# Strategic Liquidity Supply in a Market with Fast and Slow Traders

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**This version November 2011.**

The authors wish to thank Sie Ting Lau, Bohui Zhang for helpful comments. This paper was presented at an Securities and Exchange Commission seminar in September 2011 and we also thank the participants for their comments.

JEL classification: G14, G18, G19

Key Words: Regulation NMS, Limit Order, Quote Update, Trade Execution Quality

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## Abstract

Modern equity markets have both fast traders such as dealers, market makers, and High Frequency Traders and slow traders such as retail clients. We model and show empirically that latency differences allow fast liquidity suppliers to pick off slow liquidity demanders at prices inferior to the NBBO. This trading strategy is highly profitable for the fast traders. We estimate that the fast traders earn more than $281 million per year at the expense of the slow traders. Investigating the decrease in NYSE latency in March 2010, we also show that when markets become faster, execution quality improves for fast liquidity demanders, but decreases for slow liquidity demanders.

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## 1. Introduction

High frequency traders (HFTs) use computers to open and then close trading positions within milliseconds. A number of studies examine HFTs and conclude that HFTs benefit markets. According to Brogaard (2010), HFTs participate in 77% of the dollar volume traded, generating $2.8 billion of gross annual trading profits; since HFTs rarely trade with each other, these revenues come from non-HFTs. In return for incurring these costs, markets benefit because HFTs are frequently at the best quotes and dampen market volatility. Hasbrouck and Saar (2011) conclude that increased low-latency activity by HFTs improves traditional market quality measures such as short-term volatility, spreads, and displayed depth. Hendershott and Riodan ( 2011) examine algorithmic traders, of which HFTs are a subset, and conclude that they consume liquidity when it is cheap, supply liquidity when it is expensive, and help move prices toward the efficient price.

In contrast to the aforementioned studies, our research focuses on the ability of fast liquidity suppliers to use their speed advantage to the detriment of slow liquidity demanders, which we believe unambiguously lowers market quality. We show that HFTs earn about 10% of their gross annual trading profit from this strategic trading. The ability of fast traders to take advantage of slow traders is exacerbated in the U.S. by the regulatory and market environment that we describe below. Although our analysis is based on U.S. equity markets, our results are applicable wherever there is simultaneous trading of an asset in multiple markets and traders have different latencies so that some are faster than others.

In order to better integrate the various exchanges trading equities and to encourage the display of liquidity, the Securities and Exchange Commission (SEC) adopted the Order Protection Rule, Rule 611, in 2005. Simply, the Order Protection Rule protects the best bid and ask at one exchange from trades at inferior prices at another exchange. However, the SEC recognized that in computer-driven markets, quotes within an exchange can update faster than the exchange can disseminate its new prices to other exchanges for the evaluation of a National Best Bid and Offer (NBBO). If the instantaneous quoted price from an exchange is used as the reference price for the assessment of trade through violations of the Order

Protection Rule, the SEC feared that inter-market transmission latencies in disseminating quote updates would create a myriad of trade through claims. Consequently, the SEC adopted the Flicker Quote Exemption, set forth in paragraph (b)(8) of Rule 611.[1] This exemption states that the reference prices for the evaluation of a trade through are the least aggressive ask and bid quotes over the previous one second from the exchange claiming the trade through. For heavily traded companies, at least one exchange is always at the market wide best bid (NBBO Bid) and the market wide best ask (NBBO Ask). Hence, the Flicker Quote Exception implicitly defines the market wide reference price for the evaluation of a trade through as the least aggressive NBBO Ask and Bid (together the NBBO) over the previous one second of trading. We call these reference prices the Flicker Ask and the Flicker Bid, respectively, or taken together the Flicker Price. Prices equal to or better than the Flicker Price, but inferior to the NBBO are called Flicker Compliant Prices. Any trades that execute at Flicker Compliant Prices are not trade throughs under Rule 611.[2] Definitions of terms are presented in Table 1. Whenever assets are traded simultaneously in different markets, if there is no order protection rule, the ability of fast traders to take advantage of slow traders is governed only by the relative latencies of these traders

The Order Protection Rule and the Flicker Quote Exception establish the regulatory environment that forms the basis of our analysis. Markets have changed significantly since these rules were adopted. Intermarket communications have migrated from the high latency Intermarket Trading System (ITS) to the low latency communications linkages that exist today and were required by Regulation NMS (Reg NMS). High speed co-located computer systems, low latency intermarket communication linkages, and sophisticated trading algorithms for supplying liquidity to markets give centrally located fast liquidity suppliers (LSs) an advantage over slow traders when prices change. Suppose the NBBO Ask is 20.05, and updates to 20.03. The fast LS can see this price change and if she has an outstanding limit order at Exchange 2 (EX2), at 20.05, while Exchange 1 (EX1) is displaying the best price of 20.03, she can choose not to cancel and update her quote to match the new best price. From the slow trader's time

[1] In SEC release 34-51808 discusses the Flicker Quotes Exception on page 152.
[2] However, prices inferior to the Flicker Price can be accessed with the use of an Intermarket Sweep Order, or ISO (see Chakravarty, Jain, Upson, and Wood, 2011).

delayed viewpoint, the best price in the market is still 20.05. If the slow trader submits a marketable buy order to EX2, which arrives within the current one second window of the Flicker Quote Exemption, the fast trader's limit order at 20.05 is executed without triggering a trade through.[3] She can then quickly buy the security at EX1 at 20.03, closing out the arbitrage and netting 0.02 cents per share profit.[4] While this strategy requires fast speed, Hasbrouck and Saar (2011) find that LSs can respond to changes in quotes on NASDAQ in 2 to 3 milliseconds. In a real world context, LSs can be broker-dealers, market makers, or High Frequency Traders (HFT).

We propose a simple model that describes the states under which LSs rationally choose not to update outstanding quotes to match the NBBO in an effort to increase profits by trading with the slow trader.[5] Our model is based on a market with two exchanges and three types of liquidity demanders—slow liquidity demanders (SLDs) who observe quotes at a fixed time lag in the past, fast uninformed liquidity demanders (FULDs), who observe prices in real time, but trade only for liquidity purposes, and fast informed liquidity demanders (FILDs) who observe prices in real time, but have private information about the true value of the equity. We are not aware of previous microstructure models that explicitly address the impact on market liquidity caused by the varying speeds of traders.

Though simple and direct, our model has a number of intuitive implications that we test. We find that the propensity to compete at the NBBO and at Flicker Compliant Prices varies across exchanges, confirming a clientele effect identified by the model. We define the Flicker Gap (or Gap for short) as the difference in cents between the NBBO Ask (NBBO Bid) and a Flicker Compliant Price on the ask (bid) side of the market. The Flicker Max Ask (Bid) Gap is the number of cents difference between the Flicker

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[3] Alternatively, if she does not have an outstanding limit order, the fast trader can submit a limit order to an exchange not posting the best price at 20.05 in an effort to pick off a slow trader on that exchange.

[4] Although we motivate this discussion with an arbitrage argument, the fast trader could also increase profits (and risk) by submitting a limit order at the best bid of the market to close out the position.

[5] Previous literature dealing with the placement of limit orders for liquidity supply include Parlour (1998), Parlour and Seppi (2003), Goettler, Parlour, and Rajan (2005), and Foucault, Kadan, and Kandel (2005), among others. Unlike these authors, we explicitly model centrally located LSs with a speed advantage, or latency advantage, over many other market participants. Further, by incorporating multiple exchanges in our model, we also add to literature such as Chowdhry and Nanda (1991) and Baruch, Karolyi, and Lemmon (2007).

Ask (Bid) and the NBBO Ask (Bid).[6] As the Flicker Max Gap increases, relatively fewer exchanges quote at the NBBO. Moreover, the execution quality of trades at Flicker Compliant Prices is significantly lower than the execution quality of trades at the NBBO.

Our results are also economically significant. Based on our sample of 100 NYSE stocks and 168 trading days, we estimate that strategic LSs, posting liquidity at Flicker Compliant Prices earn an additional $30.3 million compared to posting at the NBBO. Extending this analysis to all securities in the Daily Trade and Quote (DTAQ) data with a price over $5, we estimate a market wide impact of the Flicker Quote Exception of about $281 million per year.

## 2. Reg NMS Flicker Quote Exception to Rule 611 Overview

Figure 1 shows the three Flicker Event states (cases 1-3). The upper left panel shows the Flicker Ask Free state. In this state, the NBBO Ask has declined, while the NBBO Bid has either declined (solid line) or remained unchanged (dotted line). The Flicker Ask is greater than the NBBO Ask while the Flicker Bid is equal to the NBBO Bid. Any trade at a price at or below the Flicker Ask, but above the NBBO Ask, is not a trade through. In a downward trending market, LSs are able to sell at prices greater than the NBBO Ask.

The lower left panel shows the Flicker Bid Free state. In this state, the NBBO Bid has increased, while the NBBO Ask has either increased (solid line) or remained unchanged (dotted line). The Flicker Bid is less than the NBBO Bid while the Flicker Ask is equal to the NBBO Ask. Any trade at a price at or above the Flicker Bid, but below the NBBO Bid, is not a trade through. In an upward trending market, LSs are able to buy at prices less than the NBBO Bid.

The upper right panel shows the Flicker Free state. Here, both the NBBO Ask and the NBBO Bid have narrowed over the previous one second, resulting in the ability of LSs to trade at strictly better Flicker Compliant Prices on both sides of the market. Typically, this state begins as either a Flicker Ask Free state or a Flicker Bid Free state.

[6] When the meaning is clear, we may use shorthand version of these terms such as simply the Flicker Max Gap.

The lower right panel shows the Flicker NBBO Lock state. Here, the NBBO has remained unchanged (solid line) or one or both of the NBBO Ask and Bid have widened (dotted lines), so that the least aggressive NBBO Ask is the current NBBO Ask and the least aggressive NBBO Bid is the current NBBO Bid.

## 3. Model

### *3.1 Description of the Model*

The Flicker Quote Exception introduces an interesting strategic choice for LSs in Reg NMS markets. Specifically, if one exchange updates the quoted price by disseminating a new quote with a lower (higher) ask (bid) price than the previous NBBO Ask (Bid), other exchanges have a choice to either (1) update their quotes to compete at the best price, or (2) delay updating their quotes with the hope that a trade will arrive at the exchange and be executed (under the Flicker Quote Exemption) at a higher (lower) price than the best ask (bid) price in the market.[7] We examine the strategic decision faced by LSs (at non-NBBO exchanges) deciding whether to update quotes to match a new NBBO, leave quotes unchanged to trade at a Flicker Price, or enter new orders at NBBO or Flicker Compliant Prices.

**Liquidity demand:** Traders submitting marketable orders are liquidity demanders. All slow liquidity demanders (Slow Liquidity Demanders—SLDs) are uninformed and observe a past quote that can be equal to or different from the current quote. Becoming an informed trader is expensive and because they are slow, SLDs are not able to capture all of the value of any information acquired. Our interpretation for SLDs is that they are retail traders who may be informed about long term changes in the value of a stock, but because they attempt to manage their trades from a distance, are uninformed about the short term state of the market over second-to-second time horizons.

[7] While naturally it is the traders on an exchange that make trading decisions, for simplicity, we may occasionally refer to these as exchange decisions.

Fast liquidity demanders can be informed (Fast Informed Liquidity Demanders—FILDs) or uninformed (Fast Uninformed Liquidity Demanders—FULDs).[8] FILDs know the state of the market and know the true value of an asset, $V_{FILD}$, prior to trading and place orders dependent on this knowledge. Fast execution requires close proximity to the exchange, but the informed traders do not necessarily reside in a location central to the market. Ivkovic and Weisbenner (2005) and Anand et al. (2011) find that traders in close geographic proximity to corporate headquarters tend to be more informed. The speed of a trader is not governed by his/her physical location, but by the location and speed of their trading platform and how quickly it can assess the state of the market. .

Having a proportion of fast traders being uninformed captures the fact that large institutional traders, such as mutual funds and pension funds, often trade for purely liquidity needs, seeking the best possible prices for execution.

Both SLDs and FULDs believe that the value of an asset is the mid-point of the observed quote. $\alpha$ is the proportion of SLDs and $(1-\alpha)$ is the proportion of FILDs and FULDs. Let $\mu$ be the proportion of fast traders that are informed. Then $(1-\alpha)\mu$ is the proportion of FILDs and $(1-\alpha)(1 - \mu)$ is the proportion of FULDs in the market.

**Liquidity supply:** Traders submitting non-marketable limit orders are LSs. LSs submit sufficient depth to satisfy all liquidity demand during the Flicker Event. All LSs are fast, observing quotes in real time. We feel that this is a reasonable assumption since significant liquidity is supplied by HFTs, dealers, and market makers. LSs do not know the true value of an asset, but know the distribution of its value.

**Additional constraints:** There are several additional constraints to the model. There are two exchanges—EX1 and EX2. To avoid an infinite loss potential to LS's, and, hence, a market collapse, trade size is set to 1 for all traders. Individual FULDs and SLDs can submit orders to only one exchange, EX1 or EX2. FILDs can submit orders to one or both exchanges, dependent on the value of the asset, but

[8] From a modeling perspective, we assume that all fast traders observe quote updates instantaneously, with zero latency. In a real world context, all traders have some level of latency in observing quotes.

of order size no more than 1 to each. This constraint may seem restrictive, but in modern post Reg NMS markets, average trade sizes have dropped to between 100 and 300 shares.

Our analysis is based only on buy demand. Ask prices are denoted as $P^a_{i,t}$, for EX*i*, *i* = 1, 2 at time *t*, while bid prices are denoted at $P^b_{i,t}$. The sequence of events for the model is shown in Figure 2. At T=0, ask and bid prices at both EXs are equal. At T=1, EX1 revises its ask quote so that $P^a_{1,1} < P^a_{2,1}$. At T=2, the LSs at EX2 decide whether to leave the quote unchanged, or revise the quote. LSs at EX2 can choose from a set of prices such that there is no price change, $P^a_{2,2} = P^a_{2,1}$, prices of EX1 are matched, $P^a_{2,2} = P^a_{1,2}$, or prices are increased, $P^a_{2,2} = P^a_{2,1} + k$. If the LSs at EX2 increase the quoted price such that $P^a_{2,2} = P^a_{2,1} + k$, then the exchange has withdrawn from the market. In this case, any order routed to EX2 cannot be executed and must be sent to EX1 for execution. This constraint matches the Order Protection Rule of Reg NMS. At T=3, quoted prices are observed in the market. FILDs and FULDs observe the prices at T=2, while SLDs observe prices at T=0. At T = 3 trades are submitted and executed, and at T = 4 the true value of the asset is revealed.

We feel that this single trade event model is appropriate because the Flicker Quotes Exception covers only one second. Further, the focus of the model is on the trading of SLDs and the strategic response of LSs. While the proportion of SLDs on any given day may be relatively stable, we believe that individual retail traders are not active enough to necessitate a repeated game model.

*3.2 Traders market selection decision*

**EX1 updates its quote and EX2 does not match.** Let $P^{a*}_{2,2}$ represent the ask price at T=2 if EX2 does not update its quote to match prices at EX1 so that $P^a_{2,0} = P^{a*}_{2,2}$. Because they observe $P^a_{1,2} < P^{a*}_{2,2}$, the FULDs route all order flow to EX1 and EX2 receives none of their order flow. The following constraints define the trading choice of the FILDs.

$V_{FILD} \le P_{1,2}^{a}$, FILDs do not trade,

$P_{1,2}^{a} < V_{FILD} \le P_{2,2}^{a*}$, FILDs only submit trades to EX1,

$P_{2,2}^{a*} < V_{FILD}$, FILDs submit orders to both EXs.

**EX1 updates its quote and EX2 matches.** Let $P_{2,2}^{a}$ represent the ask price at T=2 if EX2 updates its quote to match the price of EX1 so that the FULDs observe that $P_{1,2}^{a} = P_{2,2}^{a}$ and route trades to each EX based on an exogenous choice variable, with γ orders going to EX2 and (1-γ) going to EX1, where 0≤γ≤1. γ is exogenous because the objective of the FULDs is to minimize transaction costs. Since the prices at EX1 and EX2 are equal, there is no difference in transaction costs between the two exchanges. The SLDs see the quotes at T=0, such that $P_{1,0}^{a} = P_{2,0}^{a}$ and believe that the value of the asset is equal to $(P_{i,0}^{a} + P_{i,0}^{b})/2 = V_{SLD}$. This is the observed quote whether EX2 updates its quote or not. Since, from the time delayed point of view of the SLDs, both EXs offer the same price, they submit λ orders to EX2, and (1-λ) orders to EX1, where 0≤λ≤1. FILDs submit orders to both markets if $V_{FILD} > P_{i,2}^{a}$.

*3.3 LSs' choice*

To simplify the notation of the model, we define several simple relationships. If the LSs on EX2 update their quotes, let $X = (P_{2,2}^{a} - V_{FILD})$ be their profit. Note that $P_{2,2}^{a} = P_{2,2}^{a*} - \varepsilon$, where $\varepsilon$ is the amount EX2 must reduce the ask price to match EX1. Then the profit to the LSs using EX2 if the quotes are not updated is $X + \varepsilon$. Let $Pr = P(V_{FILD} \le P_{2,2}^{a})$ be the probability that the value of an asset is less than or equal to the best ask price. Then the following relationship holds:

$$P(V_{FILD} \le P_{2,2}^{a*}) = P(V_{FILD} \le P_{2,2}^{a}) + P(P_{2,2}^{a} < V_{FILD} \le P_{2,2}^{a*}) = Pr + Pr_{\varepsilon},$$

where $Pr_{\varepsilon} = P(P_{2,2}^{a} < V_{FILD} \le P_{2,2}^{a*})$

The profits to EX2 can then be expressed as:

No update of quote:

$$\begin{array}{ll} if\ V_{FILD} \le P_{2,2}^{a*} & if\ V_{FILD} > P_{2,2}^{a*} \\ FULD: 0 & FULD: 0 \\ SLD: \alpha\lambda(X+\varepsilon) & SLD: \alpha\lambda(X+\varepsilon) \\ FILD: 0 & FILD: (1-\alpha)\mu(X+\varepsilon) \end{array} \tag{1}$$

Quote update to match EX1:

$$\begin{array}{ll} if\ V_{FILD} \le P_{2,2}^{a} & if\ V_{FILD} > P_{2,2}^{a} \\ FULD: (1-\alpha)(1-\mu)\gamma X & FULD: (1-\alpha)(1-\mu)\gamma X \\ SLD: \alpha\lambda(X) & SLD: \alpha\lambda(X) \\ FILD: 0 & FILD: (1-\alpha)\mu(X) \end{array} \tag{2}$$

The LSs at EX2 will not update their quotes if the expected profits from (1) are greater than or equal to the expected profits from (2). Specifically, if

$$\begin{gathered}(Pr+Pr_{\varepsilon})\left[\alpha\lambda(X+\varepsilon)\right]+(1-Pr-Pr_{\varepsilon})\left[\alpha\lambda(X+\varepsilon)+(1-\alpha)\mu(X+\varepsilon)\right]\ge \\ (Pr)\left[\alpha\lambda(X)+(1-\alpha)(1-\mu)\gamma X\right]+(1-Pr)\left[\alpha\lambda(X)+(1-\alpha)(1-\mu)\gamma X+(1-\alpha)\mu X\right]\end{gathered} \tag{3}$$

After some extensive algebraic simplification, the EX2 LSs' choice is governed by

$$\alpha\lambda\varepsilon+(1-Pr-Pr_{\varepsilon})(1-\alpha)\mu\varepsilon-Pr_{\varepsilon}(1-\alpha)\mu X \ge (1-\alpha)(1-\mu)\gamma X \tag{4}$$

The derivation of equation 4 is shown in Appendix A.

The first term represents the LSs' incremental gain from SLDs trading at a higher price when the EX2 quote is not updated. The next two terms represent LSs' savings in losses vis-à-vis FILDs. The second term represents the savings due to a higher trade price. We now turn to the third term. When $P_{2,2}^{a*} \ge V_{FILD} > P_{1,2}^{a}$ so that the value of the asset is greater than the ask price at EX1, but less than or equal to the non-updated price at EX2, by not updating the LSs avoid losses on the orders that would be submitted to EX2, The third term captures the benefit of avoiding these losses. Note that when this case occurs X is negative so that the value of the third term is positive. The RHS of equation 4 represents the gains to

EX2, if the price is updated, from FULD traders. These profits are sensitive to (gamma), the proportion of FULD's that will route order flow to EX2, when both exchanges are at the same price.

*3.4 Model Limitations*

Our model simplifies reality in several ways that we know are not realistic. A market may have more than two exchanges, in the U.S. market that is the focus of this study, there are nine. While the arrival rate of trades is governed by transaction time, the Flicker Quote Exception is defined in calendar time, creating a non-linear probability of order execution as a function of the time remaining in a Flicker Event. Also, quoting at Flicker Compliant Prices can be accomplished by either submitting a new limit order or by not cancelling an existing order which was at the NBBO prior to the Flicker Event. It may be useful to discuss several of these real world situations in more detail to shed light on our empirical results and highlight possible paths for future extensions.

In our model, decisions are made in transactions time. But it might be more realistic to assume that SLDs' arrivals are distributed Poison or Exponential, at a fixed rate per millisecond. In this context, consider the case when there is only one exchange (EX1) quoting at the NBBO with an ask of 20.05. Assume that EX1 initiates a Flicker Event by lowering its ask to 20.04 (creating a new NBBO Ask and Flicker Max Gap of 1). After 990 millisecond EX1 lowers its ask to 20.03 (creating a new NBBO Ask and a Flicker Max Gap of 2). Other exchanges face the decision of whether to initiate a quote at the Flicker Price of 20.05 for 10 milliseconds or at the Flicker Compliant Price of 20.04 for 1,000 milliseconds. In this case the life of the Flicker Max Gap at 2 is low so that there are likely to be few SLD order arrivals. Hence, the incentive to quote at the higher Flicker Max Gap is substantially reduced. This choice, based on the time remaining in the Flicker Event at a specific Max Gap is not included in our model.

In our examples in previous sections, we have assume that both EX1 and EX2 are quoting at the same price, say an ask of 20.05, and that EX1 reduces it ask. In this case if EX2 simply does nothing it is quoting at the Flicker Price. Perhaps the propensity to quote at a Flicker Price without taking any action is different from the propensity to quote at a Flicker Price if a new quote is required. Hence, the price path by which a quote is achieved could lead to differences in variables such as Realized Spreads, Effective Spreads, and Depth from one Flicker Event to another. In addition, the LS at EX1 can initiate a Flicker Event and simultaneously submit orders to other exchanges at the new Flicker Price. If trades occur, the LS may collect rents from both FULDs and SLDs. Or the LS at EX1 can initiate a Flicker Event by submitting a better priced order to another exchange. Depth at EX1 would then be at the Flicker Price while depth at the alternate exchange would be at the NBBO, again allowing the possibility of collecting rents from both FULDs and SLDs. The investigation of cross market strategies is beyond the scope of this paper.

*3.5 Hypothesis Development*

Equation (4) leads to a number of empirical implications. Both SLDs and FILDs initiate trades at Flicker Compliant Prices, the latter only when the true value of the asset is above the Flicker Compliant Price. This implies that quoted depth at Flicker Compliant Prices will be smaller than quoted Depth at NBBO prices. Griffin, Harris, and Topaloglu (2003) show that retail investors have smaller trade sizes compared to institutional investors. Smaller depth is also consistent with the theoretical model of Copeland and Galai (1983). We expect that SLDs are a relatively small proportion of the market with low liquidity needs. Lower quoted depths meet the liquidity requirements of the SLDs while reducing the depth exposed to FILDs. The unconditional probability of transacting with an informed trader at a Flicker Compliant Price is $\mu/(\alpha+\mu)$ while the unconditional probability of transacting with an informed trader at the NBBO is $\mu$. Since $\alpha+\mu \leq 1$, there is a higher unconditional probability of transacting with informed traders at Flicker Compliant Prices. Holding price fixed, the rational LSs will reduced quoted depths to compensate for the higher unconditional risk.[9] These considerations lead to the following hypothesis:

**Hypothesis 1:** On an exchange by exchange basis, NBBO Depth is greater than Flicker Depth.

[9] While the unconditional probability of transaction with an informed trader is higher at the Flicker Compliant Price, if the probability is conditioned on price the probability of transacting with an informed trader would be lower.

The left hand side of Equation (4) is dependent on λ while the right hand side is dependent on γ. This implies a potential clientele effect for different exchanges. If a specific exchange attracts more FULDs than SLDs, then that exchange will be more likely to update its quote and match a new NBBO. Hasbrouck (1995) and Blume and Goldstein (1997) show that regional exchanges tend to execute more retail orders, possibly through preferenced order flow. We investigate whether some exchanges attempt to attract FULDs and others seek to target SLDs. Hence, we test the null hypothesis that the propensity to quote at the NBBO (and Flicker Compliant Prices) is the same across exchanges against the following hypothesis:

**Hypothesis 2:** The propensity to quote at the NBBO (and Flicker Compliant Prices) differs across exchanges.

The left hand side of Equation (4) is increasing in ε, the Flicker Max Gap. *Ceteris paribus*, the higher the Flicker Max Gap the lower the incentive to forgo ε by updating quotes to match the NBBO. Hence, our model implies the following hypothesis:

**Hypothesis 3:** The number of exchanges competing at NBBO prices is decreasing in the magnitude of the Flicker Max Gap.

Both SLDs and FILDs trade at the Flicker Compliant Prices. By definition, trades at Flicker Compliant Prices have higher effective spreads than trades at the NBBO. However, if FILDs (SLDs) execute most of the trades at Flicker Compliant Prices, the realized spreads of these trades should be favorable (unfavorable). We cannot compare the spreads of trades executed at Flicker Compliant Prices and NBBO prices directly because high Flicker Prices result in higher effective spreads for the trades at Flicker Compliant Prices. This issue is addressed by He, Odders-White, and Ready (2006) who propose the use of a Preferencing Measure (PM) that is defined as the ratio of realized spreads to effective spreads. We assess the execution quality of trades using PM.[10] The lower the PM the better the execution quality. We test the following hypothesis:

[10] Order preferencing is also studied in Chung, Chuwongannant, and McCormick (2004) and Perterson and Sirri (2003), among others.

**Hypothesis 4:** The execution quality of trades executed at Flicker Compliant Prices is inferior to that of trades executed at NBBO prices.

In addition to these hypotheses, we also assess the impact of a change of market speed on slow and fast traders. On 10 March 2008 the NYSE migrated to a new HP UNIX platform that significantly increased the processing capabilities of the Consolidated Tape System (CTS) Multicast data feed. It is this data feed that streams quotes and trade prices to market participants.[11] Securities Industry Automation Corporation (SIAC) processing capacity reports indicate that system capacity doubled for both trades and quotes after the system migration.[12] Results in the next section indicate that market latencies may have dropped by as much as 700 milliseconds. Our expectation is that increases in market speed positively impact the execution quality of fast traders, but negatively impact the execution quality of slow traders. Specifically, as market latencies decrease, FILDs and FULDs can apply their speed and computational advantage to better target the lowest cost liquidity posted in the market. However, LSs can use their speed and computational advantage to better extract positive rents from SLDs during Flicker Events.

## 4. Data, Methods, and Sample

### *4.1 Data and Sample*

Our sample period begins on 2 January 2008 and extends through 29 August 2008, which is 168 trading days. Our data are from the Daily Trade and Quote (DTAQ) dataset, which unlike the Monthly Trade and Quote (MTAQ) dataset used extensively in microstructure studies, is time stamped to the millisecond and also contains the exchange calculated NBBO. Our sample period matches the time period of the DTAQ dataset that we have. Our dataset includes nine trading venues, each identified by its DTAQ code. Hereafter, for simplicity, we will refer to these as exchanges although the Automated Display Facility is not an exchange.

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[11] The announcement of this system migration can be found at http://www.nyxdata.com/News/Details?id=344.
[12] The August, 2007 report can be found at http://www.nyxdata.com/News/Details?id=282 and the May, 2008 report can be found at http://www.nyxdata.com/News/Details?id=365. Additional information on the migration can be found at http://www.nyxdata.com/nysedata/asp/announcements/cta_home_announceContent.asp.

For our primary sample, we select the 100 largest NYSE listed common stocks based on market capitalization on 2 January 2008. We exclude financial stocks (SIC code 6000) from our sample because the SEC banned naked short selling on selected financial stocks in July 2008. Because of this ban, during part of our sample period trading in these stocks was unique so that inclusion of these stocks could make our results less general. Also, we restrict our sample to NYSE listed securities. The NASDAQ market provides quotes for NYSE listed firms, but the NYSE will not quote on NASDAQ firms. Hence, NASDAQ firms have one less exchange offering liquidity, which would complicate our analysis without adding any significant benefit. We focus primarily on large firms because at least one exchange is always at the NBBO Bid and NBBO Ask.

### *4.2 Aligning Trades and Quotes*

The DTAQ dataset provides trades and quotes in separate files so that a critical technical requirement of our analysis is to be able to integrate the trades with the prevailing NBBO at the time of the trade execution. We align trades and quotes as follows. First, we note that our analysis is focused on trades that are executed on an exchange rather than trades that are merely reported through an exchange. Most exchanges maintain a Trade Reporting Facility (TRF) where trades that are executed off the exchange (including dark pool trades, internalized trades, and ECN trades) are reported to the consolidated tape. TRF trades are dropped from our analysis because we do not know the quote that was in force at the non-exchange executing venue and because the latency required to report the trade to the exchange introduces an unknown time shift.[13]

Our alignment process makes the following assumption. Given that almost all trades are executed in the computerized matching engine of the exchange without human interaction or input, the most correct adjustment to align the NBBO with trade prices is the time lag that maximizes the number of trades that execute at the NBBO. Specifically, for each stock day in the sample, we test quote lag times from 0 to

[13] Recent work by O'Hara and Ye (2011) indicates that TRF trades impact market quality. However, our focus is on quote strategies at the exchange level.

900 milliseconds in 25 millisecond increments. The 25 millisecond (0.025 second) time step is selected as a compromise between computational time requirements and trade quote alignment. We then select the quote lag that maximizes the number of trades that execute at the NBBO for each stock day. Thus, for each day, there is an individual lag time for each stock.

Figure 3 displays the average lag time for each stock and the percentage of trades that execute at the NBBO and the percentage that execute at or inside of the NBBO. The remaining trades (not shown) execute at Flicker Compliant Prices. While the average lag time starts out at about 750 milliseconds, on 10 March 2008 average lag times drop substantially to only 75 milliseconds. This drop in lag times results from a major system upgrade for the NYSE and SIAC. Figure 3 indicates that within system latencies dropped by about 700 milliseconds. Unfortunately, we do not have the data to estimate the change to out of system latencies, which would vary by participant location and capabilities, and represent the change in the speed at which participants receive quote and trade information. SIAC documents indicate that the system upgrade more than doubled the ability to process trades and quotes.[14] We believe that the system upgrade also significantly reduced quote latencies for fast traders—FILDs, FULDs, and LSs—while having little impact on SLDs. We investigate the impact of this event in section 5.5.

### *4.3 Flicker Volumes*

If there is no or limited trading at Flicker Compliant Prices, the strategic liquidity supply implications of our model lack practical application. Therefore, in Table 2 we report the volume (in shares) that is traded during Flicker Events at Flicker Compliant Prices. For comparison the volume traded at the NBBO during Flicker Events is also reported. For the typical stock, about 138,000 shares are traded per day at Flicker Compliant Prices. We believe that this represents a substantial amount of trading sufficient to make Flicker Events a significant economic event.

[14] This processing assessment is based on the increase in message transmission rates and bandwidth increases between the August 30, 2007 and May14, 2008 SIAC capacity reports. See footnote 10 for links to these documents.

Flicker Volume conditioned on a Flicker Event represents (138,834/(138,834 + 1,257,255) =) about 10% of total volume during Flicker Events, which gives an estimate of $\alpha$, the proportion of slow traders in the market. This level is comparable to the findings of 13% of trade volume initiated by individual traders reported by Chakravarty (2001) based on TORQ data.

## 5. Results

### *5.1 Market Liquidity under the Flicker Quote Exemption*

We begin our analysis by evaluating the amount of time in a typical trading day that each possible Flicker state is in effect. Table 3 shows the results of our analysis. The average time that a Flicker Bid Free or Flicker Ask Free state prevails is about 7.25% each. Flicker Free states have a much lower average percentage of time of 1.45%. Overall, there is a Flicker Event in effect for almost 16% of the trading day. We also report the standard deviation, median, and 25$^{th}$ and 75$^{th}$ percentiles of the distribution of Flicker Event time percentages. These results indicate that there is substantial variability in the amount of time, on a daily basis, that a Flicker Event prevails. We note that states where the NBBO is locked or crossed are also included in our analysis. From our theoretical development, these markets are no different than regular markets in regards to Flicker Events, SLDs still see past quotes and cannot observe the better prices in the market.[15] Our results show that LSs potentially can gain rents from SLDs over a significant part of the typical trading day.

### *5.2 Exchange Depth and Competitive Focus Analysis*

Hypothesis 1 states that on an exchange by exchange basis, NBBO Depth is greater than Flicker Depth. For each of the nine reporting exchanges, Table 4, Panels A, B, and C show the daily mean time weighted depths in 100 share lots for the Flicker Bid Free, the Flicker Ask Free, and the Flicker Free

[15] Locked and crossed markets are evaluated in Shiklco, Van Ness, and Van Ness (2008).

states, respectively.[16] For each exchange, we use a paired difference t-test to test the equality of the mean NBBO and Flicker Depth. Supporting Hypothesis 1, we reject the null hypothesis of equality of means. NBBO Depth is significantly greater than Flicker Depth for each exchange except for the NYSE (N) and Pacific/Arca (P) in the Flicker Free state. The larger depths at the NBBO indicate that when Flicker Events are initiated, the price move is associated with a significant amount of posted liquidity. Flicker Events are not caused by LSs updating prices with limited associated depth to step ahead of the market.

Table 4 also reports Breadth, the time weighted number of exchanges offering depth at the NBBO or Flicker Compliant Price. Uniformly, there are significantly more exchanges quoting at the NBBO than at Flicker Compliant Prices, which again indicates that multiple markets move to the NBBO during Flicker Events.

Turning to an investigation of exchanges' competitive focus, in Table 5 we have arranged the exchanges in order (from the lowest in column 2 to the highest in column 9) by percentage of time quoting at the NBBO in the Flicker Bid Free state, normalized to 100%. Specifically we report the value of ((Time at NBBO/(Time at NBBO + Time at Flicker)) X 100) and its compliment. We omit the CBOE due to its very small market share. We reject the null hypothesis of equality of means at the 0.01 level. Hence, supporting Hypothesis 2, we conclude that exchanges differ in their competitive focus with regard to quoting at the NBBO and at Flicker Compliant Prices.

To investigate exchanges' competitive focus further, for the 91,833,932 Flicker Events during our sample period, we calculate the percentage initiated by each exchange. In Table 6, we present the percentages arranged from the lowest percentage in the Flicker Bid Free state in column 2 to the highest in column 10. We reject the hypothesis of equality of means, providing additional support for Hypothesis 2. 97.5% of the Flicker Events are initiated by just four exchanges – International Stock Exchange, NASDAQ, NYSE, and ARCA/Pacific. A higher level of initiation of Flicker Events indicates a competitive focus on FULD traders by establishing best prices in the market.

[16] During the period of our analysis AMEX and the Boston Stock Exchange were not active with no recorded trade volume or quotes.

*5.3 Flicker Price Competition as a Function of the Range of Flicker Compliant Prices*

Hypothesis 3 indicates that the level of competition at the NBBO is decreasing in the Flicker Max Gap. We test this hypothesis and present the results in Table 7, column 2. Recall that all of the observations occur during Flicker Events. In each case we reject the null hypothesis of equality of means in favor of the hypothesis that the number of exchanges quoting at the Flicker Max Gap is lower than the number quoting at the Flicker Max Gap -1. This provides strong evidence that as the Flicker Max Gap increases, exchanges are drawn away from quoting at the NBBO and toward quoting at Flicker Compliant Prices.

In Table 7, Panel A, the columns labeled 1 through 10+ show the quoting behavior for those exchanges that are quoting at Flicker Compliant Prices. We can analyze the quoting behavior of exchanges looking across the rows or down the columns. Notice that for each row the column labeled 1 and the last populated column for the row before the first column with “-- “ have the highest values. When a Flicker Event begins some exchanges are drawn to quoting at Flicker Compliant Prices. There is a tendency to begin by quoting at the Gap of 1, but as the Max Gap increases exchanges are drawn to quoting at a wider Gap. And the pull of quoting at the Max Gap increases as the size of the Max Gap increases. Hence, the first time that the number of exchanges quoting at the Max Gap equals the number quoting at the Gap of 1 is when the Max Gap is 8.

Looking down the columns, for column 1 the number of exchanges quoting at the Flicker Max Gap in each row become significantly lower as the Max Gap increases. The same pattern is evident in the columns labeled 2 through 8. We do not test the row labeled 10+ because it is a composite of more than one Max Gap.

Table 7, Panel B, which limits our observations to those Flicker Events with a life of at least 50 milliseconds, sheds additional light on exchange quoting behavior. Notice that in this Panel for each row the number of exchanges quoting at the Max Gap is highest in the column just before the first column with “-- “. This indicates that, as expected, the incentive to quote at the Max Gap increases when the life of the Flicker Event is longer. These results provide robust evidence that Flicker Events strongly affect quoting behavior.

*5.4 Spread Analysis of Trades at Flicker Compliant Prices*

In Table 8, we report effective and realized half spreads in cents for use in testing Hypothesis 4. Effective half spreads are the difference between the execution price and the prevailing NBBO at the time of execution. Realized half spreads are the difference between the execution price and the prevailing NBBO 5 minutes after the trade. The NBBO is aligned with trades for each stock day based on the method outlined in section 4.2. Since effective spreads can be zero, resulting in an infinite value of the PM measure, we eliminate observations with effective spreads less than 0.01 cents. Locked and crossed NBBO market states are included our analysis. We also remove trades that execute against hidden liquidity by requiring that trades execute at the posted quote. For the Flicker Ask (Bid) Free state, effective and realized half spreads are calculated using only trades at the ask (bid).

Table 8, Panels A, B, and C, show the Flicker Bid Free, the Flicker Ask Free, and the Flicker Free states, respectively. At Ask and At Bid refer to trades executed at the NBBO Ask and NBBO Bid, respectively, while At Flicker refers to trades executed at Flicker Compliant Prices. Uniformly, we find that the execution quality of trades at Flicker Compliant Prices is significantly lower than for NBBO trades. For example, in the Flicker Free Bid state, the PM for NBBO trades is 0.126, while for trades at Flicker Compliant Prices it is 0.707. We reject the null hypothesis of equality at the 1% level in favor of Hypothesis 4.

In addition, our results indicate that strategic LSs can improve their probabilities of trading with uninformed traders by posting liquidity at Flicker Compliant Prices. This results in substantial economic benefits to LSs. Numerically, the average Flicker Volume per stock day is 138,834 shares at an average increase in effective spreads of about 1.3 cents. With 100 companies and 168 days in our sample, the increased profits to LSs trading at Flicker Compliant Prices is (100 companies x 168 days x 1.3 cents per share x 138,834 shares per day =) $30.3 million dollars. Projected over a typical 252 day trading year the profits are estimated at $45.5 million. Since the Flicker Quote Exception is applicable to all exchange traded equities, such as Exchange Traded Funds, Real Estate Investment Trusts, and preferred stock, in section 5.7 we estimate the profit impact for an extended sample of equities.

### *5.5 The Impact of Market Speed*

#### *5.5.1 Univariate Spread Analysis*

Our model explicitly assumes that all fast traders can observe quote updates instantaneously, with zero latency. However, all traders have some level of latency in observing quote updates. The maximum possible speed that any trader can achieve is limited by the speed of the exchange. If the exchange is relatively slow at disseminating quotations, even fast traders might trade at Flicker Prices. If the market increases the speed of quote dissemination, fast liquidity demanders and suppliers are better able to take advantage of the reduced latency to target liquidity at NBBO quotes.

On 10 March 2008 the NYSE migrated to a new, more powerful, platform that significantly increased computational and communication speed. Using March 10 as the event day, we compare the effective half spread, the realized half spread and the PM of trades for slow traders (trading at Flicker Compliant Prices) and fast liquidity demanders (trading at NBBO prices) and present the results in Table 9. Using a mean difference test, for trades at the NBBO, we reject the hypothesis of equality in each case indicating that faster markets are beneficial to fast traders. However, for trades at Flicker Compliant Prices, we reject the hypothesis of equality for PM in favor of a positive change, but we cannot reject the hypothesis of equality for the two spread measures. Since a higher PM value indicates reduced execution quality, we conclude that the decrease in market latency harmed slow traders. Overall, our results indicate that increases in market speed are beneficial to fast traders, but have a negative impact on slow traders.

*5.5.2 Regression Analysis*

Our univariate analysis indicates that market quality degraded for SLDs, but improved for fast traders, after the reduction in latency on the NYSE. To extend our analysis and control for variables that could possibly affect execution quality for fast and slow traders in the pre and post periods, we estimate the following equation:

$$PM_{i,t} = \alpha + \beta_1 Spd + \beta_2 LnTrdCnt_{i,t} + \beta_3 MpVar_{i,t} + \beta_4 AvgTrdSz_{i,t} + \beta_5 TmFlk_{i,t} + \varepsilon_t \qquad (5)$$

where PM represents the preferencing measure.[17] *Spd* is a dummy variable that equals 0 prior to 10 March 2008 and 1 otherwise. *LnTrdCnt* is the log of the number of trades executed, *MpVar* is the NBBO quote midpoint variance for the full trading day, *AvgTrdSz* is the average trade size, and *TmFlk* is the percentage of the trading day with Flicker Events. We estimate the regression separately for trades at Flicker Compliant Prices and the NBBO. In addition, we estimate the regression two ways—as a cross sectional fixed effects time series regression and by stock. In the latter case, we test whether the average coefficient is statistically different from zero.[18]

Table 10 shows our regression results for PM. The key result is that the speed dummy variable is significantly positive for trades at Flicker Compliant Prices, but significantly negative for trades at the NBBO. This result confirms the univariate analysis that the decrease in latency on the NYSE degraded execution quality for SLDs, but improved execution quality for fast traders. These results are robust to both the fixed effects and stock day regression approaches. We believe that as market speed increases, fast traders are better able to target executions at NBBO prices, improving their execution quality. However, fast liquidity suppliers are also better able to target slow traders during Flicker Events, further reducing the execution quality when market speed increases.

[17] We replicate the regression analysis using Effective Spread, and Realized Spread, in turn, as the dependent variable, but we do not present the results because of their similarity to those presented here,

[18] Regression analyses to evaluate trading costs have been used by McInish and Wood (1992), Madhavan (2000), Stoll (2000), and Bessimbinder (2003).

*5.7 Market Wide Impact of Flicker Events*

To reduce computational complexities, above we used a sample of the 100 largest firms. In this section we evaluate the impact of Flicker Events for all securities (common stocks, Exchange Traded Funds, Real Estate Investment Trusts, and preferred stock) in the DTAQ database with a closing price over $5 each day for the week of 24 March 2008. This period is two weeks after the platform migration of the NYSE, allowing time for the market to stabilize. First, we align trades prices and (NBBO) quotes based on the method outlined in section 4.2. Then, for Flicker Events, we evaluate the Flicker (effective half) Spread, the NBBO (effective half) Spread, Flicker Volume, and the additional profit obtained by LSs by offering liquidity at Flicker Compliant Prices.

Table 11 shows the results of our market wide analysis. We report the mean daily value of each variable. From a policy standpoint, we feel that the one second definition of the Flicker Quote Exception is excessive in today's market. We estimate the impact of reducing the Flicker Price look back time by 200 millisecond increments. These values are shown in the column labeled Flicker Time. We calculate the additional profit to LSs from trades at Flicker Compliant Prices. If the execution price is greater than the NBBO Ask, we compute the profit per share as the execution price minus the NBBO Ask. If the execution price is less than the NBBO Bid, we compute the profit per share as the NBBO Bid minus the execution price. The total profit per trade is the profit per share multiplied by the number of shares in the transaction. As the Flicker Price look back time is decreased, we drop trades that occur at prices inferior to the Flicker Price because these trades would be rerouted to exchanges quoting at the NBBO and would not be executed at the higher price contained in the DTAQ record. We also note that NBBO (effective) Spreads drop as the Flicker Price look back time is decreased. This is an artifact of the data. As the Flicker Price look back time is decreased, the duration and frequency of Flicker Events is also reduced, dropping the effective spread of trades at the NBBO.

Under the current Flicker Quote Exemption's 1,000 millisecond look back for the Flicker Price, the average profit to LSs is about $1.12 million per day. In a typical year of 252 trading days, this yields $281 million of profit. In addition, our results indicate that over 76 million shares are traded at Flicker

Compliant Prices. As the Flicker Price look back time is reduced from 1,000 milliseconds to 200 milliseconds, LSs' profits drop to $0.66 million per day, or $165 million per year. This analysis is conservative because we are not able to take into account the decreased incentive to quote at Flicker Compliant Prices that would result from a reduction in the allowed look back time. In addition, since TRF trades are not included in our analysis because of potential alignment issues with trades and NBBO quotes, there is likely additional profit that we are not capturing. While we evaluate Flicker Price look back times as low as 200 milliseconds, we are not specifically recommending that the Flicker Price look back time should be reduced to 200 milliseconds. Instead, we feel that the Flicker Price look back time should be set based on current market conditions that evaluate the inter-exchange latency required to disseminate the NBBO. This look back time could be well under 200 milliseconds in current markets. Overall, these results indicate that the Flicker Quote Exception liquidity supply strategy is economically significant, highly profitable for LSs, and very costly for SLDs.

## 5. Conclusion

The speed of entry and either execution or cancellation of quotes has increased dramatically. However, not all traders have kept pace in their ability to deal with this fast paced trading environment. In a market with both slow and fast traders, we investigate how strategic liquidity suppliers (such as dealers, market makers, and High Frequency Traders) can submit limit orders with a high probability of transacting against slow traders (likely dominated by retail, uninformed clients). The SEC's Flicker Quote Exception to the Order Protection Rule allows trades on an exchange to occur at prices inferior to the best contemporaneous prices on other exchanges as long as the trade occurs at a price equal to or better than the Flicker Price. The Flicker Price is the least aggressive NBBO Bid and the least aggressive NBBO Ask over the past one second. Since fast traders see the market prices in real time, they only rout trades to markets with quotes at the NBBO. Slow traders, however, observe quotes at a time delay and may rout trades to markets with quotes at prices inferior to the NBBO (Flicker Compliant Prices),.

We develop a model to investigate this market environment and derive a number of empirically testable implications. We obtain the following results that support our model. On an exchange by exchange basis quoted depths are significantly smaller at Flicker Compliant Prices than at the NBBO. In addition, we demonstrate that the propensity to quote at the NBBO and at Flicker Compliant Prices varies across exchanges. The International Stock Exchange, NYSE, ARCA/Pacific, and NASDAQ quote most often at the NBBO while Chicago Stock Exchange, National Stock Exchange, Automated Display Facility, Philadelphia Stock Exchange, and the CBOE are more likely to quote at Flicker Compliant prices. Furthermore, the level of competition at the NBBO decreases as the gap between the Flicker Compliant Price and the NBBO increases. Finally, the execution quality of trades at Flicker Compliant Prices is significantly lower than for trades at the NBBO.

Based on our sample of 100 NYSE stocks and 168 days of trading, we estimate that liquidity suppliers that strategically quote at Flicker Compliant Prices earn $45.5 million in a typical year. Using an extended sample of all equities contained in the Daily Trade and Quote database with a price over $5, we estimate that the market wide impact of the Flicker Quote Exception is $281 million per year in profits to fast liquidity suppliers at the expense of slow retail traders.

On 10 March 2008 the NYSE migrated to a significantly faster computer platform. As a result of this migration, latencies dropped by as much as 700 milliseconds. We use this event to examine how increases in market speed impact fast and slow traders. Our results indicate that execution quality for fast traders improves significantly as market speed increases. However, execution quality for slow traders decreases. Our analysis indicates that as markets become faster, fast traders are better able to avoid trading at Flicker Prices. However, fast liquidity suppliers are also better able to target slow traders at Flicker Prices, earning rents. We show that while both effective and realized spreads of NBBO trades decrease after the market speed increases, the execution quality of trades at Flicker Prices also decrease. Given the speed of today’s markets, we recommend that the one second Flicker Quote Exception specification be reduced based on a periodic evaluation of market latencies.

**Appendix A**

Proof:

We show that Equation 3 from the text can be restated as Equation 4 from the text.

$$\begin{aligned}(Pr+Pr_{\varepsilon})\left[\alpha\lambda(X+\varepsilon)\right]+(1-Pr-Pr_{\varepsilon})\left[\alpha\lambda(X+\varepsilon)+(1-\alpha)\mu(X+\varepsilon)\right]\geq \\ (Pr)\left[\alpha\lambda X+(1-\alpha)(1-\mu)\gamma X\right]+(1-Pr)\left[\alpha\lambda X+(1-\alpha)(1-\mu)\gamma X+(1-\alpha)\mu X\right]\end{aligned} \quad \text{(Eq. 3)}$$

Multiplying out the equation, we have

$$\begin{aligned}&Pr\alpha\lambda X+Pr\alpha\lambda\varepsilon+Pr_{\varepsilon}\alpha\lambda X+Pr_{\varepsilon}\alpha\lambda\varepsilon+\alpha\lambda X+\alpha\lambda\varepsilon+(1-\alpha)\mu X+(1-\alpha)\mu\varepsilon-Pr\alpha\lambda X-Pr\alpha\lambda\varepsilon \\ &-Pr(1-\alpha)\mu X-Pr(1-\alpha)\mu\varepsilon-Pr_{\varepsilon}\alpha\lambda X-Pr_{\varepsilon}\alpha\lambda\varepsilon-Pr_{\varepsilon}(1-\alpha)\mu X-Pr_{\varepsilon}(1-\alpha)\mu\varepsilon\geq \\ &Pr\alpha\lambda X+Pr(1-\alpha)(1-\mu)\gamma X+\alpha\lambda X+(1-\alpha)(1-\mu)\gamma X+(1-\alpha)\mu X \\ &-Pr\alpha\lambda X-Pr(1-\alpha)(1-\mu)\gamma X-Pr(1-\alpha)\mu X\end{aligned} \quad \text{(A.1)}$$

Next we cancel terms on the same side to find:

$$\begin{aligned}&\alpha\lambda X+\alpha\lambda\varepsilon+(1-\alpha)\mu X+(1-\alpha)\mu\varepsilon-Pr(1-\alpha)\mu X \\ &-Pr(1-\alpha)\mu\varepsilon-Pr_{\varepsilon}(1-\alpha)\mu X-Pr_{\varepsilon}(1-\alpha)\mu\varepsilon\geq \\ &\alpha\lambda X+(1-\alpha)(1-\mu)\gamma X+(1-\alpha)\mu X-Pr(1-\alpha)\mu X\end{aligned} \quad \text{(A.2)}$$

Then cancel terms on both sides of the inequality to produce

$$\begin{aligned}\alpha\lambda\varepsilon+(1-\alpha)\mu\varepsilon-Pr(1-\alpha)\mu\varepsilon-Pr_{\varepsilon}(1-\alpha)\mu\varepsilon-Pr_{\varepsilon}(1-\alpha)\mu X\geq \\ (1-\alpha)(1-\mu)\gamma X\end{aligned} \quad \text{(A.3)}$$

Finally, we factor the terms in the center to have the final equation:

$$\begin{aligned}\alpha\lambda\varepsilon+(1-Pr-Pr_{\varepsilon})(1-\alpha)\mu\varepsilon-Pr_{\varepsilon}(1-\alpha)\mu X\geq \\ (1-\alpha)(1-\mu)\gamma X\end{aligned} \quad \text{(Eq. 4)}$$

Q.E.D

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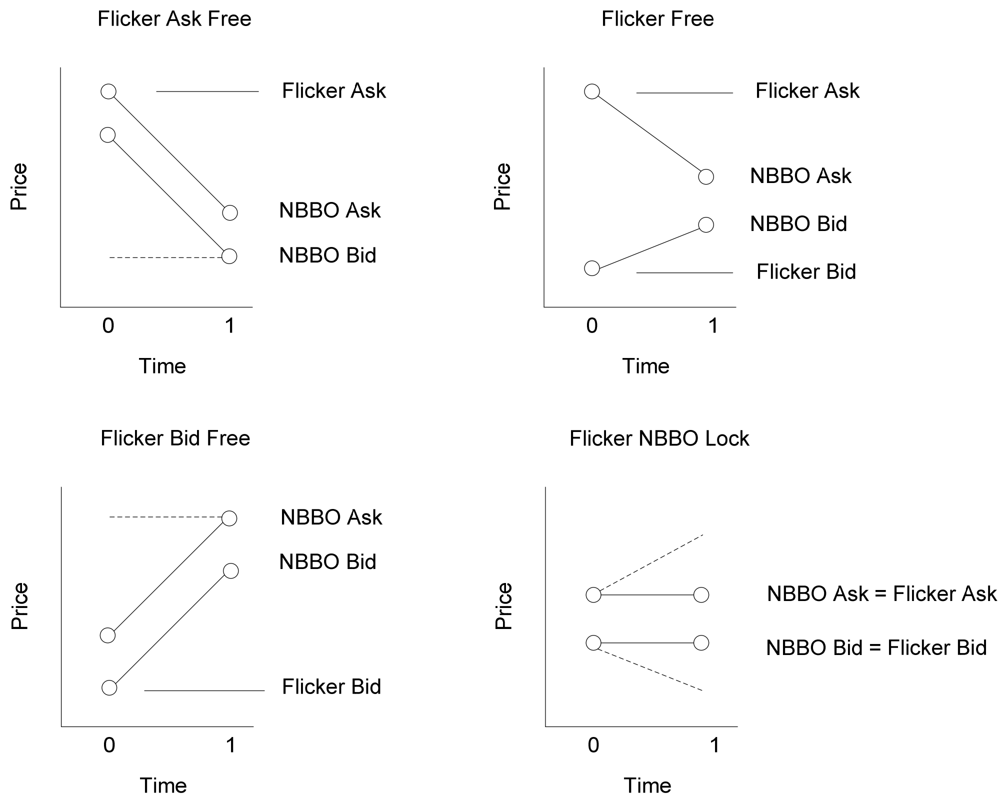


**Figure 1. Four Possible States.**

Case 1: Flicker Ask Free. In a downward trending market the NBBO Bid, either decreasing or unchanged, is equal to the Flicker Bid. The Flicker Ask is greater than the NBBO Ask.
Case 2: Flicker Bid Free. In an upward trending market the NBBO Ask, either increasing or unchanged, is equal to the Flicker Ask. The Flicker Bid is less that the NBBO Ask.
Case 3: Flicker Free. Spreads narrow from both sides of the quote creating both a Flicker Ask and Flicker Bid.
Case 4: Flicker NBBO Lock. The NBBO Ask equals the Flicker Ask and the NBBO Bid equals the Flicker Bid. On each side of the market, the quote must either remain unchanged for one second or become inferior.
Cases 1-3 are states in which a Flicker Event has occurred. The least aggressive price at which a trade can be made without triggering a trade through is the Flicker Price. If there are prices that are superior to the Flicker Price, but inferior to the NBBO, these are Flicker Compliant Prices.

| T=0 | T=1 | T=2 | T=3 | T=4 |
|---|---|---|---|---|
| $P^a_{1,0}(=P^a_{2,0})$ <br> $P^a_{2,0}(=P^a_{1,0})$ | $P^a_{1,1} < P^a_{1,0}$ <br> $P^a_{2,1} = P^a_{2,0}$ | $P^a_{1,2} = P^a_{1,1}$ <br> $P^a_{2,2} \in \{P^a_{2,1}, P^a_{1,1}, P^a_{2,1} + k\}$ | | |
| EX1 and EX2 post equal prices at the ask. | EX1 updates the ask price to a lower price than EX2 | EX2 chooses to update or not update its quote | FILDs and FULDs observe quotes at T=2 while SLDs observe quotes at T=0. Trades are submitted to the market and executed | True asset value revealed |

**Figure 2. Model Time Line.**

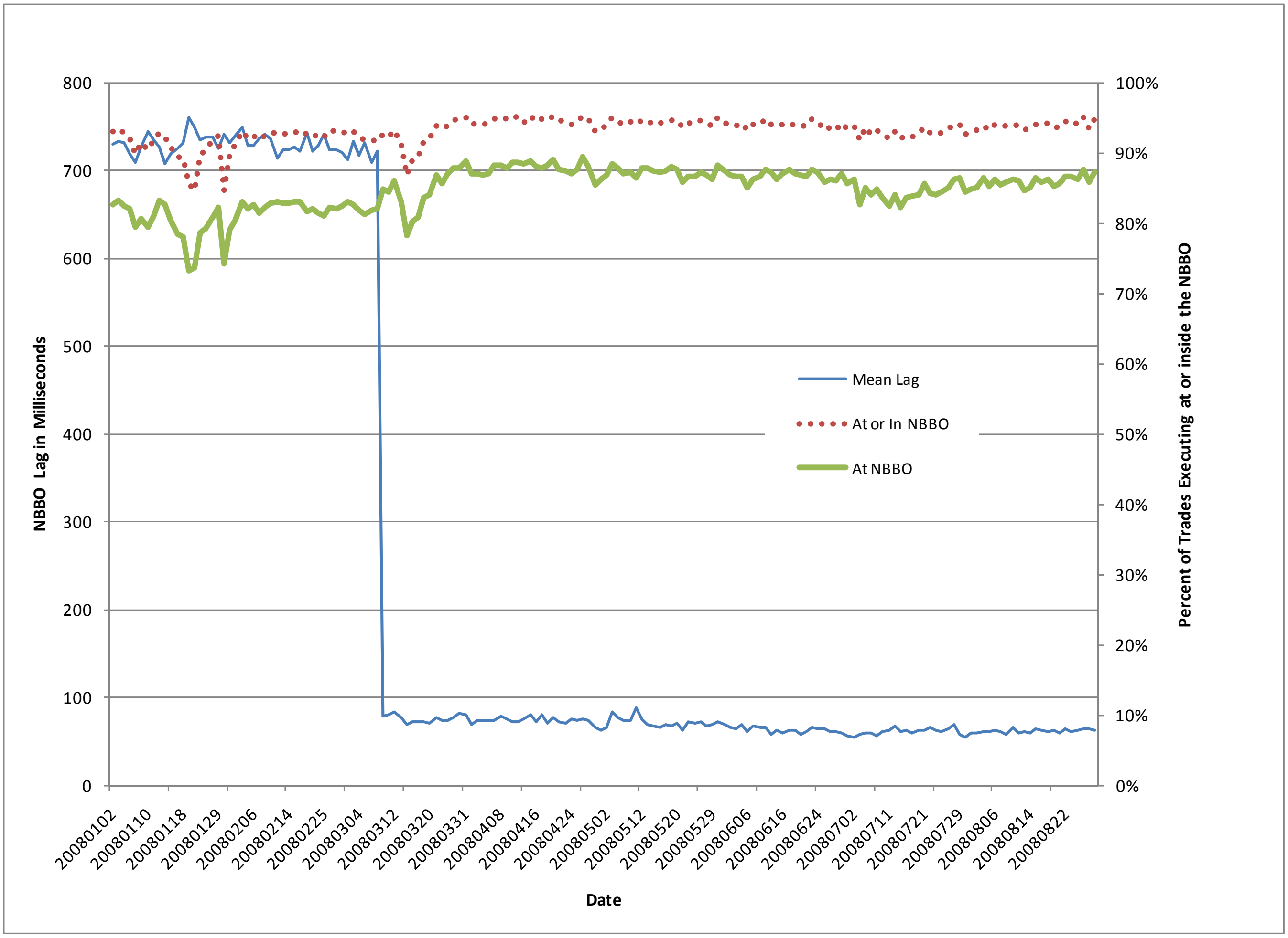


**Figure 3: Optimal Time Lag to Optimize Quote and Trade Alignment; Percentage of Trades at or Inside the NBBO.**

We need to match (align) the NBBO Ask and Bid in the Quote File with trade prices in the Trade File. The majority of trading in the post Reg NMS market takes place automatically inside each exchange's matching engine. Hence, we believe that the optimal alignment occurs when the time lag yields the highest percentage of trades executing at the NBBO. For each stock day, we examine time lags from 0 to 900 milliseconds at 25 millisecond increments, in turn, and select the time lag that produces the greatest percentage of trades that execute at the NBBO. We present the mean daily time lag on the left vertical axis and the mean percentage of trades that execute at or inside the NBBO on the right vertical axis.

**Table 1**
**Key Terms.**

| Term | Definition |
|---|---|
| Breadth | The time weighted number of exchanges offering depth at a specified price. The prices can be the NBBO Ask (Bid) or at Flicker Compliant Prices. |
| Flicker Ask Depth | The total depth on the ask side offered at Flicker Compliant Prices. |
| Flicker Ask Free | The market state in which the Flicker Ask is greater than the NBBO Ask. In this state, buyer-initiated trades can execute at prices above the NBBO Ask, but at or below the Flicker Ask, without violating the Order Protection Rule. |
| Flicker Ask | The least aggressive NBBO Ask price over the previous one second of trading. This price is used to evaluate trade throughs. |
| Flicker Bid Depth | The total depth offered on the bid side at Flicker Compliant Prices. |
| Flicker Bid Free | The market state in which the Flicker Bid is less than the NBBO Bid. In this state seller-initiated trades can execute at prices less than the NBBO Bid, but at or above the Flicker Bid, without violating the Order Protection Rule. |
| Flicker Bid | The least aggressive NBBO Bid over the previous one second. This price is used to evaluate trade throughs. |
| Flicker Compliant Price | A price equal to or better than an exchange's Flicker Price, but inferior to the NBBO. |
| Flicker Depth | The sum of the Flicker Ask Depth and the Flicker Bid Depth. |
| Flicker Event | A period when Flicker Compliant Prices are in effect. |
| Flicker Free | The market state where the Flicker Ask is greater than the NBBO Ask and the Flicker Bid is less than the NBBO Bid. Trades can occur at prices inferior to the NBBO, but at Flicker Compliant Prices without violating the Order Protection Rule. |
| Flicker Gap | The difference in cents, between the NBBO Ask (Bid) and a Flicker Compliant Price on the ask (bid) side of the market. If the Flicker Ask is 20.05 and the NBBO Ask is 20.01, then the Flicker Gap can equal 1, 2, 3, and 4 cents. |

Table 1 Continued

| | |
|---|---|
| Flicker Max Gap | The difference in cents, between the NBBO Ask (Bid) and the Flicker Ask (Bid). If the Flicker Ask is 20.05 and the NBBO Ask is 20.01, then the Flicker Max Gap is 4 cents. |
| Flicker NBBO Lock | The state in which (1) the NBBO has remained unchanged for one second, (2) both of the NBBO Ask and NBBO Bid have widened, or (3) either the NBBO Bid or NBBO Ask has widened and the other side of the market has remained unchanged for one second. In this state the Flicker Bid equals the NBBO Bid and the Flicker Ask equals the NBBO Ask. |
| Flicker Price | The Flicker Ask and the Flicker Bid taken together. |
| Flicker Quote Exemption | An exemption to the Order Protection Rule that defines the reference price (called the Flicker Price) for the evaluation of a trade through. As long as an exchange's trades are at prices equal to or better than its Flicker Price (called Flicker Compliant Prices) other exchanges cannot claim that the exchange is trading through their better quotes. |
| Flicker Spread | The difference between the Flicker Ask and the Flicker Bid. |
| Flicker Trade | A trade that occurs at a Flicker Compliant Price. |
| Flicker Volume | The total volume associated with Flicker Trades. |
| NBBO Ask | The market wide best ask. |
| NBBO Ask Depth | The total depth offered at the NBBO Ask. |
| NBBO Bid | The market wide best bid. |
| NBBO Bid Depth | The total depth offered at the NBBO Bid. |
| NBBO Depth | The sum of the NBBO Ask Depth and the NBBO Bid Depth. |
| NBBO (Quote) | The NBBO Ask and the NBBO Bid together. |

Table 1 Continued

| | |
|---|---|
| Order Protection Rule | Rule 611, adopted by the Securities and Exchange Commission (SEC) in 2005. This rule protects top of book limit orders from trade throughs at inferior prices at other exchanges when the orders are eligible for NBBO quote participation. |
| Preferencing Measure | The ratio of realized spreads to effective spreads defined by He, Odders-White, and Ready (2007) |

**Table 2**
**Flicker and NBBO Volume.**

We present the trade volume at Flicker Compliant Prices and the NBBO for each Flicker state. Volume is the mean daily trading volume for each stock for each day during Flicker Events (excluding TRF volume).

| | Volume | |
|---|---|---|
| | Flicker | NBBO |
| Flicker Free Bid | 48,491 | 508,873 |
| Flicker Free Ask | 47,722 | 509,537 |
| Flicker Free | | |
| Flicker Bid | 21,484 | 119,556 |
| Flicker Ask | 21,137 | 119,289 |
| Total | 138,834 | 1,257,255 |

**Table 3**
**Percentage of Time that the Market is in each Flicker State.**

As shown in Figure 1, there are four possible Flicker states: Flicker Ask Free, Flicker Bid Free, Flicker Free and Flicker NBBO Lock. Total is the sum for the first three Flicker states. For the period 2 January 2008 through 29 August 2008 for the 100 largest NYSE listed common stocks (excluding financial firms), we present the percentage of time that the market is in each Flicker state.

| Statistic | Flicker Bid Free | Flicker Ask Free | Flicker Free | Total | Flicker NBBO Lock |
|---|---|---|---|---|---|
| Mean | 7.24% | 7.25% | 1.45% | 15.93% | 84.07% |
| Std | 4.47% | 4.49% | 1.83% | 10.53% | 10.53% |
| Median | 6.33% | 6.32% | 0.78% | 13.50% | 86.50% |
| 25% | 3.89% | 3.88% | 0.35% | 8.19% | 78.20% |
| 75% | 9.95% | 9.94% | 1.82% | 21.80% | 91.81% |

**Table 4**
**NBBO and Flicker Depth.**

For each of nine reporting exchanges, we present the mean daily time weighted Flicker and NBBO Depth in round lots of 100 shares. NBBO Bid Depth and NBBO Ask Depth are the time weighted depths displayed at the NBBO during Flicker Events. Flicker Bid Depth and Flicker Ask Depth are the time weighted depths displayed on each side of the market, respectively, during Flicker Events. Breadth represents the time weighted number of exchanges quoting at the NBBO or at Flicker Compliant Prices. The results for the Flicker Bid Free, Flicker Ask Free, and Flicker Free states are presented in Panels A, B, and C, respectively. For each exchange, using a paired t-test, we test the null hypothesis that there is no difference between the NBBO and Flicker Depths. * indicates significance at the 0.01 level.

| | Exchange | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | D | I | M | N | P | T | X | W | Breadth |
| **Panel A: Free Bid Free** | | | | | | | | | | |
| NBBO Bid Depth | 10.56 | 5.00 | 9.49 | 3.03 | 14.10 | 10.24 | 15.74 | 1.67 | 1.95 | 2.27 |
| Flicker Bid Depth | 3.52 | 0.65 | 4.63 | 0.44 | 5.99 | 3.32 | 4.01 | 0.96 | 0.04 | 1.82 |
| Paired Difference | -7.04* | -4.35* | -4.86* | -2.59* | -8.11* | -6.91* | -11.73* | -0.72* | -1.91* | -0.45* |
| **Panel B: Free Ask Free** | | | | | | | | | | |
| NBBO Ask Depth | 7.57 | 3.58 | 10.48 | 2.13 | 6.61 | 9.19 | 14.10 | 1.70 | 1.66 | 2.26 |
| Flicker Ask Depth | 2.74 | 0.62 | 2.90 | 0.44 | 5.50 | 2.39 | 2.77 | 0.77 | 0.04 | 1.82 |
| Paired Difference | -4.83* | -2.97* | -7.57* | -1.69* | -1.11* | -6.79* | -11.33* | -0.93* | -1.63* | -0.44* |
| **Panel C: Flicker Free** | | | | | | | | | | |
| NBBO Bid Depth | 5.22 | 2.75 | 6.23 | 1.43 | 3.93 | 5.33 | 8.92 | 1.57 | 1.78 | 1.62 |
| Flicker Bid Depth | 4.36 | 0.50 | 5.20 | 0.45 | 6.48 | 5.72 | 7.93 | 0.87 | 0.06 | 2.02 |
| Paired Difference | -0.88* | -2.04* | -1.02* | -0.90* | 2.54* | 0.44* | -1.06* | -0.65* | -1.73* | 0.39* |
| | | | | | | | | | | |
| NBBO Ask Depth | 5.24 | 2.54 | 6.22 | 1.35 | 3.94 | 5.28 | 8.98 | 1.52 | 1.78 | 1.63 |
| Flicker Ask Depth | 4.42 | 0.54 | 5.28 | 0.48 | 6.69 | 5.76 | 8.12 | 0.87 | 0.05 | 2.03 |
| Paired Difference | -0.81* | -2.21* | -0.96* | -0.95* | 2.76* | 0.43* | -0.81* | -0.69* | -1.73* | 0.40* |

Note: C = National Stock Exchange, D = Automated Display Facility, I = International Stock Exchange, M = Chicago Stock Exchange, N = NYSE, P = ARCA/Pacific, T = NASDAQ, X = Philadelphia Stock Exchange, and W = CBOE.

**Table 5**
**Exchange Competitive Focus.**

We examine the competitive focus of exchanges during Flicker Events. Beginning with the times when the market is in the Flicker Bid Free state, for each exchange for each stock for each day, we calculate ((Time at NBBO/(Time at NBBO + Time at Flicker)) X 100) and report the result in the first row labeled NBBO in Panel A. The value reported in each column of the second row is 100% minus the value in the respective column of the first row. We present the results beginning with the exchange with the smallest value for NBBO in the Flicker Bid Free state and continuing with successively higher values. We repeat the analysis for the Flicker Ask Free and Flicker Free states and present the results in Panels B and C, respectively. For Panels B and C we retain the ordering of Panel A. The Ask and Bid sides of the market are combined for the Flicker Free state. The F-statistic is from an equality of means test. Although not reported, we also conduct a Tukey and Bonferroni tests for equality and obtain similar outcomes. * indicates that equality is rejected at the 1% level.

| | Exchange | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | D | M | X | C | N | P | T | I | F-statistic |
| **Panel A: Flicker Bid Free** | | | | | | | | | |
| NBBO | 17.3% | 26.6% | 38.1% | 39.9% | 46.5% | 57.8% | 58.6% | 62.5% | 10,380* |
| Flicker | 82.7% | 73.4% | 61.9% | 60.1% | 53.5% | 42.2% | 41.4% | 37.5% | |
| **Panel B: Flicker Ask Free** | | | | | | | | | |
| NBBO | 18.8% | 36.4% | 39.1% | 43.5% | 46.6% | 57.8% | 58.6% | 62.7% | 7,700* |
| Flicker | 81.2% | 63.6% | 60.9% | 56.5% | 53.4% | 42.2% | 41.4% | 37.3% | |
| **Panel C: Flicker Free** | | | | | | | | | |
| NBBO | 21.0% | 21.9% | 16.5% | 35.2% | 48.8% | 44.4% | 44.7% | 48.5% | 8,362* |
| Flicker | 79.0% | 78.1% | 83.5% | 64.8% | 51.2% | 55.6% | 55.3% | 51.5% | |

Note: C = National Stock Exchange, D = Automated Display Facility, I = International Stock Exchange, M = Chicago Stock Exchange, N = NYSE, P = ARCA/Pacific, T = NASDAQ, X = Philadelphia Stock Exchange, and W = CBOE.

**Table 6**
**Initiation of flicker events by exchange**

We report the percentage of Flicker Events initiated by each exchange. Flicker Bid Free, Flicker Ask Free, and Flicker Free states are reported in Panels A, B, and C, respectively. For each state we report results for the Full sample period and for the period before (Pre) and after (Post) the NYSE speed change. F-Stat is the F statistic of a joint test of equality. * indicates that equality is rejected at the 1% level.

| | X | W | M | D | C | P | N | I | T | F-Stat |
|---|---|---|---|---|---|---|---|---|---|---|
| **Panel A: Bid Free** | | | | | | | | | | |
| Full | 0.0% | 0.0% | 0.1% | 0.1% | 2.2% | 16.8% | 19.4% | 30.6% | 30.7% | 42,571* |
| Pre | 0.0% | 0.1% | 0.0% | 0.2% | 1.8% | 12.9% | 24.2% | 30.5% | 30.3% | 11,734* |
| Post | 0.0% | 0.0% | 0.1% | 0.1% | 2.4% | 18.3% | 17.6% | 30.7% | 30.8% | 32,484* |
| **Panel B: Ask Free** | | | | | | | | | | |
| Full | 0.0% | 0.0% | 0.1% | 0.1% | 2.3% | 17.0% | 19.0% | 30.9% | 30.6% | 43,228* |
| Pre | 0.0% | 0.1% | 0.0% | 0.1% | 1.8% | 12.9% | 24.0% | 30.8% | 30.3% | 11,924* |
| Post | 0.0% | 0.0% | 0.1% | 0.1% | 2.5% | 18.5% | 17.1% | 31.0% | 30.8% | 33,086* |
| **Panel C: Flicker Free** | | | | | | | | | | |
| Full | 0.0% | 0.2% | 0.2% | 0.8% | 3.2% | 13.0% | 41.4% | 22.0% | 19.3% | 92,366* |
| Pre | 0.0% | 0.4% | 0.1% | 0.6% | 2.8% | 11.5% | 45.9% | 19.4% | 19.2% | 33,896* |
| Post | 0.0% | 0.0% | 0.2% | 0.9% | 3.3% | 13.5% | 39.7% | 22.9% | 19.3% | 63,478* |

Note: C = National Stock Exchange, D = Automated Display Facility, I = International Stock Exchange, M = Chicago Stock Exchange, N = NYSE, P = ARCA/Pacific, T = NASDAQ, X = Philadelphia Stock Exchange, and W = CBOE.

**Table 7**
**Exchange Quoting Behavior**

We evaluate quoting behavior at the NBBO and at Flicker Compliant Prices for the overall market during Flicker Events and present the results in Panel A. Flicker Max Ask (Bid) Gap is the distance in cents between the NBBO and the Flicker Ask (Bid). We perform our analysis for each side of the market separately for each Flicker state and then average across states. The first row examines quoting behavior for Flicker Events with a Flicker Max Ask (Bid) Gap of 1 cent. During this Flicker Event, LSs at an exchange can quote at the NBBO, which has a Flicker Gap of 0, or at the Flicker Price, which has a Flicker Gap of 1. On a time weighted basis, 2.26 exchanges quote at the NBBO and 1.73 exchanges quote at the Flicker Price. The second row presents the results for Flicker Events with a Flicker Max Ask (Bid) Gap of 2 cents when exchanges can quote at the NBBO (Flicker Gap = 0), at the Flicker Price (Flicker Gap = 2), or at a Flicker Compliant Price (Flicker Gap = 1). We continue in this fashion for each of the remaining rows. The penultimate column presents the number of exchanges quoting at Flicker Compliant Prices and the last column presents Total Breadth, which is the count of the number of exchanges quoting at the NBBO and at Flicker Compliant Prices. For the columns 2-11, in turn, beginning with the second populated row in each column, we test the null hypothesis of equality of means for row i and row i-1. We do not test the row labeled 10+ because it is a composite of more than one Flicker Max Gap. We replicate the analysis limiting our observations to Flicker Events with a life of at least 50 milliseconds and present the results in Panel B. Numbers in bold are significantly lower than the number in the same column on the previous row at the 1% level.

| | Gap | | | | | | | | | | | Breadth | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flicker Max Gap | Flicker NBBO Lock (0) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ | Flicker | Total |
| **Panel A: Quoting Behavior** | | | | | | | | | | | | | |
| 1 | 2.26 | 1.73 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1.73 | 3.99 |
| 2 | **1.91** | **1.19** | 0.89 | -- | -- | -- | -- | -- | -- | -- | -- | 2.08 | 3.99 |
| 3 | **1.68** | **0.93** | **0.58** | 0.68 | -- | -- | -- | -- | -- | -- | -- | 2.19 | 3.87 |
| 4 | **1.56** | **0.71** | **0.47** | **0.40** | 0.58 | -- | -- | -- | -- | -- | -- | 2.16 | 3.71 |
| 5 | **1.45** | **0.58** | **0.36** | **0.32** | **0.33** | 0.51 | -- | -- | -- | -- | -- | 2.10 | 3.54 |
| 6 | **1.36** | **0.49** | **0.31** | **0.25** | **0.25** | **0.28** | 0.45 | -- | -- | -- | -- | 2.02 | 3.38 |
| 7 | **1.28** | **0.43** | **0.26** | **0.22** | **0.20** | **0.20** | **0.24** | 0.41 | -- | -- | -- | 1.95 | 3.22 |
| 8 | **1.19** | **0.37** | **0.22** | **0.18** | **0.17** | **0.16** | **0.17** | **0.21** | 0.37 | -- | -- | 1.84 | 3.03 |
| 9 | **1.11** | **0.33** | **0.19** | **0.16** | **0.14** | **0.14** | **0.13** | **0.15** | **0.19** | 0.34 | -- | 1.76 | 2.88 |
| 10+ | 1.20 | 0.23 | 0.13 | 0.10 | 0.09 | 0.10 | 0.09 | 0.09 | 0.09 | 0.11 | 0.82 | 1.85 | 3.05 |
| **Panel B: Quoting Behavior with Flicker Events of at least 50 milliseconds** | | | | | | | | | | | | | |
| 1 | 1.14 | 2.96 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2.96 | 4.10 |
| 2 | **1.52** | **0.68** | 1.64 | -- | -- | -- | -- | -- | -- | -- | -- | 2.32 | 3.84 |
| 3 | **1.46** | **0.62** | **0.37** | 1.23 | -- | -- | -- | -- | -- | -- | -- | 2.23 | 3.69 |
| 4 | **1.41** | **0.53** | **0.35** | **0.28** | 0.96 | -- | -- | -- | -- | -- | -- | 2.12 | 3.52 |
| 5 | **1.34** | **0.46** | **0.29** | **0.24** | **0.25** | 0.79 | -- | -- | -- | -- | -- | 2.03 | 3.37 |
| 6 | **1.29** | **0.42** | **0.26** | **0.21** | **0.20** | **0.22** | 0.64 | -- | -- | -- | -- | 1.95 | 3.24 |
| 7 | **1.23** | **0.38** | **0.23** | **0.19** | **0.17** | **0.17** | **0.20** | 0.55 | -- | -- | -- | 1.88 | 3.10 |
| 8 | **1.16** | **0.33** | **0.20** | **0.16** | **0.15** | **0.14** | **0.15** | **0.18** | 0.47 | -- | -- | 1.77 | 2.93 |
| 9 | **1.09** | **0.30** | **0.17** | **0.14** | **0.13** | **0.13** | **0.12** | **0.13** | **0.17** | 0.42 | -- | 1.71 | 2.80 |
| 10+ | 1.12 | 0.17 | 0.10 | 0.08 | 0.07 | 0.07 | 0.07 | 0.06 | 0.07 | 0.08 | 0.89 | 1.65 | 2.77 |

**Table 8**
**Execution Quality Analysis.**

We present statistics for effective and realized half spreads and PM by Flicker state. Results for Flicker Bid Free, Flicker Ask Free, and Flicker Free are shown in Panels A, B, and C, respectively. Effective half spreads are the difference between the execution price and the prevailing NBBO at the time of execution. Realized half spreads are the difference between the execution price and the prevailing NBBO 5 minutes after the trade. Trades and quotes are aligned for each stock day by selecting the quote lag that maximizes the number of trades executing at the prevailing NBBO. PM is the ratio of realized spread to effective spread. We conduct a test for equality of means for PM and report the results in column 4 (PM Difference). * indicates significant at the 1% level.

| | Half Spreads | | |
|---|---|---|---|
| | Effective | Realized | PM |
| **Panel A: Flicker Bid Free** | | | |
| At Ask | 0.657 | 0.242 | 0.126 |
| At Flicker | 1.916 | 1.110 | 0.707 |
| PM Difference | | | -0.581* |
| | | | |
| **Panel B: Flicker Ask Free** | | | |
| At Ask | 0.658 | 0.172 | 0.060 |
| At Flicker | 1.966 | 0.971 | 0.656 |
| PM Difference | | | -0.596* |
| | | | |
| **Panel C: Flicker Free** | | | |
| At Ask | 0.507 | 0.019 | 0.010 |
| At Flicker | 1.876 | 1.003 | 0.575 |
| PM Difference | | | -0.565* |
| | | | |
| At Bid | 0.514 | 0.146 | 0.139 |
| At Flicker | 1.893 | 1.132 | 0.644 |
| PM Difference | | | -0.506* |

**Table 9**
**Latency and Execution Quality.**

We calculate the daily effective half spread, realized half spread, and the PM during Flicker Events for each stock day and present the means for the period before (Pre) and after (Post) 10 March 2008. Using a mean difference test, we test the null hypothesis that there is no difference in Pre- and Post-event means. We present the respective mean differences in columns 4 and 7. * indicates significant at the 1% level.

| | Trades at | | | | | |
|---|---|---|---|---|---|---|
| | Flicker Complaint Prices | | | NBBO | | |
| Measure | Pre-event | Post-event | Mean Difference | Pre-event | Post-event | Mean Difference |
| Effective Half Spread | 1.984 | 1.918 | -0.066 | 0.682 | 0.613 | -0.069* |
| Realized Half Spread | 1.036 | 1.055 | 0.020 | 0.259 | 0.174 | -0.085* |
| PM | 0.617 | 0.676 | 0.058* | 0.220 | 0.073 | -0.147* |

**Table 10**
**Regression Results.**

We estimate the following equation as a fixed effects regression and at the stock level for trades at both Flicker Compliant Prices and the NBBO:

$$PM = \alpha + \beta_1 Spd + \beta_2 LnTrdCnt_{i,t} + \beta_3 MpVar_{i,t} + \beta_4 AvgTrdSz_{i,t} + \beta_5 TmFlk_{i,t} + \varepsilon_t$$

where PM is the daily average PM of trades at Flicker Compliant Prices or at the NBBO, in turn, *Spd* is a dummy variable that equals 1 for days on or after 10 March 2008, and zero otherwise, *LnTrdCnt* is the log of the number of executed trades, *MpVar* is the NBBO mid-point volatility for day t, *AvgTrdSz* is the average size of each trade, and *TmFlk* is the percentage of the trading day with Flicker Events. At the stock level, we estimate the equation for each stock and then report the average coefficients. We test the null hypothesis that the mean of these coefficients equals zero. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

| | Trades at | | | |
|---|---|---|---|---|
| | Flicker Compliant Prices | | NBBO | |
| | Cross sectional | Stock level | Cross sectional | Stock level |
| Intercept | 0.489*** | 0.208 | -1.390*** | -0.287** |
| Spd | 0.076*** | 0.058** | -0.152*** | -0.134*** |
| LnTrdCnt | 0.051*** | 0.063** | 0.200*** | 0.091*** |
| MpVar | 0.021** | 0.559** | 0.040* | 0.977*** |
| AvgTrdSz | 0.000 | 0.001 | 0.000* | 0.000 |
| TmFlk | -0.339* | -1.101** | -0.975*** | -1.480*** |
| | | | | |
| Effects | Fixed | | Fixed | |
| R-Sq | 0.022 | | 0.046 | |
| N | 16,760 | | 16,760 | |

**Table 11**
**Estimated Profit from Supplying Liquidity at Flicker Compliant Prices.**

For the week of 24 March 24 2008, we evaluate the market wide impact of the Flicker Quote Exception and assess the sensitivity of Flicker Volumes and profits to the length of Flicker Price look back time. Specifically, for all securities in the DTAQ database with a closing price over $5, for each trading day, we align the trades and quotes based on the method outlined in section 4.2. Then for each Flicker Event, we calculate the effective half spread of trades at Flicker Compliant Prices and at the NBBO. If the Effective Half Spread is greater than $0.50, the trade is dropped as a possible reporting error. As the Flicker Price look back time decreases, trades that occur outside of the Flicker Price are dropped from the analysis because under the Order Protection Rule, these trades would be re-routed to exchanges posting better prices. Flicker Volume is the total volume executed at Flicker Compliant Prices. Flicker profit is calculated as the difference between the execution price and the NBBO Bid or Ask, as appropriate, multiplied by the number of shares traded, and summed for each day. Results presented are the daily average over the five trading days. On average, there are 7,090 observations per day.

| | Effective Half Spread | | | |
|---|---|---|---|---|
| Flicker Time | Flicker | NBBO | Volume (shares) | Profit (dollars) |
| 1,000 | 2.256 | 0.704 | 76,028,886 | 1,116,054 |
| 800 | 2.242 | 0.689 | 72,250,797 | 1,051,563 |
| 600 | 2.227 | 0.669 | 67,515,762 | 972,610 |
| 400 | 2.214 | 0.641 | 60,763,102 | 861,505 |
| 200 | 2.214 | 0.611 | 47,358,589 | 656,569 |