t-4}\|$	0.107***	0.114***	0.112***	0.103***	0.092***	0.083**	0.010
	(<.001)	(<.001)	(<.001)	(<.001)	(0.001)	(0.022)	(0.801)
$\|MPE_{t-5}\|$	0.087***	0.080***	0.072***	0.058**	0.060**	0.065*	0.009
	(<.001)	(<.001)	(0.002)	(0.019)	(0.038)	(0.055)	(0.773)
$\|MPE_{t-6}\|$	0.097***	0.091***	0.101***	0.104***	0.108***	0.094***	0.062**
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.003)	(0.043)
$\|MPE_{t-7}\|$	0.078***	0.083***	0.084***	0.084***	0.071***	0.055*	0.027
	(<.001)	(<.001)	(<.001)	(0.001)	(0.007)	(0.088)	(0.367)
$\|MPE_{t-8}\|$	0.069***	0.073***	0.070***	0.075***	0.067***	0.082***	0.049
	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(<.001)	(0.187)
Constant	-0.068	-0.127***	-0.167***	-0.239	-0.304***	-0.345***	-0.224
	(0.114)	(0.002)	(<.001)	(0.000)	(<.001)	(<.001)	(0.267)
R^2	0.6119	0.6081	0.6023	0.5916	0.5711	0.5259	0.4103

4. CONCLUSIONS

We have studied the influences of penny pricing on the efficiency of the cash/futures pricing system. We show that penny pricing has lowered mean arbitrage profits and led to a reduction in the willingness of arbitrageurs to engage in arbitrage trading, which has, in turn, led to lower pricing efficiency on average. We have shown that after the move to penny pricing, although the average signal, average profit and correlation of signal and profit appear to be significantly lower, the mispricing analyses by quantile regressions nevertheless show significant increases in mispricing errors on average for both ETFs. Using the quantile regression method, we show that the improvement in pricing efficiency only occur when the mispricing size is extremely large.

These findings are consistent with our hypothesis that the pricing efficiency between ETFs and E-mini futures would deteriorate after decimalization, and are also consistent with the results of Chakravarty et al. (2005), who argue that institutional traders seeking quick executions may have been hurt by penny pricing. Decimalization is likely to reduce the feasibility of arbitrage trades, due to the reduction in profitable market depth, and the increase in execution risks. It seems clear, therefore, that decimalization has reduced the ability and willingness of arbitrageurs to engage in arbitrage activities unless the mispricing size is enough to cover the execution risk. This has resulted in the worsening of the pricing efficiency of the cash/futures pricing system on average.

CHAPTER 3. CORPORATE GOVERNANCE AND EQUITY LIQUIDITY: ANALYSES OF INTERNAL AND EXTERNAL GOVERNANCE MECHANISMS

1. INTRODUCTION

Corporate governance is an extremely important issue for the whole of investor. Within those firms where poor corporate governance is adopted, managers are more likely to use their information advantage to pursue a private benefit of control, which will ultimately lead to an increase in the agency costs faced by shareholders. As the agency problem worsens, insiders (such as executives or controlling owners) can easily exploit the wealth and rights of small shareholders; it is for this reason that poor corporate governance is associated with the bad disclosure practices and weak shareholder rights.

The most widely accepted statement of good corporate governance practices are those established by Organisation for Economic Co-operation and Development (OECD).[19] Following the OECD Council Meeting Ministerial level on 27-28 April 1998, OECD developed six corporate governance principles (revised in 2004) that may be used as reference guidelines for businesses in the implementation of their corporate governance system: (1) Ensuring the basis for an effective corporate governance framework; (2) The rights of shareholders and key ownership functions; (3) The equitable treatment of shareholders; (4) The role of stakeholders in corporate governance; (5) Disclosure and transparency; and (6) The responsibilities of the board. These principles obviously focus on several key areas, i.e., shareholder rights and roles, disclosure and transparency, and responsibilities of boards.

[19] "OECD Principles of Corporate Governance," The Organisation for Economic Co-operation and Development, 2004. This paper is obtained from website: www.oecd.org.

Chapter 3 Corporate Governance and Equity Liquidity

Gillan (2006) develop a corporate governance framework and provided a board overview of recent corporate governance research. The governance mechanisms that have been extensively studied can be broadly characterized as being either internal or external to the firm. Gompers et al. (2003) mention that the power-sharing relationship between investors and managers is defined by the rules of corporate governance. Denis and McConnell (2003) define corporate governance as both institutional and market-based mechanisms that induce the self-interested controllers of a company to make decisions that maximize the value of the company to the supplies of capital. According to previous studies, the internal mechanisms of primary interest are the board of directors and the equity ownership structure of the firm; the primary external mechanisms are the external market for corporate control (the takeover market) and the legal system.

On the aspect of internal mechanism of corporate governance, improving transparency and disclosure practices ultimately leads to better corporate governance, largely because the disclosure practices of a firm can be viewed as effective mechanisms for the protection of the rights of outsiders. Better transparency and disclosure practices can help shareholders to gain a better understanding of firms' management practices, thereby helping to reduce the information asymmetry faced by investors.

The issue of firms' financial transparency and information disclosure has recently gained greater attention, from both market regulators and investors alike, with the ranking institutions, such as Standard & Poor's and Moody's, now using financial transparency and information disclosure as one of the criteria for assessing the management capabilities and reputation of firms; indeed, the results of a Transparency and Disclosure Study (the T&D Study) were published by Standard & Poor's on 16 October 2002.[20] This study provides the T&D rankings of firms under three disclosure categories, according to the T&D practices of each

[20] The T&D study focus on several issues, such as which companies were providing the most extensive disclosure in their basic corporate filings, and which companies had disclosed above and beyond what the law requires. See Patel and Dallas (2002) for a detailed description.

firm, and then calculates a final ranking; these final rankings ultimately provide a reference enabling investors to assess the transparency and disclosure practices of any given firm.

On the aspect of external mechanism of corporate governance, changes in the control of firms virtually always occur at a premium, thereby creating value for the target firm's shareholders. Furthermore, the mere threat of a change in control can provide management with incentives to keep firm value high, so that the value gap is not large enough to warrant an attack from the outside. Thus, there is an important governance mechanism existed in the takeover market.

A few studies have raised concerns about the use of anti-takeover measures. Gomper et al. (2003) examine the relation between 24 different anti-takeover measures and firm performance, and develop a "Governance Index", which adds one point for every provisions that reduces shareholder rights, as a proxy for the level of shareholder rights. Based on this analysis, Bebchuk et al. (2004) put forward an "Entrenchment Index" based on six provisions which consist of four constitutional provisions and two takeover readiness provisions. Following their studies, therefore, we treat the two indexes as measures of anti-takeover protection as well as a proxy for external governance mechanism.

According to these previous studies, the fact that internal and external governance mechanisms are complements is recognized. Relating these governance proxies to the equity market, investors are not only willing to pay a higher price for buying stocks in those companies with better corporate governance but also to trade in them. Conversely, when firms reveal poor corporate governance, liquidity providers (such as market makers or dealers) will take action to protect their prices, broadening the spreads of the affected stocks to compensate for potential losses arising from trading in these equities by informed traders.

Whilst there is an abundance of studies on the effects of corporate governance on equity prices, to the best of our knowledge, few studies have been undertaken on the liquidity costs of poor corporate governance. The purpose of this study is to investigate the simultaneous relationship between corporate governance and equity liquidity, arguing that companies with poor corporate governance will incur both higher agency costs and higher asymmetric information risk. Liquidity providers will broaden the equity spreads of firms exhibiting poor corporate governance, with such price protection action reducing the market liquidity of these equities.

The S&P T&D rankings and the two indexes, which are used in this study as two proxy variables for internal and external corporate governance, are employed to examine whether the firms with better corporate governance exhibit better liquidity on the stock market. There should, theoretically, be a direct correlation between the governance proxy variables and the information asymmetry component, because a lower T&D ranking and a higher governance index (entrenchment index) imply poor corporate governance, which in turn will lead to liquidity providers facing higher asymmetric information risks.

In response, and so as to compensate for this higher risk, liquidity providers must increase the information asymmetry component of the effective spread. We therefore predict that a stronger negative correlation will exist between the firm's governance quality and the information asymmetry component of the effective spread.

Several of the prior works have indicated that simultaneity may exist both in the determination of bid-ask spread and a firm's governance quality (Dye, 1985; Lang and Lundholm, 1993; Welker, 1995). When managers determine a firm's disclosure policy or anti-takeover provisions, they are likely to consider the present market liquidity of the firm's stock; indeed, when liquidity providers quote the bid and ask price of a stock, they will, as a matter of course, refer to the governance quality of a firm as an important measure of the degree of information asymmetry.

This study adopts the three-stage least squares (3SLS) method to obtain more efficient estimates and more robust test results, whilst also employing the generalized method of moments (GMM) estimation method, since this places no restrictions on either the conditional or unconditional variance matrix of the disturbance term. Under the GMM framework, we obtain the asymptotically efficient and consistent estimator without making any additional assumptions, which clearly enables the study to achieve the most robust results.

After controlling for firms' trading characteristics and several determinants of corporate governance measures, the empirical results from the 3SLS and GMM estimations reveal a significant negative (positive) relationship between the T&D rankings (governance index or entrenchment index) and our liquidity measures. These findings are consistent with our hypothesis, that better corporate governance is associated with better equity liquidity.

This study has several contributions to the financial literature and practices. First of all, the study links information asymmetry, the agency problem and corporate governance to equity liquidity, and finds that the empirical results are not only statistically significant, but also consistent with our hypothesis that better corporate governance is accompanied by better equity liquidity. Especially, the study investigates this relationship considering the effects of internal and external governance mechanisms on firms. Secondly, the potential problem of endogeneity within the internal and external governance measures are explored by using 3SLS and GMM estimation methods within the study in order to provide more reliable empirical evidence for our examination of the impact of corporate governance on equity liquidity. Thirdly, it estimates the information asymmetry components of the effective spread as a means of measuring the asymmetric information costs demanded by liquidity providers so as to compensate for possible losses arising from informed trading activities.

We find that the T&D rankings have a significant and negative relationship and the governance index has a positive relationship with the information asymmetry component, implying that poorer corporate governance will lead to lower equity liquidity as a result of the increased asymmetric information costs demanded by liquidity providers, essentially because order processing costs are invariably fixed. Finally, we suggest that investors should be cautious in their use of these rankings and indexes as a means of directly assessing the extent of corporate governance of a given firm.

The remainder of this paper is organized as follows. A review of the related literature and hypothesis development is undertaken in the next section, followed by an introduction to the models adopted for our liquidity measures, the control variables used within our dependent variables, and a description of the data and the research methodology adopted for the study. The penultimate section presents the empirical results of our study, followed, in the final section, by some concluding remarks drawn from this research.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1. Disclosure Practices, Corporate Governance and Information Asymmetry

The relationship between disclosure practices and corporate governance is already well covered within the prior literature. Lowenstein (1996), for example, argues that good disclosure is an extremely efficient and effective mechanism for ensuring that managers perform better; this implies that firms with better information disclosure may achieve better corporate governance. Healy et al. (1999) also suggest that increases in the disclosure ratings are accompanied by increases in firms' stock returns, institutional ownership, analyst following and stock liquidity; their findings reinforce those within the management forecast literature where it is argued that voluntary disclosures are credible.

La Porta et al. (1998) go on to suggest that financial transparency has a crucial role to play in corporate governance through the information which it provides to investors, and whilst noting that there were four major corporate governance attributes, with regard to voluntary disclosure, that were provided by listed firms in the Hong Kong stock market, Ho and Wong (2001) subsequently go on to reveal a number of significant relationships. Mitton (2002) uses disclosure quality as one of the firm-level corporate governance proxy measures as a means of examining whether corporate governance practices could have some impact on stock price performance.

In their report on S&P T&D methodology, and the T&D study itself, Patel and Dallas (2002) argue that good corporate governance must include a vigilant board of directors, adequate and timely disclosure of financial information, meaningful disclosure about the board and its management processes, and a transparent ownership structure identifying any conflicts of interests between managers, directors, shareholders and other related parties. Financial transparency and disclosure are therefore very basic, but very important, elements of corporate governance, which implies that good corporate governance is associated with good disclosure practices.

The extent of a firm's disclosure practices can affect the quality of its corporate governance by reducing the asymmetric information faced by investors. Botosan (1997) finds that the increasing level of disclosure by firms can reduce the information asymmetry between managers and investors, and thus reduce the cost of a firm's equity capital. Lang and Lundholm (1999) indicate that higher levels of disclosure should lead to a lower cost of capital by reducing both the information risk and the transaction costs. Patel and Dallas (2002) also show that both the composite and annual basis T&D rankings have a negative relationship with market risk, whilst Leuz et al. (2003) point out, in particular, that strong and well-enforced outsider rights could limit the acquisition of private control benefits by insiders, and as a consequence, may mitigate the insiders' incentives to manage accounting earnings, largely because there would be little to conceal from other traders.

Since the disclosure practices of firms can be viewed as mechanisms for the effective protection of outsider rights, in terms of helping shareholders to gain a better understanding of the firm's management, they can also prevent managers from using their information advantage to pursue a private benefit of control. Consequently, the agency cost will be reduced in those firms with better financial disclosure practices, and it is within these firms that better corporate governance will be established. Accordingly, we argue that if the S&P

T&D rankings are able to provide an accurate description of the disclosure practices of firms, those firms with higher T&D rankings will have better disclosure practices, accompanied by lower asymmetric information risk and better corporate governance.

2.2. Corporate Governance and Market Liquidity

It is widely accepted that corporate governance is an important factor in financial market development, firm value, the concentration of ownership, and many other different aspects of firm performance.[21] Hauswald and Marquez (2006) provide one of the most recent studies on these specific issues, presenting a theoretical model in which it was argued that by promoting greater transparency, firms' disclosure policies fostered external scrutiny, and thus increased activity in the market for corporate control. There have, nevertheless, been very few studies which have set out with the overall aim of investigating the impact of corporate governance on the equity liquidity of firms.

Within the prior empirical literature, Heflin et al. (2005) investigate the relationship between disclosure policy and market liquidity using Financial Analysts Federation (FAF) reports and effective spreads. Having found that effective spreads and disclosure policy ratings are inversely related, they argue that a policy of enhanced financial disclosure is related to improved market liquidity. Similarly, Brown and Hillegeist (2006) examine the ways in which disclosure quality is related to long-run information asymmetry. Their analyses indicate that disclosure by firms is negatively related to the average level of information asymmetry. Accordingly, the first hypothesis proposed in our study is:

Hypothesis1: *The equities of those firms with better corporate governance will have relatively better market liquidity.*

[21] See: La Porta et al. (1997, 1998, 1999, 2000), Conyon and Peck (1998), Himmelberg et al. (1999), Vafeas (1999), Johnson et al. (2000), Mitton (2002), Gompers et al. (2003), Alves and Mendes (2004), Brown and Caylor (2004), Klapper and Love (2004), Lee and Yeh (2004), Cremers and Nair (2005) and Nelson (2005). A theoretical model of comparative corporate governance is also provided by John and Kedia (2003).

Stoll (1978a, 1978b) models the source of the spreads in the spirit of Demsetz (1968) by analyzing the cross-sectional relationship between a stock's proportional quoted half-spreads and the trading characteristics of the firm, and finds that this relationship has changed little over time, remaining strong. It is subsequently further argued Lin et al. (1995) that demanders of immediacy services rarely received prices which are less favorable than the prevailing quotes on the NYSE. Therefore, the effective spread, which is defined as the absolute value of the difference between the trade price and the quote midpoint just prior to the trade, is viewed as a more precise and better measure of a firm's market liquidity. Following on from these prior works, this study uses both the quoted half-spread and the effective spread as proxies for the market liquidity of firms.

The information asymmetry component is a compensation arising from the asymmetric information risk faced by liquidity providers. Since it is difficult to determine who the informed traders are, the providers of liquidity cannot prevent the losses incurred when they actually trade with an informed trader. Effective spread must therefore include an appropriate information asymmetry component in order to compensate for this risk of loss, thereby enabling liquidity providers to maintain their operations against informed trading activities. We follow the model developed by Lin et al. (1995) to calculate the information asymmetry component of the effective spread, and then use this as a measure of the immediate transaction costs arising from a firm's asymmetric information risk.

Extending the prior research of Welker (1995) and Brockman and Chung (2003), this study uses the S&P T&D rankings and the governance index as proxies for firms' governance quality, arguing that the ranking and the index could be effective measures of the corporate governance and asymmetric information risk perceived by both market makers and dealers. In addition to using the quoted bid-ask spread, we use the effective spread, a more precise measure of a firm's liquidity, along with the adverse information component of the effective spread, to examine the relationship between the disclosure practices of firms and their market liquidity levels.

If the S&P T&D rankings and the governance index (entrenchment index) are indeed good proxies for firms' governance quality, we expect that those firms with a higher T&D ranking or a lower governance index (entrenchment index) will have smaller effective spreads and information asymmetry components, implying that some association does exist between good market liquidity and good corporate governance.

2.3. Internal Corporate Governance Proxy Variable

This study uses the Transparency and Disclosure (T&D) rankings, provided by the S&P Transparency and Disclosure study, as a proxy for the disclosure practices of firms. Patel and Dallas (2002) identify 98 disclosure items, classified into three broad categories:

(i) Ownership structure and investor rights;

(ii) Financial transparency and information disclosure; and

(iii) Board and management structure and process.

Their study indicates whether these individual items are disclosed, focusing primarily on annual reports as the primary source of information disclosure. They also consider other forms of regulatory filings as an additional source of corporate disclosure. Their study therefore evaluates firms' disclosure patterns, based initially upon annual reports alone (annual basis), and secondly on annual reports, 10-Ks and other proxy statements (composite basis). Each ranking within the three categories is evaluated on both bases, from which the final rankings are then calculated.

A number of recent studies have provided compelling evidence to show that a firm's T&D ranking could be a good proxy for corporate governance. In her examination of the relationship between corporate governance, transparency and financial disclosure, Mallin (2002) notes that surveys of investor opinions place significant emphasis on the importance of transparency and disclosure in a good corporate governance system. She therefore argues that transparency and disclosure are key attributes of any model of good corporate governance.

Cheng et al. (2003) use the T&D rankings as proxies for corporate governance in their investigation of the effects of both the level of the rankings, and the differential rankings between composite and annual report rankings on three market metrics, market beta, risk-adjusted abnormal returns and earnings response coefficients surrounding the announcement date.[22] The results reveal that the release of the S&P T&D rankings bring new information to the market, with the rankings affecting shareholder wealth in a manner consistent with the rankings measuring the strength of corporate governance.

In their investigation of the relationship between corporate governance and valuation using Credit Lyonnais Securities Asia (CLSA) and S&P score data, Durnev and Kim (2005) find a significant correlation between the CLSA composite index and the S&P aggregate score. Their findings indicate that those companies which score high on corporate governance under the CLSA scoring system also score high on disclosure under the S&P scoring system. They also demonstrate a positive correlation between the S&P T&D rankings and the strength of corporate governance in emerging countries.

In this study, we also regard the S&P T&D rankings as a good proxy for internal corporate governance, and use the annual basis T&D final ranking (AFR) and the composite basis T&D final ranking (CFR) to examine whether firms with higher S&P T&D rankings have better equity liquidity.

2.4. External Corporate Governance Proxy Variable

If the fact that it is difficult or costly to replace managers is true, then the managers may be more willing and able to extract private benefits. Denis and McConnell (2003) mention that

[22] Patel and Dallas (2002) argue that whilst transparency and disclosure are key components of corporate governance, T&D rankings are not proxies for corporate governance; nevertheless, they still find that the rankings reveal some interesting relationships between transparency and disclosure and a firm's market risk, capitalization and price to book ratio.

when internal control mechanism fail to a large enough degree, i.e., when the gap between the actual value of a firm and its potential value is sufficiently large, there is incentive for outside parties to seek control of the firm. Therefore, takeovers and takeover threats are the source of external governance considered in a few studies which have raised concerns about the use of anti-takeover measures (Daines and Klausner, 2001; Field and Karpoff 2002; Bebchuk and Cohen, 2005; Bebchuk et al., 2003; Gomper et al., 2003). The Investor Responsibility Research Center (IRRC) tracks 22 charter provisions, bylaw provisions, and other firm-level rules plus coverage under six state takeover laws; duplication between firm-level provisions and state laws yields 24 unique provisions. Gomper et al. (2003) examine the relation between those 24 different anti-takeover measures and firm performance. They develop a "Governance Index" to proxy for the level of shareholder rights. Using this measure, they find that firms with few anti-takeover protections have higher firm value, higher sales growth, lower capital expenditures, and made fewer corporate acquisitions.

The governance index is constructed from 24 provisions. According to the study of Gomper et al. (2003), these provisions are divided into five groups:

(i) Delay: tactics for delaying hostile bidders

(ii) Voting: voting rights

(iii) Protection: director/officer protection

(iv) Other: other takeover defenses

(v) State: state laws

The governance index is just the sum of one point for the existence (or absence) of each provision. Therefore, the governance index has a possible range from 0 to 24 and is not just the sum of the five subindices.

Among the set of 24 provisions developed by Gomper et al. (2003), Bebchuk et al. (2004)

argue that some provisions within the 24 IRRC provisions might have little relevance, and some provisions might be even positively correlated with shareholder value. In addition, some provisions that are negatively correlated with firm value or stock returns, some might be more so than others. Furthermore, some provisions might be at least in part the endogenous product of the allocation of power between shareholders and managers set by other provisions. Therefore, they identify six provisions to develop an "Entrenchment Index" in order to simplify the negative relationship between the governance index and the firm value. The entrenching provisions belong to two categories: the first group included four constitutional provisions that prevent a majority of shareholders from having their way (staggered boards, limits to shareholder bylaw amendments, supermajority requirements for mergers, and supermajority requirements for charter amendments), and the second group included two takeover readiness provisions that boards put in place to be ready for a hostile takeover (poison pills and golden parachutes). The six provisions are as follows:

(i) Staggered Boards

(ii) Limits to Amend By-Laws

(iii) Supermajority Requirements for Mergers

(iv) Supermajority Requirements for Charter Amendments

(v) Poison Pills

(vi) Golden Parachutes

Using the entrenchment index by constructing from the six entrenching provisions, they find that the index fully drive the findings documented by prior research that the IRRC provisions in the aggregate are correlated with Tobin's Q as well as returns during the 1990s.

Within the anti-takeover measures, staggered board is viewed by legal scholars as a particularly potent anti-takeover defense. Bebchuk and Cohen (2005) argue that the most effective mechanism of anti-takeover provisions is staggered board. They investigate how the value of publicly traded firm is affected by arrangements that protect management from removal, staggered boards. Their evidence suggests that staggered boards bring about a reduced firm value, and helps to explain what drivers the negative correlation between firm value and a board index based on the 24 IRRC provisions.

Extensions of Gomper et al. (2003) were developed by a few studies. Cremers and Nair (2005) find that external and internal governance mechanisms are strong complements being associated with long-term abnormal returns and accounting measures of profitability through to investigate the interaction caused by market between corporate control (external governance) and shareholder activism (internal governance). In addition, they argue that the importance of internal governance crucially depends on the extent of external governance. Core et al. (2006) extend the study of Gomper et al. (2003) to investigate the question why public information about governance does not appear to be impounded in stock price in a timely manner. Their evidence points away from the hypothesis that differences in shareholder rights cause higher returns, and suggests that time-period-specific returns and/or differences in expected returns likely play a role in explaining the documented abnormal stock returns of strong governance firms. In other words, their research results do not support the hypothesis that weak governance causes poor stock returns.

Some studies extend the study of Gomper et al. (2003) to other issues in finance. Ferreira and Laux (2007) study the relationship of corporate governance policy and idiosyncratic risk. They argue that firms with fewer anti-takeover provisions display higher levels of idiosyncratic risk, trading activity, private information flow, and information about future earnings in stock prices. Their results are consistent with an information-flow interpretation, that the component of volatility unrelated to governance is associated with the efficiency of corporate investment. Masulis et al. (2007) examine whether the market for corporate control affects the probability of firm acquisitions. Their results support the hypothesis that managers at firms protected by more anti-takeover provisions are less subject to the disciplinary power of the market for corporate control and thus are more likely to indulge in empire-building acquisitions that destroy shareholder value.

Accordingly, we use the governance index developed by Gomper et al. (2003) and the entrenchment index constructed by Bebchuk et al. (2004) as proxies for external corporate governance measure to examine whether firms with lower score in these two indexes have better equity liquidity. We argue that if the two indexes are able to provide an accurate description of the shareholder rights of firms, those firms with lower score in these two indexes will have strong shareholder rights, accompanied by lower asymmetric information risk and better corporate governance.

2.5. The Simultaneity of Equity Liquidity and Corporate Governance

Several of the prior studies, both theoretical and empirical, have indicated that simultaneity may exist in the determination of bid-ask spread and a firm's disclosure policy. Dye (1985), for example, designs a theoretical model in which the information asymmetry between managers and investors could influence firms' disclosure policies, whilst Lang and Lundholm (1993) analyze the determinants of voluntary disclosure policy, arguing that there is simultaneity in the determination of both bid-ask spread and disclosure practices.

Welker (1995) suggests that disclosure policy choice could be influenced by the level of information asymmetry between management and uninformed investors, as well as other determinants of bid-ask spreads. Heflin et al. (2005) test for a simultaneous relationship between disclosure policy and effective spreads using a two-stage least squares (2SLS) instrumental variable procedure, and find that relative effective spreads were inversely related to disclosure policy ratings.

Durnev and Kim (2005) investigate the relationship between valuation (Tobin's Q) and S&P transparency rankings, also using a three-stage least squares (3SLS) method, because of the problem of endogeneity in the regression analysis. By controlling for the simultaneity between governance and valuation, they conclude that better governance within firms would lead to higher valuation, whilst Brown and Hillegeist (2006) go on to use a three-stage least squares instrumental variable estimation procedure to examine the simultaneous relationship between disclosure quality and information asymmetry. Following these works, we develop our second hypothesis, as follows:

Hypothesis 2: *The determination of equity liquidity and firms' governance quality will be simultaneous.*

If simultaneity does indeed exist, employing the ordinary least squares (OLS) estimation procedure will generate inconsistent estimates, rendering the inferences invalid. Accordingly, we utilize the determinants of the corporate governance and equity liquidity, as instrumental variables, to construct a system of simultaneous equations, and employ the 3SLS method to estimate and test the coefficients within these equations.

We also use a more robust estimation method, the general method of moments (GMM), to estimate and test the simultaneous equations. If the coefficient of our liquidity measure does not demonstrate any strong explanatory capability with regard to the corporate governance measures, we can argue that no simultaneity exists in the determination of the equity liquidity and corporate governance.

3. DATA AND RESEARCH METHODOLOGY

3.1. The Data

Since the Patel and Dallas (2002) report on the S&P T&D study provided only the T&D rankings for the constituent firms in the S&P 500 index, these are necessarily the companies that make up the sample for this study. We use the annual basis T&D final ranking (AFR) and the composite basis T&D final ranking (CFR) as proxies for a firm's internal corporate governance. Since the S&P T&D study report was published on 16 October 2002, we take the whole trading days for 2002 as our study period. For the firms' external governance measure, in addition, we use the governance index and the entrenchment index as proxies for our sample firms.[23]

A number of empirical studies, including Huang and Stoll (1996) and Barclay et al. (1999), have compared dealer and auction markets, such as the NASDAQ and the NYSE. Based upon these (and other) studies, Stoll (2000) notes that market design appears to have some effect on spread. In particular, spreads in the dealer markets were wider than those in the auction markets, largely because dealers within the dealer markets may have more market power; the main reason for this is the expectation that dealers, or market makers, with stronger market power will increase their revenue by widening the spreads.

In order to eliminate this distinction between the constituent stocks on the S&P 500 index, we choose only those stocks listed on the NYSE. Under such a condition, our sample size becomes 424 stocks. For the same reason, the intraday data used to estimate and calculate our liquidity measures are based upon those transactions and quotes taking place in the NYSE only.

The daily intraday transaction and quote data for these 424 stocks are obtained from the Trade and Quote (TAQ) database, along with the daily number of trades, daily dollar volume and closing prices of each stock. In addition, each stock's daily returns (without dividends) are taken from the CRSP database in order to calculate the standard deviation on the returns for the previous year. Finally, the accounting data used to calculate the other selected variables in this study are all obtained from the Compustat database. After calculating the values of all of the selected variables, we then delete those firms for which any of the

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[23] The governance index and entrenchment index data are obtained from website: finance.wharton.upenn.edu/%7Emetrick/data.htm and www.law.harvard.edu/faculty/bebchuk/, respectively.

variables have missing values, thereby further reducing our sample size to 244.

3.2. Measures of Liquidity and the Information Asymmetry Component

In addition to the measures of equity liquidity, such as the effective spread (ESP) and the information asymmetry cost (INF), we consider the effective spread, which is defined as the absolute value of the one-half signed effective spread:

$$ESP_{i,t} = |z_{i,t}| = |P_{i,t} - Q_{i,t}| \tag{14}$$

where $P_{i,t}$ is the trade price for the trade in firm *i*, at time *t*, and $Q_{i,t}$ is the prevailing quote midpoint for the transaction in firm *i*, at time *t*. Our model of the information asymmetry component of spread is based on Lin et al. (1995):

$$Q_{i,t+1} - Q_{i,t} = \lambda_{i,t} z_{i,t} + \varepsilon_{i,t+1} \tag{15}$$

$$z_{i,t+1} = \theta_{i,t} z_{i,t} + \eta_{i,t+1} \tag{16}$$

where $Q_{i,t}$ is the prevailing quote midpoint for the transaction in firm *i*, at time *t*, and $z_{i,t}$ is the one-half signed effective spread, defined as the transaction price minus the prevailing quote midpoint, with $z_{i,t} < 0$ for a sell order, and $z_{i,t} > 0$ for a buy order. Van Ness et al. (2001) indicate that the idea of this model is that both bid and ask quotes at time $t+1$ would have quote revisions of λz to reflect any potential adverse information revealed by the trade at time *t*. Since λ reflects the quote revision in response to a trade as a fraction of the effective spread, it can be viewed as the information asymmetry component of the effective spread.

In addition to quote data, we also need intraday transaction data in order to effectively estimate the model for the effective spread and information asymmetry component. Following the procedure of Lin et al. (1995), the transaction time and trade price are identified for each transaction, along with the prevailing bid and ask prices.

After obtaining the transaction data with prevailing quotes, we estimate Equation (15) under the OLS method so as to obtain the daily estimate of the information asymmetry component, $\hat{\lambda}$, for each equity in our sample, using all transaction data with prevailing quotes during each day, and then calculating the annual average information asymmetry component for each firm.[24]

In order to obtain the real cost of the asymmetric information risk induced by informed trading, we multiply each stock's annual average information asymmetry component by the annual average of its effective spread, with our measure of the asymmetric information cost of the effective spread being defined as:

$$INF_{i,t} = \hat{\lambda}_i \times ESP_{i,t} \tag{17}$$

The effective spreads and the relative effective spreads are calculated from the transaction data with prevailing quotes. For each security in our sample, the dollar effective spread and the relative effective spread are first computed for each transaction during the normal daily transaction time, followed by calculation of the daily averages for each trading day during our study period. Finally, the annual averages are then calculated, using these daily averages.

3.3. The Determinants of Equity Liquidity and Corporate Governance

In order to construct a system of simultaneous equations for our liquidity measure, as well as the corporate governance measures for the 3SLS and GMM estimations, we need to specify the liquidity measure, the T&D final rankings and the two indexes models.

3.3.1 The Determinants of the Liquidity Measure

It has been suggested in many of the prior cross-sectional studies on spreads (for example,

[24] Following Lin et al. (1995) and Van Ness et al. (2001), the logarithms of the transaction price and the quote midpoint are used to yield a continuously compounded rate of return for the dependent variable, and a relative spread for the independent variable. This transformation can generate estimates of the information asymmetry components as a percentage of the effective spread, and thereby reduce the problem of price discreteness.

Welker, 1995; Lin et al., 1995; Stoll, 2000; Van Ness et al., 2001; Brockman and Chung, 2003; Agrawal et al., 2004; and others) that any empirical analyses should control for a number of spread determinants, other than disclosure policy, with the closing price, daily dollar volume, return volatility, number of trades per day and market value being the most common determinants of spread adopted in these studies.

Stoll (2000), in particular, models the source of the spread, and finds that the closing price, daily dollar volume, return volatility, number of trades per day and market value are all significantly related to the proportional quoted half-spread. Stoll (2000) finds that these variables could explain over 65 per cent of the cross-sectional variance in the proportional quoted half-spread. Therefore, along with the T&D ranking, we follow Stoll (2000) to use the closing price of the stock (CLP), daily dollar volume (DOLVOL), return standard deviation (RETSTD), number of trades (N) and market value (MKV) as our preliminary candidates for control variables in the liquidity measures (i.e., the effective spread and the information asymmetry component).

In accordance with the empirical evidence provided by Stoll (2000), as well as the other aforementioned studies, we predict that any increase in the dollar volume, the number of trades and the market value will lead to an increase in equity liquidity and a lowering of the spread. The return volatility of a stock reflects the risk of any price change in that stock; thus, we predict that higher return volatility will be associated with a higher spread.

The definitions of the control variables in the liquidity measures are described as follows:

CLP_i = the closing price average of all trading days for firm *i* during the study period.

$DOLVOL_i$ = the daily dollar volume average of all trading days for firm *i* during the study period.

$RETSTD_i$ = the standard deviation of the daily returns of stocks in firm *i* during the previous year.

N_i = the average daily number of trades in firm *i* during the study period.

MKV_i = the average monthly market value of firm *i* during the study period.

Furthermore, price acts as a control for the effect of discreteness, and is an additional proxy for risk, insofar as low price stocks tend to be riskier (Stoll, 2000). We therefore predict that price will be positively related to the effective spread and the information asymmetry component.

3.3.2 The Determinants of Disclosure Practice

The determinants of disclosure practice used in this study relate mainly to those of Lang and Lundholm (1993), Welker (1995) and Ho and Wong (2001). Lang and Lundholm (1993) find that both market-adjusted return and firm size are positively correlated to disclosure policy, which in turn, has a negative association with return standard deviation and the return-earnings correlation.

Following on from these findings, Welker (1995) uses share price, security offering, market-adjusted return and the return standard deviation as the determinants of disclosure practice. Ho and Wong (2001) subsequently go on to test a theoretical framework relating four major corporate governance attributes to the extent of voluntary disclosure provided by firms listed on the Hong Kong stock market. Ho and Wong follow several of the prior works which have focused on investigations into voluntary disclosure decisions, using firm size (Chow and Won-Boren, 1987), assets-in-place (Hossain et al., 1994), financial leverage (Bradbury, 1992) and profitability and industry type (Meek et al. 1995) as the control variables in their empirical models.

Thus, following on from these studies, our preliminary candidates for control variables in the disclosure practices of firms are: firm size (SIZE), return standard deviation (RETSTD), closing price (CLP), assets-in-place (AIP), financial leverage (LEV), profitability (PROFIT) and a dummy variable for industry type. The empirical findings of the aforementioned studies suggest that firm size, price, assets-in-place and profitability are positively related to the disclosure practices of firms, and that return volatility has a negative correlation with the quality of the firms' disclosure. The control variables for disclosure practices which have not yet been defined are as follows:

$SIZE_i$	=	the total assets of firm *i* at the end of 2002.
AIP_i	=	the ratio of the net book value of fixed assets to total assets for firm *i* at the end of 2002.
LEV_i	=	the ratio of total debt to total equity for firm *i* at the end of 2002.
$PROFIT_i$	=	the return on capital employed at the end of 2002.
$D1_i$	=	1, when the firm's S&P Industry Index Code is between 700 and 719 (the Financials group), otherwise 0.
$D2_i$	=	1, when the firm's S&P Industry Index Code is between 900 and 921 (Information Technology group), otherwise 0.

3.3.3 The Determinants of Governance Index and Entrenchment Index

The determinants of governance index used in this study relate mainly to Gomper et al. (2003). Their results indicate that capital expenditures and corporate acquisitions are positively correlated to the governance index, which in turn, has a negative association with returns, firm value, profits and sales growth. Since the calculation of the entrenchment index is based on six provisions which are selected from a set of twenty-four provisions followed by the IRRC, the determinants of entrenchment index are similar with the governance index.

Following on from the previous studies, our preliminary candidates for control variables in the governance index and the entrenchment index of firms are: return on assets (ROA), capital expenditure scaled by sales (CE), book-to-market ratio (BM), financial leverage (LEV), external financial needs (EFN), past three-year sales growth (SG3) and a dummy variable for industry type. The empirical findings of the previous studies suggest that return on assets, book-to-market ratio and sales growth are negatively related to the governance index and entrenchment index of firms, and that capital expenditure and external financial needs may have a positive correlation with the two indexes. For the relationship between financial leverage and the two indexes, Chiyachantana et al. (2005) point out that the association between leverage and governance quality is not linear but parabolic and convex. In other words, they show that leverage is negatively related to governance quality up to a certain point and the relationship reverses and becomes positive as governance quality improves further. Since our sample firms are selected from the constituent firms in the S&P 500 index, we conjecture that financial leverage is negatively related to the two indexes. The control variables for the governance index and the entrenchment index which have not yet been defined are as follows:

ROA_i = the ratio of the net income to total assets for firm *i* at the end of 2002.

CE_i = the ratio of capital expenditure to sales for firm *i* at the end of 2002.

BM_i = the ratio of book value to market value for firm *i* at the end of 2002.

EFN_i = the past two-year geometric average growth rate in total assets minus the past two-year average sustainable growth rate for firm *i* at the end of 2002

$SG3_i$ = the past three-year sales growth for firm *i* at the end of 2002.

3.4. Simultaneous Equation Model

We first calculate the variance inflation factors (VIFs) for the control variables of the liquidity measures and those of the disclosure practices of firms. The VIFs measure the extent to which multicolinearity exists in the selected explanatory variables; any explanatory variables with higher VIFs will have a more serious multicolinearity problem and a greater likelihood of affecting the estimation regression results. Following calculation of the VIFs, we find that those of daily dollar volume (DOLVOL), market value (MKV) and daily number of trades (N) are greater than those of the other control variables.

By omitting any two of the variables, the VIFs of all the independent variables of the liquidity measures will be lower than 2, thereby indicating that the multicolinearity problem is solved. Since the OLS coefficient estimates of both market value and daily number of trades are less significant than those of daily dollar volume, and since the latter is used much more frequently in the microstructure literature than market value and daily number of trades, we omit these two variables, whilst retaining the daily dollar volume within the equity liquidity equation.

Thus, the control variables of our liquidity measure are now the closing price (CLP), daily dollar volume (DOLVOL), and the previous year's return standard deviation (RETSTD). The VIFs of the predetermined control variables of the internal and external governance measures of firms are all less than 2, which indicate that no serious multicolinearity problem exists in the selected control variables.

The second step is to filter out any inadequate instrumental variables for the 3SLS and GMM instrumental variable estimations. Wooldridge (2002) indicates that a key condition for instrumental variable estimation is that once all the other exogenous variables in all equations have been netted out, the selected additional instruments for an endogenous variable must have some partial correlation.[25]

The results of the first-stage regression on all of the liquidity measures reveal that the three control variables, CLP, DOLVOL and RETSTD, have a partially strong correlation with our liquidity measures. For the S&P T&D final rankings, the results of the first-stage regressions reveal that only RETSTD and AIP are partially correlated with the composite basis final rankings, and that SIZE, RETSTD and AIP are partially correlated with the annual basis final rankings. For the external governance measures, the results of the first-stage regressions exhibit that LEV, D1, D2 and SG3 are partially correlated with the governance index, and that LEV, D1 and D2 are partially correlated with the entrenchment index. Therefore, after excluding any inadequate instrumental variables from the equations, our simultaneous equation systems can be constructed as follows:

$$\begin{aligned}
&\text{Liquidity}_i = \alpha_{10} + \alpha_{11}\text{AFR}_i + \alpha_{12}\text{GI}_i + \alpha_{13}\text{lnDOLVOL}_i + \alpha_{14}\text{CLP}_i + \alpha_{15}\text{RETSTD}_i + \varepsilon_{1,i} \\
&\text{AFR}_i = \alpha_{20} + \alpha_{21}\text{Liquidity}_i + \alpha_{22}\text{GI}_i + \alpha_{23}\text{lnSIZE}_i + \alpha_{24}\text{RETSTD}_i + \alpha_{25}\text{AIP}_i + \varepsilon_{2,i} \\
&\text{GI}_i = \alpha_{30} + \alpha_{31}\text{Liquidity}_i + \alpha_{32}\text{AFR}_i + \alpha_{33}\text{LEV}_i + \alpha_{34}\text{D1}_i + \alpha_{35}\text{D2}_i + \alpha_{36}\text{SG3}_i + \varepsilon_{3,i}
\end{aligned} \tag{18}$$

$$\begin{aligned}
&\text{Liquidity}_i = \alpha_{10} + \alpha_{11}\text{AFR}_i + \alpha_{12}\text{EI}_i + \alpha_{13}\text{lnDOLVOL}_i + \alpha_{14}\text{CLP}_i + \alpha_{15}\text{RETSTD}_i + \varepsilon_{1,i} \\
&\text{AFR}_i = \alpha_{20} + \alpha_{21}\text{Liquidity}_i + \alpha_{22}\text{EI}_i + \alpha_{23}\text{lnSIZE}_i + \alpha_{24}\text{RETSTD}_i + \alpha_{25}\text{AIP}_i + \varepsilon_{2,i} \\
&\text{EI}_i = \alpha_{30} + \alpha_{31}\text{Liquidity}_i + \alpha_{32}\text{AFR}_i + \alpha_{33}\text{LEV}_i + \alpha_{34}\text{D1}_i + \alpha_{35}\text{SG3}_i + \varepsilon_{3,i}
\end{aligned} \tag{19}$$

$$\begin{aligned}
&\text{Liquidity}_i = \alpha_{10} + \alpha_{11}\text{CFR}_i + \alpha_{12}\text{GI}_i + \alpha_{13}\text{lnDOLVOL}_i + \alpha_{14}\text{CLP}_i + \alpha_{15}\text{RETSTD}_i + \varepsilon_{1,i} \\
&\text{CFR}_i = \alpha_{20} + \alpha_{21}\text{Liquidity}_i + \alpha_{22}\text{GI}_i + \alpha_{23}\text{RETSTD}_i + \alpha_{24}\text{AIP}_i + \varepsilon_{2,i} \\
&\text{GI}_i = \alpha_{30} + \alpha_{31}\text{Liquidity}_i + \alpha_{32}\text{CFR}_i + \alpha_{33}\text{LEV}_i + \alpha_{34}\text{D1}_i + \alpha_{35}\text{D2}_i + \alpha_{36}\text{SG3}_i + \varepsilon_{3,i}
\end{aligned} \tag{20}$$

$$\begin{aligned}
&\text{Liquidity}_i = \alpha_{10} + \alpha_{11}\text{CFR}_i + \alpha_{12}\text{EI}_i + \alpha_{13}\text{lnDOLVOL}_i + \alpha_{14}\text{CLP}_i + \alpha_{15}\text{RETSTD}_i + \varepsilon_{1,i} \\
&\text{CFR}_i = \alpha_{20} + \alpha_{21}\text{Liquidity}_i + \alpha_{22}\text{EI}_i + \alpha_{23}\text{RETSTD}_i + \alpha_{24}\text{AIP}_i + \varepsilon_{2,i} \\
&\text{EI}_i = \alpha_{30} + \alpha_{31}\text{Liquidity}_i + \alpha_{32}\text{CFR}_i + \alpha_{33}\text{LEV}_i + \alpha_{34}\text{D1}_i + \alpha_{35}\text{SG3}_i + \varepsilon_{3,i}
\end{aligned} \tag{21}$$

where lnDOLVOL_i and lnSIZE_i are the logarithms of DOLVOL_i and SIZE_i; Liquidity_i represents the liquidity measure, and can be replaced by any of our liquidity measures, the effective spread

[25] See Wooldridge (2002), Chapters 5 and 6.

(ESP) or the information asymmetry component (INF).[26]

4. EMPIRICAL RESULTS AND ANALYSIS

4.1. Summary Statistics and Correlations

Table 8 presents the descriptive statistics of all variables in our simultaneous equation systems. Our sample period runs from 1 January to 31 December 2002, giving a total of 252 trading days. Panel A of Table 8 displays the descriptive statistics of the liquidity measures and their control variables. The mean of effective spread (ESP) is 1.6267 cents, ranging between 0.6652 cents and 3.6086 cents; the INF of the effective spread has an average value of 0.6610 cents, ranging between 0.2172 cents and 1.3402 cents;[27] the CLP for our sample is approximately US$38.30, with a range between US$4.56 and US$121.73; DOLVOL has a mean of US$69.22 millions, with a sample range between US$4.41 millions to US$610.34 millions; and RETSTD has an average value of about 2.6406%, with the sample ranging between 1.3931% and 7.6836%.

[26] The values of ESP_i and INF_i are so small that the estimated coefficients of the control variables of these liquidity measures are also very small; we therefore multiply the measures by 100, and in consequence, 'cents' becomes the unit of measurement.

[27] Lin et al. (1995) argue that demanders of immediacy services rarely receive prices which are less favorable than the prevailing quotes on the NYSE.

Table 8 Descriptive statistics of all variables

The sample comprises of a total of 244 S&P 500 index constituent stocks listed on the NYSE between 1 January and 31 December 2002. ESP = the effective spread; INF = the dollar value of the information asymmetry component of the effective spread; CLP = the closing price; DOLVOL = the daily dollar volume; RETSTD = the return standard deviation in the previous year; AFR = the annual basis S&P T&D final ranking; CFR = the composite basis S&P T&D final ranking; SIZE = the firm's total asset at the end of 2002; AIP = the assets-in-place defined as the book value of fix asset divided by total asset; GI = the governance index; EI = the entrenchment index; LEV = the financial leverage defined as the total debt divided by total equity; D1 = the dummy variable for the Financials group; D2 = the dummy variable for Information Technology group; and SG3 = the past three-year sales growth.

Variables	Mean	Std. Dev.	Minimum	Maximum
Panel A: The liquidity measures and their control variables				
ESP (cents)	1.6267	0.4601	0.6652	3.6086
INF (cent)	0.6610	0.2143	0.2172	1.3402
CLP	38.2961	18.9560	4.5627	121.7333
DOLVOL (millions)	69.2203	85.2788	4.4059	610.3353
RETSTD (%)	2.6406	0.9383	1.3931	7.6836
Panel B: The internal governance measures and their control variables				
AFR	4.8320	0.9731	1	8
CFR	7.5697	0.5204	7	9
SIZE (millions)	42,989	116,237	669	887,515
AIP (%)	30.0785	23.2007	0.0000	93.2126
Panel C: The external governance measures and their control variables				
GI	9.8443	2.5126	3	16
EI	2.3934	1.3398	0	5
LEV	2.2464	5.3375	0.0000	52.2460
D1	0.0984	0.2984	0	1
D2	0.1844	0.3886	0	1
SG3 (%)	22.0351	39.6143	-102.8659	177.0896

The descriptive statistics of the S&P T&D final rankings, and their control variables, are presented in Panel B of Table 8. The mean of the annual basis T&D final rankings (AFR) is 4.8320, with a range between 1 and 8, whilst the mean of the composite basis T&D final ranking (CFR) is 7.5698, with a range between 1 and 8. Taking note of the difference between these two rankings, AFR has a lower mean but greater range, whilst CFR has a higher mean but smaller range. This characteristic is consistent with the argument of Patel and Dallas (2002), who suggest that the annual basis rankings, which focus only on a firm's annual reports, could be regarded as the extent of a firm's voluntary disclosure; conversely, the composite basis ranking, which includes annual reports, 10-Ks and other proxy statements, may be regarded as regulatory disclosure practices. Thus, as a result of the strict laws on investor protection in the US, as well as the stringent disclosure regulations, the firms reveal consistently higher rankings on a composite basis, along with smaller differences between the firms' composite basis rankings, than in their annual basis rankings.

Panel C of Table 8 displays the descriptive statistics of the external governance measures and their control variables. The mean of the governance index (GI) is 9.8443, ranging between 3 and 16, whilst the mean of the entrenchment index (EI) is 2.3934, ranging between 0 and 5. Bebchuk et al. (2004) argue that some provisions within 24 IRRC provisions might have some problems on the negative relationship with shareholder value. Therefore, they identify six provisions to develop the entrenchment index in order to simplify the negative relationship between the governance index and the firm value.

The Pearson correlation coefficients of all variables are presented in Table 9. One issue which immediately draws our attention is the fact that INF and ESP have a strong positive correlation, implying that the higher asymmetric information costs induce higher equity spread, given that order processing costs are largely fixed.

Table 9 Pearson correlation coefficients of all variables

The sample comprises of a total of 244 S&P 500 index constituent stocks listed on the NYSE between 1 January and 31 December 2002. Figures in parentheses are *p*-values. ESP = the effective spread; INF = the dollar value of the information asymmetry component of the effective spread; CLP = the closing price; DOLVOL = the daily dollar volume; RETSTD = the return standard deviation in the previous year; AFR = the annual basis S&P T&D final ranking; CFR = the composite basis S&P T&D final ranking; SIZE = the firm's total asset at the end of 2002; AIP = the assets-in-place defined as the book value of fix asset divided by total asset; GI = the governance index; EI = the entrenchment index; LEV = the financial leverage defined as the total debt divided by total equity; and SG3 = the past three-year sales growth.

Variables	ESP	INF	CLP	DOLVOL	RETSTD	AFR	CFR	SIZE	AIP	GI	EI	LEV	SG3
ESP	1												
INF	0.9379	1											
	(<.0001)												
CLP	0.8743	0.788	1										
	(<.0001)	(<.0001)											
DOLVOL	0.1435	-0.0903	0.3586	1									
	(0.0250)	(0.1599)	(<.0001)										
RETSTD	-0.3345	-0.383	-0.4781	-0.0445	1								
	(<.0001)	(<.0001)	(<.0001)	(0.4893)									
AFR	0.0047	0.0188	0.0225	0.0115	-0.1544	1							
	(0.9421)	(0.7707)	(0.7262)	(0.8584)	(0.0158)								
CFR	-0.0797	-0.041	-0.0379	-0.0796	-0.0956	0.3117	1						
	(0.2147)	(0.5242)	(0.5562)	(0.2156)	(0.1364)	(<.0001)							
SIZE	0.0117	-0.1101	0.1886	0.5738	-0.0821	0.0579	0.0539	1					
	(0.8555)	(0.0861)	(0.0031)	(<.0001)	(0.2010)	(0.3675)	(0.4023)						
AIP	-0.2061	-0.196	-0.1867	-0.1263	0.0786	0.1079	0.1634	-0.2705	1				
	(0.0012)	(0.0021)	(0.0034)	(0.0487)	(0.221)	(0.0926)	(0.0106)	(<.0001)					
GI	-0.0413	-0.0295	-0.0967	-0.1483	0.0357	0.0179	-0.0672	-0.0894	0.0258	1			
	(0.5212)	(0.6466)	(0.1321)	(0.0205)	(0.5793)	(0.7813)	(0.2958)	(0.1639)	(0.6886)				
EI	-0.0226	0.015	-0.0811	-0.1478	0.0437	-0.0059	-0.0277	-0.1614	0.0353	0.7004	1		
	(0.7253)	(0.8158)	(0.2071)	(0.0209)	(0.4970)	(0.9270)	(0.6671)	(0.0116)	(0.5835)	(<.0001)			
LEV	0.0393	-0.0016	0.1468	0.1914	-0.0416	0.0452	0.1109	0.6251	-0.1641	-0.1058	-0.1717	1	
	(0.5410)	(0.9807)	(0.0218)	(0.0027)	(0.5181)	(0.4820)	(0.0840)	(<.0001)	(0.0102)	(0.0991)	(0.0072)		
SG3	0.0329	0.0483	0.0278	-0.0621	-0.0381	-0.1254	-0.0999	-0.0383	0.0285	-0.0648	-0.0416	-0.0049	1
	(0.6094)	(0.4527)	(0.6658)	(0.3339)	(0.5536)	(0.0503)	(0.1195)	(0.5514)	(0.6574)	(0.3134)	(0.5178)	(0.9390)	

Table 9 also presents the Pearson correlation coefficients of the S&P T&D final rankings, and their control variables. SIZE and AIP reveal positive correlations to the T&D final rankings, although the positive correlation between SIZE and these two rankings is insignificant. RETSTD has a significantly negative correlation with the annual basis T&D final ranking, but has an insignificantly negative correlation with the composite basis T&D ranking. This finding is consistent with the results of the first-stage regression. For the Pearson correlation coefficients of the governance index and their control variables, LEV and SG3 reveal negative correlations to GI and EI, but only the negative correlation between LEV and these two indexes is significant.

4.2. OLS, 3SLS and GMM Estimation Results

This section presents the results of the effective spread and the internal and external corporate governance measures, beginning with an examination of the relationships between the effective spread, the internal and external governance measures by applying the 3SLS and GMM estimation methods. The estimation results of ESP and the internal and external corporate governance measures are reported in Tables 10 to Table 13.

The internal (AFR and CFR) and external (GI and EI) governance measures reveal significant negative and positive relationships respectively with the effective spread under the 3SLS and GMM estimations of the first equation, with the results once again supporting our hypothesis that the stocks of firms with better corporate governance have relatively lower effective spreads. This finding is consistent with the results of Heflin et al. (2005), who investigate the relationship between the FAF scores and the effective spreads.

We also find that the relationships between ESP and our corporate governance measures are not statistically significant in the first equation under the OLS estimation. Moreover, the simultaneous estimation of the second equation shows that ESP has significant relationships with the composite basis S&P T&D final rankings, indicating that there is probability of simultaneity existing in the determination of ESP and CFR. However, this result is not presented in the relationship between ESP and the external governance measures in the third equation, implying that there is little probability of any simultaneity existing in the determination of ESP and external governance measures. Our results do not exhibit the simultaneity existing in the determination of the internal and external governance measures in Table 10 to Table 13.

All of the ESP control variables present significant coefficient estimates, with signs that are consistent with our expectations. The signs of the coefficient estimates of the AFR and CFR instruments are as predicted, with each of these being statistically significant at common confidence levels. Similarly, the signs of the coefficient estimates of the GI and EI instruments are significant in the third equation except for the relationship between the EI and D1.

4.3. Information Asymmetry Cost Estimation Results

The information asymmetry component of effective spread represents the asymmetric information costs faced by market liquidity providers when trading with informed traders, and therefore reflects the market's perception of the firm's asymmetric information risk. Furthermore, since the two S&P T&D rankings and the two indexes measure the extent of a firm's internal and external corporate governance, we predict that they will be directly related to the firm's asymmetric information risk. In this section, therefore, we examine the relationship between the dollar value of the information asymmetry component and our corporate governance measures by applying the 3SLS and GMM estimations to determine whether better corporate governance is associated with better equity liquidity.

Table 14 and Table 15 present the simultaneous estimation results of the dollar value of INF, AFR and the external governance measures, whilst Table 16 and Table 17 present the results of the dollar value of INF, CFR and the external governance measures.

We find that both AFR and CFR have significantly negative relationships with INF in the first equation under both 3SLS and GMM estimations, but that under the OLS estimation, this reverse partial relationship has no statistical significance. Furthermore, under the GMM estimation method in Table 17, INF reveals significant relationship with CFR in the second equation, indicating once again that there is probability of simultaneity existing within the determination of INF and CFR. However, this result is not presented in the relationships between INF and other governance measures. It should be noted that this result is similar with the Brown and Hillegeist (2006) study, within which the wrong sign is produced in the simultaneous equations estimation.

The significantly negative relationships between INF and the two S&P T&D final rankings in the first equation in Table 14 to Table 17, under both the 3SLS and GMM estimations, again provide support for our hypothesis, that firms with better disclosure practice and shareholders rights will demonstrate better corporate governance and that their stocks will have lower information asymmetry cost.

Table 10 OLS, 3SLS and GMM estimation results of the effective spread (ESP), annual basis S&P T&D final ranking (AFR) and governance index (GI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the annual basis T&D ranking (governance index) is significantly and negatively (positively) correlated with the effective spread. In the second equation of Panel B, the effective spread does not reveal any significant negative correlation to the annual basis T&D ranking, indicating that simultaneity may not exist in the determination of spread and internal governance measure. In the third equation of Panel C, the effective spread does not reveal any significant positive correlation to the governance index, indicating that simultaneity may not exist in the determination of spread and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (ESP)				
Intercept		3.0433***	3.3433***	3.7800***
		(<.0001)	(<.0001)	(<.0001)
AFR	–	-0.0009	-0.2149***	-0.2803***
		(0.9425)	(<.0001)	(<.0001)
GI	+	0.0017	0.0427**	0.0421**
		(0.7190)	(0.0145)	(0.0453)
CLP	+	0.0270***	0.0262***	0.0263***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1541***	-0.1274***	-0.1338***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	9.2911***	5.1595***	5.0902*
		(<.0001)	(0.0098)	(0.0832)
Panel B: The second equation of the simultaneous equation systems (AFR)				
Intercept		2.3845**	0.6533	1.4664
		(0.0469)	(0.6835)	(0.2340)
ESP	–	-0.0188	-0.0583	-0.0182
		(0.8963)	(0.7230)	(0.8951)
GI	–	0.0164	0.1582**	0.1290**
		(0.5046)	(0.0337)	(0.0266)
lnSIZE	+	0.1110**	0.1293***	0.1022***
		(0.0123)	(0.0047)	(0.0050)
RETSTD	–	-16.4063**	-15.8212**	-13.5862**
		(0.0188)	(0.0244)	(0.0382)
AIP	+	0.0059**	0.0046**	0.0046***
		(0.0321)	(0.0423)	(0.0074)
Panel C: The third equation of the simultaneous equation systems (GI)				
Intercept		10.7578***	8.4193***	7.8438***
		(<.0001)	(0.0012)	(0.0024)
ESP	+	-0.1366	-0.1157	-0.3015
		(0.6824)	(0.7486)	(0.4025)
AFR	–	0.0190	0.4871	0.6739
		(0.9050)	(0.3336)	(0.1685)
LEV	–	-0.0006*	-0.0006**	-0.0007***
		(0.0529)	(0.0341)	(0.0065)
D1	–	-1.5517***	-1.4013***	-1.6855***
		(0.0032)	(0.0053)	(0.0008)
D2	–	-1.9319***	-1.7066***	-1.6224***
		(<.0001)	(<.0001)	(<.0001)
SG3	–	-0.0067*	-0.0072*	-0.0088**
		(0.0879)	(0.0710)	(0.0169)
Number of Obs.		244	244	244

Table 11 OLS, 3SLS and GMM estimation results of the effective spread (ESP), annual basis S&P T&D final ranking (AFR) and entrenchment index (EI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the composite basis T&D ranking (entrenchment index) is significantly and negatively (positively) correlated with the effective spread. In the second equation of Panel B, the effective spread does not reveal any significant negative correlation to the composite basis T&D ranking, indicating that simultaneity may not exist in the determination of spread and internal governance measure. In the third equation of Panel C, the effective spread does not reveal any significant positive correlation to the entrenchment index, indicating that simultaneity may not exist in the determination of spread and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (ESP)				
Intercept		3.0383***	3.6471***	3.9350***
		(<.0001)	(<.0001)	(<.0001)
AFR	–	-0.0008	-0.2456***	-0.3054***
		(0.9497)	(<.0001)	(<.0001)
EI	+	0.0059	0.0922**	0.1012*
		(0.4931)	(0.0408)	(0.0580)
CLP	+	0.0270***	0.0260***	0.0262***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1537***	-0.1234***	-0.1255***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	9.2710***	4.4925**	4.7049
		(<.0001)	(0.0360)	(0.1270)
Panel B: The second equation of the simultaneous equation systems (AFR)				
Intercept		2.5858**	1.7883	2.3850**
		(0.0257)	(0.2150)	(0.0362)
ESP	–	-0.0224	-0.0728	-0.0441
		(0.8770)	(0.6565)	(0.7419)
EI	–	0.0120	0.2645	0.1928
		(0.7940)	(0.1465)	(0.1721)
lnSIZE	+	0.1083**	0.1217**	0.0966**
		(0.0145)	(0.0100)	(0.0138)
RETSTD	–	-16.4090**	-15.8521**	-11.4802*
		(0.0189)	(0.0254)	(0.0943)
AIP	+	0.0058**	0.0042*	0.0040**
		(0.0327)	(0.0513)	(0.0222)
Panel C: The third equation of the simultaneous equation systems (EI)				
Intercept		2.7025***	1.4316	0.7526
		(<.0001)	(0.3013)	(0.5884)
ESP	+	-0.0279	-0.0437	-0.0847
		(0.8782)	(0.8247)	(0.6794)
AFR	–	0.0021	0.2666	0.4194
		(0.9806)	(0.3307)	(0.1289)
LEV	–	-0.0005***	-0.0004***	-0.0005***
		(0.0044)	(0.0042)	(<.0001)
D1	–	-0.4476	-0.4217	-0.4393
		(0.1161)	(0.1185)	(0.1394)
D2	–	-0.6953***	-0.6228***	-0.5709***
		(0.0016)	(0.0036)	(0.0019)
Number of Obs.		244	244	244

Table 12 OLS, 3SLS and GMM estimation results of the effective spread (ESP), composite basis S&P T&D final ranking (CFR) and governance index (GI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the composite basis T&D ranking is significantly and negatively correlated with the effective spread. In the second equation of Panel B, the effective spread reveal significant negative correlation to the composite basis T&D ranking under the GMM estimation, indicating that simultaneity may exist in the determination of spread and internal governance measure. In the third equation of Panel C, the effective spread does not reveal any significant positive correlation to the governance index, indicating that simultaneity may not exist in the determination of spread and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (ESP)				
Intercept		3.2313***	5.5137***	6.0498***
		(<.0001)	(<.0001)	(<.0001)
CFR	–	-0.0244	-0.3440***	-0.3873***
		(0.2751)	(0.0004)	(<.0001)
GI	+	0.0013	0.0166	0.0059
		(0.7786)	(0.2959)	(0.7217)
CLP	+	0.0269***	0.0259***	0.0259***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1539***	-0.1483***	-0.1551***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	9.1009***	6.3987***	7.2146***
		(<.0001)	(0.0006)	(0.0020)
Panel B: The second equation of the simultaneous equation systems (CFR)				
Intercept		7.9869***	8.0174***	7.9004***
		(<.0001)	(<.0001)	(<.0001)
ESP	–	-0.1092	-0.1213	-0.1419*
		(0.1581)	(0.1513)	(0.0685)
GI	–	-0.0146	-0.0136	-0.0027
		(0.2663)	(0.7037)	(0.9306)
RETSTD	–	-7.6368**	-7.7507**	-6.3311*
		(0.0406)	(0.0401)	(0.0638)
AIP	+	0.0035**	0.0029**	0.0031***
		(0.0161)	(0.0277)	(0.0033)
Panel C: The third equation of the simultaneous equation systems (GI)				
Intercept		13.2226***	10.3530	10.8549
		(<.0001)	(0.3027)	(0.2784)
ESP	+	-0.1649	-0.1098	-0.2742
		(0.6218)	(0.7724)	(0.4865)
CFR	–	-0.3072	0.0631	0.0434
		(0.3034)	(0.9612)	(0.9730)
LEV	–	-0.0005*	-0.0007**	-0.0009***
		(0.0709)	(0.0345)	(0.0057)
D1	–	-1.5641***	-1.4310***	-1.7516***
		(0.0029)	(0.0052)	(0.0036)
D2	–	-1.9236***	-1.9289***	-1.9905***
		(<.0001)	(<.0001)	(<.0001)
SG3	–	-0.0072*	-0.0074*	-0.0114***
		(0.0676)	(0.0736)	(0.0084)
Number of Obs.		244	244	244

Table 13 OLS, 3SLS and GMM estimation results of the effective spread (ESP), composite basis S&P T&D final ranking (CFR) and entrenchment index (EI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the composite basis T&D ranking is significantly and negatively correlated with the effective spread. In the second equation of Panel B, the effective spread reveal significant negative correlation to the composite basis T&D ranking under the GMM estimation, indicating that simultaneity may exist in the determination of spread and internal governance measure. In the third equation of Panel C, the effective spread does not reveal any significant positive correlation to the governance index, indicating that simultaneity may not exist in the determination of spread and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (ESP)				
Intercept		3.2226***	5.3402***	5.6171***
		(<.0001)	(<.0001)	(<.0001)
CFR	–	-0.0244	-0.3158**	-0.3436***
		(0.2729)	(0.0157)	(0.0026)
EI	+	0.0057	0.0267	0.0119
		(0.5115)	(0.5557)	(0.7658)
CLP	+	0.0269***	0.0259***	0.0260***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1534***	-0.1452***	-0.1476***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	9.0775***	6.5367***	6.8746***
		(<.0001)	(0.0012)	(0.0020)
Panel B: The second equation of the simultaneous equation systems (CFR)				
Intercept		7.8681***	8.2356***	8.3214***
		(<.0001)	(<.0001)	(<.0001)
ESP	–	-0.1069	-0.1268	-0.1440*
		(0.1675)	(0.1497)	(0.0934)
EI	–	-0.0114	-0.1473	-0.1795**
		(0.6440)	(0.1058)	(0.0163)
RETSTD	–	-7.6665**	-7.6945**	-6.5874*
		(0.0404)	(0.0427)	(0.0641)
AIP	+	0.0035**	0.0032**	0.0030**
		(0.0166)	(0.0248)	(0.0111)
Panel C: The third equation of the simultaneous equation systems (EI)				
Intercept		2.8070**	4.5517	5.5280
		(0.0302)	(0.4175)	(0.2942)
ESP	+	-0.0291	-0.0601	-0.1531
		(0.8735)	(0.7746)	(0.4591)
CFR	–	-0.0123	-0.2377	-0.3493
		(0.9398)	(0.7439)	(0.6091)
LEV	–	-0.0005***	-0.0005***	-0.0005***
		(0.0047)	(0.0018)	(<.0001)
D1	–	-0.4482	-0.2739	-0.0946
		(0.1155)	(0.2676)	(0.7295)
D2	–	-0.6947***	-0.6344***	-0.5954***
		(0.0016)	(0.0022)	(0.0011)
Number of Obs.		244	244	244

Table 14 OLS, 3SLS and GMM estimation results of the information asymmetry component (INF), annual basis S&P T&D final ranking (AFR) and governance index (GI)

The empirical results show that under the GMM and (3SLS) estimations, in the first equation of Panel A, the annual basis T&D ranking (governance index) is significantly and negatively (positively) correlated with the information asymmetry component. In the second equation of Panel B, the information asymmetry component does not reveal any significant negative correlation to the annual basis T&D ranking, indicating that simultaneity may not exist in the determination of information asymmetry component and internal governance measure. In the third equation of Panel C, the information asymmetry component does not reveal any significant positive correlation to the governance index, indicating that simultaneity may not exist in the determination of information asymmetry component and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (INF)				
Intercept		2.3648***	2.5737***	2.7369***
		(<.0001)	(<.0001)	(<.0001)
AFR	–	-0.0008	-0.1204***	-0.1554***
		(0.8759)	(<.0001)	(<.0001)
GI	+	-0.0014	0.0144*	0.0159
		(0.4910)	(0.0867)	(0.1454)
CLP	+	0.0126***	0.0122***	0.0120***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1281***	-0.1118***	-0.1116***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	3.1128***	0.8897	0.6600
		(<.0001)	(0.3761)	(0.6514)
Panel B: The second equation of the simultaneous equation systems (AFR)				
Intercept		1.9960	-0.2976	1.0542
		(0.1249)	(0.8589)	(0.4120)
INF	–	0.1628	0.0481	-0.0116
		(0.6229)	(0.8974)	(0.9703)
GI	–	0.0173	0.1778**	0.1378**
		(0.4827)	(0.0168)	(0.0211)
lnSIZE	+	0.1190**	0.1544***	0.1117***
		(0.0105)	(0.0012)	(0.0026)
RETSTD	–	-14.6683**	-13.5937*	-11.2007*
		(0.0415)	(0.0603)	(0.0777)
AIP	+	0.0062**	0.0043**	0.0042***
		(0.0233)	(0.0413)	(0.0064)
Panel C: The third equation of the simultaneous equation systems (GI)				
Intercept		10.6218***	7.8595***	6.1626**
		(<.0001)	(0.0021)	(0.0145)
INF	+	-0.1302	0.0890	-0.2431
		(0.8559)	(0.9075)	(0.7648)
AFR	–	0.0193	0.5448	0.9526*
		(0.9033)	(0.2795)	(0.0549)
LEV	–	-0.0006*	-0.0005**	-0.0006***
		(0.0508)	(0.0453)	(0.0089)
D1	–	-1.5468***	-1.4481***	-1.5600***
		(0.0033)	(0.0036)	(0.0015)
D2	–	-1.9357***	-1.7112***	-1.6497***
		(<.0001)	(<.0001)	(<.0001)
SG3	–	-0.0068*	-0.0057	-0.0071**
		(0.0873)	(0.1438)	(0.0412)
Number of Obs.		244	244	244

Table 15 OLS, 3SLS and GMM estimation results of the information asymmetry component (INF), annual basis S&P T&D final ranking (AFR) and entrenchment index (EI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the annual basis T&D ranking is significantly and negatively correlated with the information asymmetry component. In the second equation of Panel B, the information asymmetry component does not reveal any significant negative correlation to the annual basis T&D ranking, indicating that simultaneity may not exist in the determination of information asymmetry component and internal governance measure. In the third equation of Panel C, the information asymmetry component does not reveal any significant positive correlation to the entrenchment index, indicating that simultaneity may not exist in the determination of information asymmetry component and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (INF)				
Intercept		2.3200***	2.7796***	2.9482***
		(<.0001)	(<.0001)	(<.0001)
AFR	–	-0.0009	-0.1508***	-0.1864***
		(0.8696)	(<.0001)	(<.0001)
EI	+	0.0040	0.0270	0.0279
		(0.2997)	(0.2326)	(0.3218)
CLP	+	0.0126***	0.0121***	0.0120***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1268***	-0.1094***	-0.1091***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	3.0809***	0.1598	0.1822
		(<.0001)	(0.8893)	(0.9187)
Panel B: The second equation of the simultaneous equation systems (AFR)				
Intercept		2.2273*	1.2818	2.1526*
		(0.0761)	(0.3990)	(0.0656)
INF	–	0.1488	-0.0087	-0.0432
		(0.6529)	(0.9814)	(0.8917)
EI	–	0.0121	0.3007*	0.2338*
		(0.7924)	(0.0972)	(0.0925)
lnSIZE	+	0.1156**	0.1344***	0.1000**
		(0.0126)	(0.0061)	(0.0114)
RETSTD	–	-14.7334**	-14.2073*	-9.7752
		(0.0409)	(0.0517)	(0.1572)
AIP	+	0.0062**	0.0032	0.0027*
		(0.0240)	(0.1080)	(0.0786)
Panel C: The third equation of the simultaneous equation systems (EI)				
Intercept		2.5647***	1.3076	0.5997
		(<.0001)	(0.3353)	(0.6633)
INF	+	0.1463	0.0162	-0.0498
		(0.7082)	(0.9691)	(0.9124)
AFR	–	0.0015	0.2758	0.4303
		(0.9866)	(0.3126)	(0.1260)
LEV	–	-0.0005***	-0.0004***	-0.0004***
		(0.0043)	(0.0078)	(<.0001)
D1	–	-0.4499	-0.4830*	-0.5375*
		(0.1143)	(0.0602)	(0.0593)
D2	–	-0.6995***	-0.6548***	-0.5749***
		(0.0015)	(0.0017)	(0.0029)
Number of Obs.		244	244	244

Table 16 OLS, 3SLS and GMM estimation results of the information asymmetry component (INF), composite basis S&P T&D final ranking (CFR) and governance index (GI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the composite basis T&D ranking is significantly and negatively correlated with the information asymmetry component. In the second equation of Panel B, the information asymmetry component does not reveal any significant negative correlation to the composite basis T&D ranking, indicating that simultaneity may not exist in the determination of information asymmetry component and internal governance measure. In the third equation of Panel C, the information asymmetry component does not reveal any significant positive correlation to the governance index, indicating that simultaneity may not exist in the determination of information asymmetry component and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (INF)				
Intercept		2.3645***	3.5671***	3.5019***
		(<.0001)	(<.0001)	(<.0001)
CFR	–	-0.0005	-0.1640***	-0.1503***
		(0.9568)	(0.0001)	(0.0009)
GI	+	-0.0014	0.0006	-0.0037
		(0.4880)	(0.9377)	(0.5985)
CLP	+	0.0126***	0.0120***	0.0123***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1280***	-0.1238***	-0.1251***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	3.1241***	1.7285**	2.4290**
		(<.0001)	(0.0388)	(0.0182)
Panel B: The second equation of the simultaneous equation systems (CFR)				
Intercept		7.8854***	7.9274***	7.8586***
		(<.0001)	(<.0001)	(<.0001)
INF	–	-0.1467	-0.2460	-0.2578
		(0.3858)	(0.1806)	(0.1295)
GI	–	-0.0142	-0.0075	-0.0046
		(0.2792)	(0.8341)	(0.8786)
RETSTD	–	-7.1649*	-7.8343**	-6.4754*
		(0.0602)	(0.0435)	(0.0633)
AIP	+	0.0037**	0.0028**	0.0033***
		(0.0118)	(0.0281)	(0.0037)
Panel C: The third equation of the simultaneous equation systems (GI)				
Intercept		12.9839***	8.7006	8.0331
		(<.0001)	(0.3745)	(0.3939)
INF	+	-0.1543	0.1605	-0.1036
		(0.8294)	(0.8394)	(0.9014)
CFR	–	-0.2974	0.2431	0.3685
		(0.3180)	(0.8488)	(0.7618)
LEV	–	-0.0005*	-0.0006*	-0.0008***
		(0.0670)	(0.0565)	(0.0068)
D1	–	-1.5579***	1.5071***	-1.7935***
		(0.0030)	(0.0041)	(0.0027)
D2	–	-1.9285***	-1.9333***	-2.0047***
		(<.0001)	(<.0001)	(<.0001)
SG3	–	-0.0072*	-0.0073*	-0.0111***
		(0.0674)	(0.0836)	(0.0087)
Number of Obs.		244	244	244

Table 17 OLS, 3SLS and GMM estimation results of the information asymmetry component (INF), composite basis S&P T&D final ranking (CFR) and entrenchment index (EI)

The empirical results show that under the 3SLS and GMM estimations, in the first equation of Panel A, the composite basis T&D ranking is significantly and negatively correlated with the information asymmetry component. In the second equation of Panel B, the information asymmetry component reveal significant negative correlation to the composite basis T&D ranking under the GMM estimation, indicating that simultaneity may exist in the determination of information asymmetry component and internal governance measure. In the third equation of Panel C, the information asymmetry component does not reveal any significant positive correlation to the entrenchment index, indicating that simultaneity may not exist in the determination of information asymmetry component and external governance measure. Figures in parentheses are *p*-values. "***", "**", and "*" represent significance levels of 1%, 5%, and 10%, respectively.

	Prediction	OLS	3SLS	GMM
Panel A: The first equation of the simultaneous equation systems (INF)				
Intercept		2.3133***	3.8306***	3.9028***
		(<.0001)	(<.0001)	(<.0001)
CFR	–	0.0002	-0.1982***	-0.2089***
		(0.9809)	(0.0009)	(0.0006)
EI	+	0.0040	-0.0099	-0.0224
		(0.2993)	(0.6408)	(0.2336)
CLP	+	0.0126***	0.0119***	0.0118***
		(<.0001)	(<.0001)	(<.0001)
lnDOLVOL	–	-0.1268***	-0.1216***	-0.1195***
		(<.0001)	(<.0001)	(<.0001)
RETSTD	+	3.0996***	1.4028	1.5156
		(<.0001)	(0.1440)	(0.1879)
Panel B: The second equation of the simultaneous equation systems (CFR)				
Intercept		7.7678***	8.1758***	8.2632***
		(<.0001)	(<.0001)	(<.0001)
INF	–	-0.1414	-0.2561	-0.3183*
		(0.4046)	(0.1794)	(0.0804)
EI	–	-0.0104	-0.1274	-0.1536**
		(0.6721)	(0.1619)	(0.0325)
RETSTD	–	-7.1870*	-7.8154**	-7.0951*
		(0.0602)	(0.0469)	(0.0530)
AIP	+	0.0037**	0.0025*	0.0024**
		(0.0122)	(0.0650)	(0.0259)
Panel C: The third equation of the simultaneous equation systems (EI)				
Intercept		2.6288**	5.0224	5.8235
		(0.0382)	(0.3509)	(0.2429)
INF	+	0.1456	-0.0201	-0.2521
		(0.7096)	(0.9631)	(0.5664)
CFR	–	-0.0075	-0.3107	-0.3979
		(0.9630)	(0.6585)	(0.5421)
LEV	–	-0.0005***	-0.0005***	-0.0005***
		(0.0045)	(0.0035)	(<.0001)
D1	–	-0.4502	-0.3330	-0.1339
		(0.1138)	(0.2113)	(0.6656)
D2	–	-0.6992***	-0.6448***	-0.6286***
		(0.0015)	(0.0027)	(0.0012)
Number of Obs.		244	244	244

5. CONCLUSIONS

Poor disclosure practice and weak shareholders rights within a firm are accompanied by poor corporate governance and higher levels of asymmetric information risk; as a result, liquidity providers will tend to broaden the equity spread of those firms exhibiting poor corporate governance, since such price-protection action will have the effect of reducing the market liquidity of the stock. In this study, we have used the two S&P T&D rankings as proxy variables for internal corporate governance and the two indexes as proxy variables for external corporate governance, subsequently employing this in our examination of whether the stocks of those firms with higher ranking in the two S&P T&D rankings and lower score in the two indexes have better market liquidity.

The empirical evidence supports our hypothesis that the stocks of those companies with better corporate governance have better market liquidity, with the two T&D final rankings and the two indexes having significantly negative and positive partial effects respectively on the effective spread. We also find that the corporate governance measures have a significant relationship with the information asymmetry component of the effective spread, which implies that better disclosure practices and large shareholder rights can reduce the asymmetric information risk perceived by the market, and thereby lower the spread of the equity by reducing the asymmetric information costs demanded by liquidity providers as a means of compensating for any potential losses arising from informed trading activities.

Furthermore, we find that the two T&D rankings and the two indexes have a significantly negative and positive relationship respectively with the information asymmetry component, implying that poorer disclosure practices and shareholder rights will lead to lower equity liquidity, as a result of the increased asymmetric information costs demanded by liquidity providers, essentially as a result of order processing costs being largely fixed.

Finally, the results of our study have some important implications for corporate governance; we suggest that managers should endeavor to conform to the various disclosure regulations and investor protection codes by disclosing, to the best of their ability, all the information they possess on the firm. When a firm is able to provide better levels of transparency and disclosure, the information asymmetry and agency problems will be effectively mitigated, and the quality of the firm's internal corporate governance will be improved immensely. Similar suggestion that managers should enhance the shareholder rights by narrowing the gap between the firm's actual and potential value is provided to improve the quality of the firm's external corporate governance. Consequently, the firm will have a smaller information asymmetry component, along with a smaller effective spread, which implies that its stocks will have better market liquidity.

CHAPTER 4. SUMMARY AND CONCLUSIONS

The rate of change in financial markets has accelerated in recent years, with an unprecedented proliferation of new markets and instruments. This dissertation focuses on several important issues in market microstructure, including tick size, arbitrage efficiency and market liquidity.

The first essay in this dissertation investigates the impact of decimalization (penny pricing) on the arbitrage relationship between index exchange-traded funds (ETFs) and E-mini index futures. Our empirical results reveal that subsequent to penny pricing, there is a significant fall in the mean ex-ante arbitrage profit, especially in the cases with higher transaction costs. Using the method of ordinary least squares (OLS) and quantile regressions to control for the influences of changes in other market characteristics, we find that the overall pricing efficiency has deteriorated in the post-decimalization period. From the quantile regression analyses, it is found that the pricing efficiency is improved only when an extremely large mispricing signal is observed, implying that due to increased execution risk after decimalization, arbitragers will only execute trades when the expected profit is large enough. These results are consistent with the hypothesis that, due to the lowered market depth and increased execution risks, the introduction of decimalization has in general resulted in weakening the ability and willingness of arbitrageurs to initiate arbitrage trades, which subsequently leads to a reduction in the general efficiency of the cash/futures pricing system.

The second essay examines the effects of the internal and external corporate governance mechanisms, on equity liquidity, arguing that those companies adopting poor disclosure practices and weak shareholder rights will experience serious information asymmetry. Since poor corporate governance leads to greater information asymmetry, liquidity providers will incur relatively higher adverse information risks and will therefore offer higher information asymmetry components in their effective bid-ask spreads. The Transparency and Disclosure

(T&D) rankings, the governance index (GI) and the entrenchment index (EI) of the individual stocks on the S&P 500 index are employed to examine whether firms with greater T&D ranking and lower score in these two index have lower information asymmetry components and lower stock spreads. Our results reveal that the economic costs of equity liquidity, i.e., the effective spread and the asymmetric information cost, are greater for those companies with poor corporate governance.

In summary, the essays of this dissertation provide some insights into the issues of market microstructure, emphasize on the importance of tick size and corporate governance on financial markets. The research results would furnish us with the empirical evidences to explain the occasion of some distinctive phenomena in financial markets. The results, therefore, should be treated circumspectly.

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APPENDIX: QUANTILE REGRESSION

Quantile regression, developed by Koenker and Bassett (1978), is an extension of the classical least squares estimation of the conditional mean to a collection of models for different conditional quantile functions. In this appendix, the lecture notes of Kuan (2004) and the book of Koenker (2005) are quoted to interpret the computation and inference of the quantile regression estimator.

A1. The Method of Quantile Regression

This section is extracted from the lecture notes of Kuan (2004). Given the data $(y_t, \boldsymbol{x}_t')'$ for $t = 1, \ldots, T$, where $\boldsymbol{x}_t$ is $k \times 1$, consider the following linear specification:

$$y_t = \boldsymbol{x}_t'\boldsymbol{\beta} + e_t \tag{A1}$$

This specification can approximate a particular conditional quantile of y_t provided that $\boldsymbol{\beta}$ is estimated properly.

The θ^{th} quantile regression estimator of $\boldsymbol{\beta}$ can be obtained by minimizing its sample counterpart, i.e., the average of asymmetrically weighted absolute errors with weight θ on positive errors and weight $(\theta - 1)$ on negative errors:

$$V_T(\boldsymbol{\beta};\theta) := \frac{1}{T}\left[\theta \sum_{t:y_t \geq \boldsymbol{x}_t'\boldsymbol{\beta}} |y_t - \boldsymbol{x}_t'\boldsymbol{\beta}| + (1-\theta) \sum_{t:y_t < \boldsymbol{x}_t'\boldsymbol{\beta}} |y_t - \boldsymbol{x}_t'\boldsymbol{\beta}|\right] \tag{A2}$$

For $\theta = 0.5$, 2 times (A2) is exactly the objective function for LAD estimation:

$$V_T^m(\boldsymbol{\beta}) := 2V_T(\boldsymbol{\beta}; 0.5) = \frac{1}{T}\sum_{t=1}^{T} |y_t - \boldsymbol{x}_t'\boldsymbol{\beta}| \tag{A3}$$

Hence, a regression estimated via the method of LAD is in effect a special case of conditional quantile regression and is usually referred to as a "median regression".

Appendix: Quantile Regression

Let ρ_θ denote the so-called "check" function such that $\rho_\theta(a)=\theta_a$ if $a \geq 0$ and $\rho_\theta(a)=(\theta-1)a$ if $a \leq 0$. We can write (A2) in a compact form:

$$V_T(\boldsymbol{\beta};\theta)=\frac{1}{T}\sum_{t=1}^{T}\rho_\theta(y_t-\boldsymbol{x}_t'\boldsymbol{\beta})=\frac{1}{T}\sum_{t=1}^{T}\left(\theta-\mathbf{1}_{\{y_t-\boldsymbol{x}_t'\boldsymbol{\beta}<0\}}\right)(y_t-\boldsymbol{x}_t'\boldsymbol{\beta}) \tag{A4}$$

where $\mathbf{1}_A$ is the indicator function of the event A. The first order condition of minimizing (A2) is

$$\frac{1}{T}\sum_{t=1}^{T}\varphi_\theta(y_t-\boldsymbol{x}_t'\boldsymbol{\beta}):=\frac{1}{T}\sum_{t=1}^{T}\boldsymbol{x}_t\left(\theta-\mathbf{1}_{\{y_t-\boldsymbol{x}_t'\boldsymbol{\beta}<0\}}\right)=0 \tag{A5}$$

except at $y_t=\boldsymbol{x}_t'\boldsymbol{\beta}$ the derivative is not defined. Solving (A5) for $\boldsymbol{\beta}$ we obtain $\hat{\boldsymbol{\beta}}_\theta$, the θ^{th} quantile regression estimator of $\boldsymbol{\beta}$.

A2. Computation of the Estimator

This section is also extracted from the lecture notes of Kuan (2004). The quantile regression estimator $\hat{\boldsymbol{\beta}}_\theta$ is not easy to compute because it does not have a closed form. It can also be seen that the objective function (A2) is not differentiable everywhere so that standard numerical optimization method is not readily applicable.

In practice, the quantile regression estimates are usually computed by solving a linear programming problem. To see this, write the linear specification as

$$y_t=\boldsymbol{x}_t'\boldsymbol{\beta}+e_t=\sum_{j=1}^{k}x_{t,j}\left(\beta_j^+-\beta_j^-\right)+\left(e_t^+-e_t^-\right) \tag{A6}$$

where β_j is the j^{th} coefficient of $\boldsymbol{\beta}$ such that $\beta_j^+=\max(\beta_j,0)$ is its positive part and $\beta_j^-=-\min(\beta_j,0)$ is its negative part. Thus, $\beta_j=\beta_j^+-\beta_j^-$; similarly, $e_t=e_t^+-e_t^-$. Let $\boldsymbol{e}^+$ be the vector of e_t^+, $\boldsymbol{e}^-$ be the vector of e_t^-, $\boldsymbol{\beta}^+$ be the vector of β_j^+, $\boldsymbol{\beta}^-$ be the vector of β_j^-, and $\boldsymbol{z}=[\boldsymbol{\beta}^+{}',\boldsymbol{\beta}^-{}',\boldsymbol{e}^+{}',\boldsymbol{e}^-{}']'$, a $2(k+T)$-dimensional vector of non-negative elements.

We can then write the linear specification as

$$y = Az = X(\beta^{+\prime} - \beta^{-\prime}) + (e^{+} - e^{-}) \tag{A7}$$

where y is the $T \times 1$ vector containing all y_t, X the $T \times k$ matrix with the t^{th} row x_t', and $A = [X, -X, I_T, -I_T]$ is $T \times 2(k+T)$. Setting

$$c = [0', 0', \theta 1', (1-\theta)1']' \tag{A8}$$

where $\mathbf{0}$ is the k-dimensional vector of zeros and $\mathbf{1}$ denotes the T-dimensional vector of ones, it follows that the objective function (A2) is $c'z/T$. Minimizing (A2) is thus equivalent to minimizing $c'z$ with respect to z, subject to the constraint that $y = Az$ and that z contains only non-negative elements.

To solve the linear programming problem, Barrodale and Roberts (1974) designed a simplex-based algorithm for LAD estimation, which was subsequently extended by Koenker and d'Orey (1987) to quantile regression estimation. Koenker and Park (1996) also extend the interior method of Karmarkar (1984) to quantile regression.

A3. Inference for Quantile Regression: The Bootstrap

There is quite an extensive literature on the use of the bootstrap and related resampling schemes for quantile regression. Efron (1982) suggested the residual bootstrap for a nonlinear median regression problem, and this form of the bootstrap has been considered by De Angelis et al. (1993) and several others.

This section is mainly to refer to chapter 3 in the book of Koenker (2005). In the linear quantile regression setting, let

$$\hat{\beta}_\theta = \arg\min_{\beta} \left[\theta \sum_{t: y_t \geq x_t'\beta} |y_t - x_t'\beta| + (1-\theta) \sum_{t: y_t < x_t'\beta} |y_t - x_t'\beta| \right] \tag{A9}$$

and let $\hat{F}_T$ denote the empirical distribution of the residuals, $\hat{e}_t = y_t - \boldsymbol{x}'_t\hat{\boldsymbol{\beta}}_\theta$, with respect to this fit:

$$\hat{F}_T(e) = T^{-1}\sum_{t=1}^{T} I(\hat{e}_t < e) \tag{A10}$$

Now, consider drawing bootstrap samples $e_1^*,\ldots,e_T^*$ from $\hat{F}_T(e)$; with replacement, set $y_t^* = \boldsymbol{x}'_t\hat{\boldsymbol{\beta}}_\theta + e_t^*$ and compute

$$\boldsymbol{\beta}_\theta^* = \arg\min_\beta \left[\theta \sum_{t:y_t^* \geq \boldsymbol{x}'_t\boldsymbol{\beta}} \left|y_t^* - \boldsymbol{x}'_t\boldsymbol{\beta}\right| + (1-\theta) \sum_{t:y_t^* < \boldsymbol{x}'_t\boldsymbol{\beta}} \left|y_t^* - \boldsymbol{x}'_t\boldsymbol{\beta}\right|\right] \tag{A11}$$

De Angelis et al. (1993) show that under iid error conditions the distribution of the bootstrapped $\boldsymbol{\beta}_\theta^*$s,

$$\hat{G}(z) = P\left(\sqrt{T}\left(\beta_{\theta,j}^* - \hat{\beta}_{\theta,j}\right) \leq z_j,\ j = 1,\ldots,p \,|\, \chi\right) \tag{A12}$$

conditional on the initial sample $\chi = \{(x_t, y_t): t = 1,\ldots,T\}$ converges to the limiting distribution of $\sqrt{T}\left(\hat{\boldsymbol{\beta}}_\theta - \boldsymbol{\beta}_\theta\right)$ and, furthermore, that the error of this approximation is of order $O\left(T^{-1/4}\right)$ as $T \to \infty$.

Given the bootstrap realizations $\left\{\hat{\beta}_{\theta,i}^* : i = 1,\ldots,N\right\}$, there are several options that have been considered for constructing tests and confidence intervals. Most straightforwardly, one can compute the empirical covariance matrix of the realizations and construct tests and confidence intervals directly from it. Alternatively, one can form percentile intervals as discussed, for example, by Efron and Tibshirani (1993). Many important practical aspects of the implementation of the bootstrap, including the crucial question of how to choose the number of replications, N, are treated by Andrews and Buchinsky (2000, 2001).