

Appendices

Appendix 1: Sample Stocks

Table A1. Sample Stocks

List of 116 securities in the final sample and their respective market capitalizations on January 3 2011 (billions).

| Ticker Symbol | Market Cap. (billions) | Firm Name | Ticker Symbol | Market Cap. (billions) | Firm Name |
|----------------------|-------------------------------|---|----------------------|-------------------------------|--------------------------------------|
| AA | 16.14 | Alcoa Inc. | CKH | 2.199 | SEACOR Holdings Inc. |
| AAPL | 302.3 | Apple Inc. | CMCSA | 46.30 | Comcast Corp. (Cl A) |
| ABD | 0.485 | ACCO Brands Corp. | CNQR | 2.768 | Concur Technologies Inc. |
| ADBE | 15.92 | Adobe Systems Inc. | COO | 2.606 | Cooper Cos. |
| AGN | 21.36 | Allergan Inc. | COST | 31.33 | Costco Wholesale Corp. |
| AINV | 2.200 | Apollo Investment Corp. | CPSI | 0.512 | Computer Programs & Systems Inc. |
| AMAT | 18.79 | Applied Materials Inc. | CPWR | 2.571 | Compuware Corp. |
| AMED | 1.013 | Amedisys Inc. | CR | 2.452 | Crane Co. |
| AMGN | 52.48 | Amgen Inc. | CRI | 1.681 | Carter's Inc. |
| AMZN | 82.68 | Amazon.com Inc. | CRVL | 0.584 | Corvel Corp. |
| ANGO | 0.390 | AngioDynamics Inc. | CSCO | 113.6 | Cisco Systems Inc. |
| APOG | 0.394 | Apogee Enterprises Inc. | CSE | 2.318 | CapitalSource Inc. |
| ARCC | 3.451 | Ares Capital Corp. | CSL | 2.469 | Carlisle Cos. |
| AXP | 52.24 | American Express Co. | CTRN | 0.367 | Citi Trends Inc. |
| AYI | 2.556 | Acuity Brands Inc. | CTSH | 22.87 | Cognizant Technology Solutions Corp. |
| AZZ | 0.510 | AZZ Inc. | DCOM | 0.525 | Dime Community Bancshares |
| BAS | 0.693 | Basic Energy Services Inc. | DELL | 26.62 | Dell Inc. |
| BHI | 24.71 | Baker Hughes Inc. | DIS | 71.62 | Walt Disney Co. |
| BIIB | 16.01 | Biogen Idec Inc. | DK | 0.402 | Delek US Holdings Inc. |
| BRCM | 20.19 | Broadcom Corp. | DOW | 40.60 | Dow Chemical Co. |
| BRE | 2.822 | BRE Properties Inc. | EBAY | 37.39 | eBay Inc. |
| BXS | 1.378 | BancorpSouth Inc. | EBF | 0.452 | Ennis Inc. |
| BZ | 0.687 | Boise Inc. | ERIE | 3.383 | Erie Indemnity Co. (Cl A) |
| CB | 18.37 | Chubb Corp. | ESRX | 29.63 | Express Scripts Inc. |
| CBEY | 0.478 | Cbeyond Inc. | EWBC | 2.920 | East West Bancorp Inc. |
| CBT | 2.558 | Cabot Corp. | FCN | 1.700 | FTI Consulting Inc. |
| CBZ | 0.313 | CBIZ Inc | FFIC | 0.451 | Flushing Financial Corp. |
| CCO | 0.600 | Clear Channel Outdoor Holdings Inc. | FL | 3.062 | Foot Locker Inc |
| CDR | 0.433 | Cedar Shopping Centers Inc. | FMER | 2.210 | FirstMerit Corp. |
| CELG | 28.25 | Celgene Corp. | FPO | 0.658 | First Potomac Realty Trust |
| CETV | 1.205 | Central European Media Enterprises Ltd. | FRED | 0.553 | Fred's Inc. |

Table A1. Sample Stocks (Cont.)

| Ticker Symbol | Market Cap. (billions) | Firm Name | Ticker Symbol | Market Cap. (billions) | Firm Name |
|----------------------|-------------------------------|------------------------------------|----------------------|-------------------------------|-------------------------------------|
| FULT | 2.083 | Fulton Financial Corp. | MFB | 0.574 | Maidenform Brands Inc. |
| GAS | 2.294 | Nicor Inc. | MIG | 0.553 | Meadowbrook Insurance Group Inc. |
| GE | 195.4 | General Electric Co. | MMM | 62.04 | 3M Co. |
| GENZ | 18.59 | Genzyme Corp. | MOD | 0.801 | Modine Manufacturing Co. |
| GILD | 29.70 | Gilead Sciences Inc. | MOS | 33.98 | Mosaic Co. |
| GLW | 29.99 | Corning Inc. | MRTN | 0.480 | Marten Transport Ltd. |
| GOOG | 150.1 | Google Inc. (Cl A) | MXWL | 0.509 | Maxwell Technologies Inc. |
| GPS | 13.65 | Gap Inc. | NC | 0.743 | NACCO Industries Inc. (Cl A) |
| HON | 42.29 | Honeywell International Inc. | NSR | 1.945 | NeuStar Inc. (Cl A) |
| HPQ | 93.62 | Hewlett-Packard Co. | NUS | 1.894 | Nu Skin Enterprises Inc. (Cl A) |
| IMGN | 0.654 | Immunogen Inc. | NXTM | 1.238 | NxStage Medical Inc. |
| INTC | 116.3 | Intel Corp. | PBH | 0.593 | Prestige Brands Holdings Inc. |
| IPAR | 0.585 | Inter Parfums Inc. | PFE | 141.6 | Pfizer Inc. |
| ISIL | 1.824 | Intersil Corp. (Cl A) | PG | 183.8 | Procter & Gamble Co. |
| ISRG | 10.57 | Intuitive Surgical Inc. | PNC | 32.32 | PNC Financial Services Group Inc. |
| JKHY | 2.534 | Jack Henry & Associates Inc. | PNY | 2.039 | Piedmont Natural Gas Co. |
| KMB | 25.54 | Kimberly-Clark Corp. | PPD | 0.610 | Pre-Paid Legal Services Inc. |
| KNOL | 0.592 | Knology Inc. | PTP | 1.776 | Platinum Underwriters Holdings Ltd. |
| KR | 14.00 | Kroger Co. | RIGL | 0.402 | Rigel Pharmaceuticals Inc. |
| LANC | 1.616 | Lancaster Colony Corp. | ROC | 3.070 | Rockwood Holdings Inc. |
| LECO | 2.820 | Lincoln Electric Holdings Inc. | ROCK | 0.423 | Gibraltar Industries Inc. |
| LPNT | 1.968 | Lifepoint Hospitals Inc. | ROG | 0.633 | Rogers Corp. |
| LSTR | 2.028 | Landstar System Inc. | RVI | 0.802 | Retail Ventures Inc. |
| MAKO | 0.591 | MAKO Surgical Corp. | SF | 2.217 | Stifel Financial Corp. |
| MANT | 0.963 | ManTech International Corp. (Cl A) | SFG | 2.136 | StanCorp Financial Group Inc. |
| MDCO | 0.768 | Medicines Co. | SJW | 0.489 | SJW Corp. |
| MELI | 3.094 | MercadoLibre Inc. | SWN | 13.20 | Southwestern Energy Co. |

Appendix 2: Market Fragmentation and Dark venues on U.S. Equities Markets

In the National Market System (NMS) for U.S. equities, price information is provided to the public via the consolidated data of the two Securities Information Processors (SIPs). The SIPs widely disseminate real-time consolidated quotation data on the best-priced quotations, and consolidated trade data on trades as they are executed. The SEC defines dark liquidity as trading interest that is not included in the consolidated quotation data for NMS.¹ The fair access rules of Reg ATS require alternative trading systems that execute more than 5% trading volume in an NMS security provide their best-priced quotations for inclusion in the consolidated quotation data and provide traders execution access to those quotations (Rule 301(b)(3)). The SEC Rule 3a1-1 also exempts trading venues from being registered as an exchange if their trading volume is below certain thresholds.² As a result, trading on registered exchanges and electronic communication networks (i.e. the lit markets) is subject to both pre-trade and post-trade transparency, while only post-trade information is provided by dark venues. The fair access rules exempt ATSS that execute less than 5% of trading volume in an NMS security from the equal access requirement of Rule 301(b)(5). As registered exchanges or large ATSS, lit markets are not permitted to select or exclude customers.

The SEC identifies two sources of dark liquidity for market centers which are not part of the NMS quotation data: dark pools and broker-dealer internalization (SEC Release No. 60997, 2010).³ Dark pools are registered ATSS that are not required to provide their best priced orders to the consolidated quotation data. Dark pools operate in a variety of ways (Mittal, 2008). One type of dark pool operates in a similar way to ECNs by accepting limit and market orders. In these markets, customer order flow interacts with those from other customers and potentially with the proprietary trading interest of the dark pool operator and other external liquidity partners that

¹ See Securities Exchange Act Release No. 60997, November 13, 2009. For more details on the classification of dark liquidity and dark markets, refer to Kwan and McInish (2012).

² SEC Rule 3a1-1 specifies that a trading venue must be registered as an exchange if its dollar trading volume is: a) 50% or more of the daily average dollar trading volume in any security and 5% or more in any class of securities; or b) 40% or more of the daily average dollar trading volume in any class of securities. By August 2011, the biggest dark pool, CrossFinder owned by Credit Suisse has a market share of less than 2.5% of consolidated volume. See Rosenblatt “Let there be light” August 2011.

³ We are unable to further differentiate between individual dark venues due to the limitations of our dataset.

may include high frequency firms. Another type of dark pool operates as continuous crossing networks that cross buy and sell orders as they arrive at a price derived from the NBBO (typically at the midpoint). A third type of dark pool accepts only immediate or cancel (IOC) orders from customers, which are executed against the operator's proprietary flow at the operator's discretion.⁴ Internalizers are broker-dealers that execute client trades either as agent or principal (SEC Release No. 60997, 2009) within their own trading system. The two main categories of internalizers are retail market makers, who handle order flow routed by retail brokerage firms and block positioners, who directly negotiate trades with customers or other broker-dealers. Similar to dark pools, internalized trades of broker-dealers represent liquidity that is not included in the consolidated quotation data. Many dark pools and broker-dealer systems are linked to each other and an order may directly or indirectly transit many dark venues in search of a counterparty.

Transactions executed on dark venues are reported first to a trade reporting facility (TRF) before the report is submitted to the consolidated trade data. Thus, dark trades are included in consolidated trade data under the TRF identifier as are lit trades from fully transparent, equal access, ECNs.⁵ Previous research has relied on this combined data to provide an insight into the trading on dark venues (see O'Hara and Ye, 2011). Currently, all off-exchange trading volumes are reported through the FINRA/Nasdaq and FINRA/NYSE TRFs.

Most dark venues are referred to as dark pools underscoring that they are designed to conceal a trader's trading intentions. Compared with lit markets, the intended purpose of allowing pre-trade opacity on dark venues was to significantly reduce the market impact costs associated with large orders, which is especially attractive to institutional investors who usually have large orders to fill and are more concerned about information leakage. However, as presented in Section 2 dark venues today are no longer large trade facilitators and instead they compete with lit markets for trades of all sizes. Their pre-trade opacity is also beneficial to professional liquidity providers who wish to avoid quote competition and posting widely accessible firm quotes. In addition, the

⁴ This type of dark pool is typically not a registered ATS and thus do not fall into the SEC's definition of a dark pool. However, these trading centers offer electronic execution services that are analogous to those offered by dark pools (SEC Concept Release No. 34-61358).

⁵ The major ECNs in our sample period are Lava and Bloomberg Tradebook.

ability to grant market access to selected customers further complicates the relationship between dark trading and market quality.

Figure A1 depicts the growth in dark trading volume from 1st July 2010 to 31st March 2011.⁶ We calculate the daily trading volume on lit and dark markets, and also the value weighted percentage of dark trading volume. The graph shows that dark market share steadily increases from 26% in July 2010 to above 33% by the end of March 2011, representing an approximate 30% increase over the 9 month period. The rapid growth in dark trading shown in Figure A1 illustrates the importance of understanding the economic consequences of dark trading.

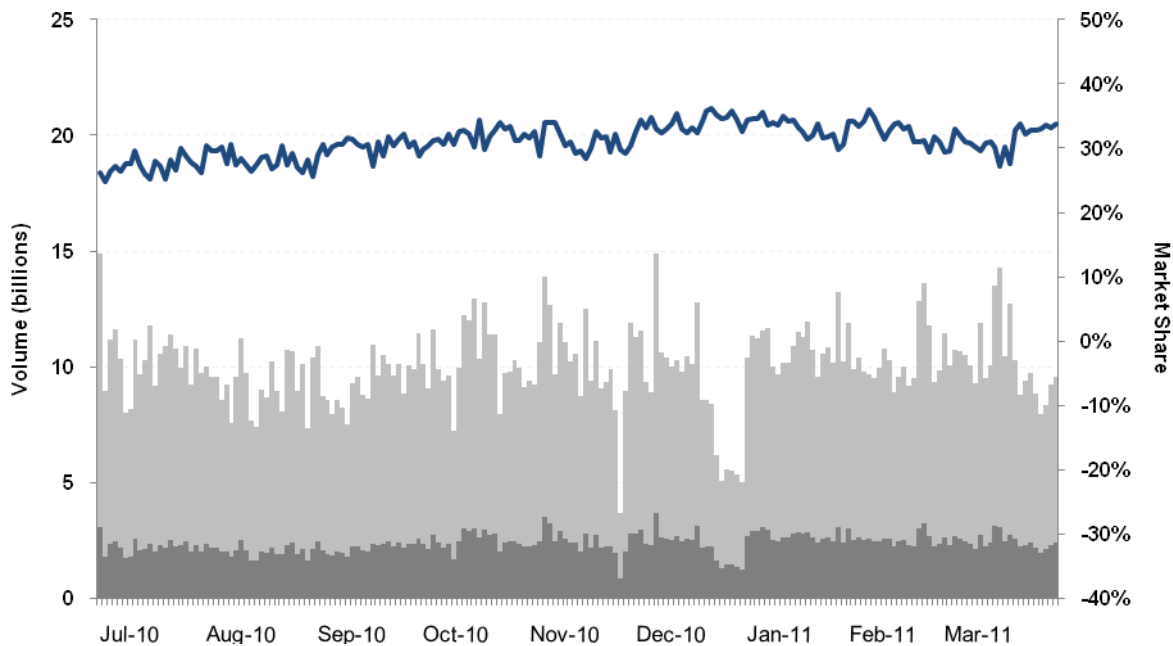


Figure A2. Growth in Dark Market Share

This figure shows trends in dark market share for a sample of 116 stocks listed on NYSE, Nasdaq and AMEX from 1 July 2010 to 31 March 2011. The lighter and darker columns represent daily consolidated trading volume on lit and dark markets, respectively. Daily dark market share is calculated by dividing dark volume by consolidated volume. We remove dark volume contributed by Direct Edge, which gained exchange status and stopped reporting to the NMS on 19 July 2011.

⁶ The summary of daily trading statistics is provided by NASDAQ.

Appendix 3: Testing for Trade Time Adjustment

The process of interleaving quote and trade data based on reported time stamps may introduce errors in trade classification when quotes are reported ahead of the trade (Lee and Ready, 1991). Moreover, there are major differences in methods of trade reporting for lit and dark trades. While lit trades are reported directly to the tapes, dark trades are first reported to a trade reporting facility (TRF) before transmission to the trade tapes,⁷ resulting in longer reporting delays for dark trades than for lit trades. Lee and Ready (1991) demonstrate that imposing a 5 second delay on trades can greatly reduce trade misclassification. Using more recent data, Ellis, Michaely and O’Hara (2000) and Bessembinder (2003) show that trades are best matched to contemporaneous quotes. However, these studies do not address the differences in reporting methods by lit and dark venues.

We test the impact of timing errors on trade and quote matching for the full sample of 116 stocks on 10 randomly selected days based on the data requirements described previously. There are 19,896,655 transactions in the sample. The frequency of trades occurring at or inside the best bid price and ask price (*inquote%*) is used to proxy for the degree of matching accuracy. Table A3-1 below reports *inquote%* when trades are matched to quotes in effect 1, 5, 10, 50, 100 and 200 milliseconds prior to the trade report time, separated into *Lit* and *Dark* trading venues.⁸

Table A3-1. Trade and quote matching accuracy

This table reports *inquote%* when trades are matched to quotes at various time lags. The sample contains trades on 10 randomly selected trading days between January 3 2011 and March 31 2011 for all 116 stocks in the sample (19,896,655 observations). The indicated time delay is subtracted from the reported time of each trade. *Inquote%* is the percentage of trades that fall within the prevailing best bid and ask price at the adjusted time of the trade.

| | Time delay (ms) | | | | | | |
|------|-----------------|-------|-------|-------|-------|-------|-------|
| | 0 | 1 | 5 | 10 | 50 | 100 | 200 |
| All | 96.39 | 96.21 | 95.74 | 95.18 | 93.01 | 91.80 | 90.34 |
| Lit | 97.08 | 96.81 | 96.14 | 95.31 | 92.20 | 90.78 | 89.17 |
| Dark | 93.99 | 94.14 | 94.36 | 94.71 | 95.80 | 95.32 | 94.37 |

⁷ For the majority of dark trades, reporting must be completed within 30 seconds of trade execution (http://finra.complinet.com/en/display/display_viewall.html?rbid=2403&element_id=4439&record_id=5533).

⁸ In results not presented, we also tested time delays up to 10 seconds in 1second intervals.

For the full sample of transactions, there is a monotonic decrease in *inquote%* as a longer time delay is imposed on trades. Dividing transactions into *Lit* and *Dark* indicates that there are systematic differences in the way lit and dark trades are reported. At no delay, *inquote%* is 97.08% for *Lit* and 93.99% for *Dark*. Increasing the time delay reduces *inquote%* for *Lit* monotonically. Thus, it is optimal to match *Lit* trades to contemporaneous quotes. For *Dark*, however, *inquote%* improves until a delay of 50 milliseconds. At 100 and 200 millisecond delays, *inquote%* is lower. From these results, the optimal time delay for *Dark* is between 10 and 100 milliseconds. Similar tests are repeated for *Dark* using 5 millisecond increments occurring between 10 and 100 milliseconds. Table A3-2 reports the results for time delays of 30 to 60 milliseconds in 5 millisecond increments.

Table A3-2. Trade and Quote Matching Accuracy for Dark Venues

This table reports *inquote%* when dark trades are matched to quotes at various time lags. The sample contains dark trades on 10 randomly selected trading days between January 3 2011 and March 31 2011 for all 116 stocks in the sample (4,457,877 observations). The indicated time delay is subtracted from the reported time of each dark trade. *Inquote%* is the percentage of trades that fall within the prevailing best bid and ask price at the adjusted time of the trade.

| Time delay (ms) | | | | | | |
|-----------------|-------|-------|-------|-------|-------|-------|
| 30 | 35 | 40 | 45 | 50 | 55 | 60 |
| 95.74 | 95.81 | 95.84 | 95.82 | 95.80 | 95.76 | 95.73 |

Table A3-2 shows that the optimal time delay is 40 milliseconds, as this time delay corresponds to the highest value for *inquote%*. Based on these results, dark trades are matched to quotes in effect 40 milliseconds before the trade report time. No time delay is applied to lit trades.

Appendix 4: Effective Spreads, Adverse Selection Costs and Realized Spreads

Table A4-1. Comparison of Relative Effective Spreads between Lit and Dark Markets

This table contains a comparison of effective spreads between lit and dark markets. Trade and quote data of 116 stocks listed on the NASDAQ and NYSE are examined over the period January 3 2011 to March 31 2011. Stocks are ranked into terciles based on their market capitalization on January 3 2011. For each stock, transactions are ranked into terciles based on the size of the prevailing quoted spread (*qspread*) at the time of the trade. Daily value weighted effective spreads are calculated for each stock across *qspread* terciles and venue types. Reported are the mean and median effective spreads in basis points for each venue type. The difference of effective spreads cost between the lit and dark markets is tested, and * and *** indicates a significance level of 5% and 0.1% respectively based on a two-tailed *t*-test (Wilcoxon signed rank test) of the differences in means (medians).

| Qspread | Lit | | Dark | | Dark-Lit | | | |
|-------------------------------|--------|--------|--------|--------|----------|--------|--------|-----|
| | Mean | Median | Mean | Median | Mean | Median | | |
| <i>Panel A: Full sample</i> | | | | | | | | |
| Small | 2.253 | 1.684 | 1.819 | 1.277 | -0.434 | *** | -0.407 | *** |
| Medium | 3.397 | 2.672 | 2.872 | 2.108 | -0.525 | *** | -0.564 | *** |
| Large | 5.227 | 3.648 | 5.417 | 3.510 | 0.190 | * | -0.138 | |
| <i>Panel B: Large stocks</i> | | | | | | | | |
| Small | 1.128 | 0.829 | 0.896 | 0.601 | -0.232 | *** | -0.228 | *** |
| Medium | 1.290 | 0.999 | 1.053 | 0.841 | -0.237 | *** | -0.157 | *** |
| Large | 1.381 | 1.282 | 1.636 | 1.503 | 0.255 | *** | 0.220 | *** |
| <i>Panel C: Medium stocks</i> | | | | | | | | |
| Small | 1.637 | 1.221 | 1.309 | 1.004 | -0.329 | *** | -0.216 | *** |
| Medium | 2.343 | 1.961 | 1.927 | 1.647 | -0.416 | *** | -0.314 | *** |
| Large | 4.000 | 3.663 | 4.072 | 3.472 | 0.072 | | -0.191 | ** |
| <i>Panel D: Small stocks</i> | | | | | | | | |
| Small | 3.547 | 3.194 | 2.925 | 2.621 | -0.622 | *** | -0.573 | *** |
| Medium | 5.752 | 5.216 | 4.957 | 4.294 | -0.795 | *** | -0.921 | *** |
| Large | 10.192 | 9.322 | 10.317 | 9.159 | 0.126 | | -0.163 | |

Table A4-2. Comparison of Relative Adverse Selection Costs between Lit and Dark Markets

This table contains a comparison of adverse selection costs between lit and dark markets. Trade and quote data of 116 stocks listed on the NASDAQ and NYSE are examined over the period January 3 2011 to March 31 2011. Short-term (30 seconds) and long-term (5 minutes) adverse selection costs are calculated for each transaction. Stocks are ranked into terciles based on their market capitalization on January 3 2011. For each stock, transactions are ranked into terciles based on the size of the prevailing quoted spread (*qspread*) at the time of the trade. Daily value weighted adverse selection costs are calculated for each stock across *qspread* terciles and venue types. Reported are the mean and median adverse selection costs in basis points for each venue type. The difference of adverse selection cost between the lit and dark markets is tested, and *** indicates a significance level of 0.1% based on a two-tailed *t*-test (Wilcoxon signed rank test) of the differences in means (medians).

| | Qspread | Lit | | Dark | | Dark - Lit | | | |
|-------------------------------|---------|-------|--------|-------|--------|------------|--------|--------|-----|
| | | Mean | Median | Mean | Median | Mean | Median | | |
| <i>Panel A: Full sample</i> | | | | | | | | | |
| Short-term | Small | 3.239 | 2.488 | 0.642 | 0.390 | -2.596 | *** | -2.098 | *** |
| | Medium | 3.720 | 2.770 | 0.814 | 0.481 | -2.906 | *** | -2.289 | *** |
| | Large | 3.830 | 2.875 | 1.293 | 0.710 | -2.537 | *** | -2.165 | *** |
| Long-term | Small | 3.564 | 2.418 | 1.046 | 0.571 | -2.518 | *** | -1.847 | *** |
| | Medium | 4.394 | 2.947 | 1.068 | 0.649 | -3.326 | *** | -2.298 | *** |
| | Large | 4.565 | 3.254 | 1.496 | 0.991 | -3.070 | *** | -2.263 | *** |
| <i>Panel B: Large stocks</i> | | | | | | | | | |
| Short-term | Small | 1.544 | 1.241 | 0.393 | 0.279 | -1.152 | *** | -0.963 | *** |
| | Medium | 1.787 | 1.388 | 0.424 | 0.330 | -1.364 | *** | -1.058 | *** |
| | Large | 1.569 | 1.372 | 0.454 | 0.411 | -1.115 | *** | -0.960 | *** |
| Long-term | Small | 1.650 | 1.222 | 0.485 | 0.362 | -1.165 | *** | -0.860 | *** |
| | Medium | 2.007 | 1.369 | 0.620 | 0.422 | -1.387 | *** | -0.948 | *** |
| | Large | 1.727 | 1.287 | 0.336 | 0.469 | -1.392 | *** | -0.818 | *** |
| <i>Panel C: Medium stocks</i> | | | | | | | | | |
| Short-term | Small | 2.564 | 2.222 | 0.544 | 0.434 | -2.020 | *** | -1.788 | *** |
| | Medium | 2.819 | 2.546 | 0.588 | 0.485 | -2.232 | *** | -2.062 | *** |
| | Large | 3.221 | 2.946 | 1.052 | 0.716 | -2.169 | *** | -2.230 | *** |
| Long-term | Small | 2.803 | 2.304 | 0.980 | 0.673 | -1.823 | *** | -1.631 | *** |
| | Medium | 3.140 | 2.719 | 0.734 | 0.642 | -2.406 | *** | -2.077 | *** |
| | Large | 3.787 | 3.433 | 1.157 | 1.133 | -2.630 | *** | -2.299 | *** |
| <i>Panel D: Small stocks</i> | | | | | | | | | |
| Short-term | Small | 4.961 | 4.379 | 0.904 | 0.677 | -4.057 | *** | -3.703 | *** |
| | Medium | 5.820 | 4.772 | 1.284 | 0.855 | -4.536 | *** | -3.917 | *** |
| | Large | 6.637 | 5.745 | 2.324 | 1.547 | -4.312 | *** | -4.198 | *** |
| Long-term | Small | 5.507 | 4.932 | 1.497 | 0.979 | -4.009 | *** | -3.953 | *** |
| | Medium | 7.118 | 5.791 | 1.677 | 1.247 | -5.441 | *** | -4.544 | *** |
| | Large | 8.102 | 6.746 | 2.924 | 2.215 | -5.178 | *** | -4.531 | *** |

Table A4-3. Comparison of Relative Realized Spread between Lit and Dark Markets

This table contains a comparison of realized spread between lit and dark markets. Trade and quote data of 116 stocks listed on the NASDAQ and NYSE are examined over the period January 3 2011 to March 31 2011. Short-term (30 seconds) and long-term (5 minutes) realized spreads are calculated for each transaction. Stocks are ranked into terciles based on their market capitalization on January 3 2011. For each stock, transactions are ranked into terciles based on the size of the prevailing quoted spread (*qspread*) at the time of the trade. Daily value weighted realized spreads are calculated for each stock across *qspread* terciles and venue types. Realized spreads are also reported after adjustment for the amount of the liquidity rebate or charge offered by the market center where the trade is executed, which are outlined in Appendix 4. Reported are the mean and median realized spreads in basis points for each venue type. The difference between the realized spread on dark venues and the rebate-adjusted realized spread on lit markets and tested, and *** and ** indicate significance levels of 0.1% and 1% respectively based on a two-tailed *t*-test (Wilcoxon signed rank test) of the differences in means (medians).

| | | Lit | | | | Dark | | Dark - Lit | | | |
|-------------------------------|--------|----------------|--------|-------------|--------|-------|-------|------------|--------|-------|-----|
| | | No Rebate Adj. | | Rebate Adj. | | | | Dark - Lit | | | |
| Qspread | | Mean | Med. | Mean | Med. | Mean | Med. | Mean | Median | | |
| <i>Panel A: Full sample</i> | | | | | | | | | | | |
| Short-term | Small | -0.987 | -0.617 | -0.059 | 0.030 | 1.176 | 0.805 | 1.235 | *** | 0.775 | *** |
| | Medium | -0.332 | -0.284 | 0.625 | 0.368 | 2.054 | 1.351 | 1.429 | *** | 0.983 | *** |
| | Large | 1.380 | 0.544 | 2.391 | 1.286 | 4.124 | 2.631 | 1.733 | *** | 1.345 | *** |
| Long-term | Small | -1.304 | -0.658 | -0.371 | 0.029 | 0.747 | 0.668 | 1.119 | *** | 0.639 | *** |
| | Medium | -0.995 | -0.422 | -0.036 | 0.235 | 1.779 | 1.179 | 1.815 | *** | 0.944 | *** |
| | Large | 0.663 | 0.371 | 1.675 | 1.061 | 3.927 | 2.386 | 2.252 | *** | 1.325 | *** |
| <i>Panel B: Large stocks</i> | | | | | | | | | | | |
| Short-term | Small | -0.417 | -0.346 | 0.077 | 0.101 | 0.503 | 0.462 | 0.425 | *** | 0.361 | *** |
| | Medium | -0.497 | -0.342 | 0.027 | 0.136 | 0.629 | 0.582 | 0.601 | *** | 0.446 | *** |
| | Large | -0.217 | -0.075 | 0.405 | 0.410 | 1.179 | 1.048 | 0.774 | *** | 0.638 | *** |
| Long-term | Small | -0.521 | -0.285 | -0.024 | 0.165 | 0.409 | 0.465 | 0.433 | ** | 0.300 | *** |
| | Medium | -0.715 | -0.234 | -0.188 | 0.195 | 0.431 | 0.542 | 0.618 | ** | 0.347 | *** |
| | Large | -0.370 | -0.022 | 0.254 | 0.471 | 1.298 | 0.999 | 1.044 | *** | 0.528 | *** |
| <i>Panel C: Medium stocks</i> | | | | | | | | | | | |
| Short-term | Small | -0.927 | -0.792 | -0.237 | -0.217 | 0.764 | 0.734 | 1.001 | *** | 0.952 | *** |
| | Medium | -0.482 | -0.392 | 0.235 | 0.214 | 1.338 | 1.256 | 1.103 | *** | 1.042 | *** |
| | Large | 0.759 | 0.596 | 1.596 | 1.322 | 3.016 | 2.659 | 1.421 | *** | 1.337 | *** |
| Long-term | Small | -1.162 | -0.825 | -0.467 | -0.193 | 0.321 | 0.656 | 0.788 | ** | 0.849 | *** |
| | Medium | -0.796 | -0.566 | -0.076 | 0.061 | 1.182 | 1.085 | 1.258 | *** | 1.024 | *** |
| | Large | 0.208 | 0.234 | 1.046 | 0.971 | 2.914 | 2.433 | 1.867 | *** | 1.463 | *** |
| <i>Panel D: Small stocks</i> | | | | | | | | | | | |
| Short-term | Small | -1.416 | -1.057 | 0.011 | 0.302 | 2.020 | 1.848 | 2.008 | *** | 1.546 | *** |
| | Medium | -0.086 | 0.163 | 1.376 | 1.585 | 3.664 | 3.203 | 2.288 | *** | 1.618 | *** |
| | Large | 3.554 | 3.179 | 5.117 | 4.646 | 7.999 | 6.919 | 2.883 | *** | 2.273 | *** |
| Long-term | Small | -1.949 | -1.347 | -0.516 | 0.053 | 1.380 | 1.409 | 1.895 | *** | 1.356 | *** |
| | Medium | -1.362 | -0.585 | 0.101 | 0.820 | 3.234 | 2.984 | 3.133 | *** | 2.163 | *** |
| | Large | 2.121 | 2.232 | 3.686 | 3.691 | 7.410 | 6.402 | 3.724 | *** | 2.711 | *** |

Appendix 5: Rebate Rates

Table A5. Rebate Rates for Selected Market Centers

This table shows the maker-taker rebates that applied to selected market centers during January 3 2011 to March 31 2011. Maker (taker) pricing schedules are used in calculations of adjusted realized spreads (Table 2) and adjusted effective spreads (Table A6) respectively. Positive values represent rebates while negative values represent costs incurred, from the perspective of the maker or taker as indicated in the column headings.

| Venue | Maker (cents per share) | Taker (cents per share) |
|----------------------------|-------------------------|-------------------------|
| <i>Maker-taker</i> | | |
| NYSE | 0.15 | -0.23 |
| ARCA | 0.30 | -0.30 |
| NASDAQ OMX | 0.295 | -0.30 |
| PSX ¹ | 0.24/0.26 | -0.27 |
| BATS BZX | 0.27 | -0.28 |
| EDGX ² | 0.26/0.23 | -0.30 |
| <i>Reverse maker-taker</i> | | |
| BX | -0.15 | 0.14 |
| BATS BYX | 0 | 0.03 |
| EDGA | -0.025 | 0.015 |

¹ PSX provides a 0.24 (0.26) cents per share rebate for orders less than (equal to or more than) 2,000 shares.

² EDGX changed the rebate for adding liquidity on March 1 2011 to 0.23 cents per share. Previously, the rebate for adding liquidity was 0.26 cents per share.

Appendix 6: Effective Spreads adjusted for Maker-Taker Pricing

Section 2.1 compares effective spreads between lit and dark markets without taking into account maker-taker pricing schemes. We adjust the effective spread for each transaction for the taker fee or rebate based on the market center at which execution occurs. Dark venues may also impose maker-taker pricing schedules. However, in contrast to lit markets they are not required to publicly disclose their pricing schemes and for this reason, we make no adjustment to the effective spreads on dark venues.

Effective spreads for lit market are adjusted as:

$$Effective\ spread = q_t \frac{(p_t - m_t)}{m_t} + \frac{rebate}{m_t}$$

where m_t is the bid ask midpoint at the time when the current trade takes place, p_t is the trade price and q_t is a buy-sell indicator, which equals to 1 (-1) if the trade is buyer- (seller-) initiated. The results are reported in Table A6.

Compared to the results in Table 2, the magnitude of effective spreads on lit markets are greater after the rebate adjustment. This is because most lit markets impose a cost to traders for taking liquidity (see Appendix 5). Consistent with Table 2, effective spreads are significantly larger on lit markets than dark venues across all stock sizes and *qspread* terciles.

Table A6. Comparison of Relative Effective Spreads Adjusted for Maker-Taker Pricing between Lit and Dark Markets

This table contains a comparison of effective spreads between lit and dark markets. Trade and quote data of 116 stocks listed on the NASDAQ and NYSE are examined over the period January 3 2011 to March 31 2011. Stocks are ranked into terciles based on their market capitalization on January 3 2011. For each stock, transactions are ranked into terciles based on the size of the prevailing quoted spread (*qspread*) at the time of the trade. Daily value weighted effective spreads are calculated for each stock across *qspread* terciles and venue types. Reported are the mean and median effective spreads in basis points for each venue type. Effective spreads are adjusted for maker-taker costs and rebates outlined in Appendix 3. The difference of effective spreads cost between the lit and dark markets is tested, and * and *** indicates a significance level of 5% and 0.1% respectively based on a two-tailed *t*-test (Wilcoxon signed rank test) of the differences in means (medians).

| Qspread | Lit | | Dark | | Dark - Lit | | | |
|-------------------------------|--------|--------|--------|--------|------------|-----|--------|-----|
| | Mean | Median | Mean | Median | Mean | | Median | |
| <i>Panel A: Full sample</i> | | | | | | | | |
| Small | 3.272 | 2.438 | 1.819 | 1.277 | -1.453 | *** | -1.161 | *** |
| Medium | 4.449 | 3.414 | 2.872 | 2.108 | -1.577 | *** | -1.307 | *** |
| Large | 6.338 | 4.525 | 5.417 | 3.510 | -0.921 | *** | -1.015 | *** |
| <i>Panel B: Large stocks</i> | | | | | | | | |
| Small | 1.666 | 1.240 | 0.896 | 0.601 | -0.770 | *** | -0.639 | *** |
| Medium | 1.863 | 1.362 | 1.053 | 0.841 | -0.810 | *** | -0.521 | *** |
| Large | 2.060 | 1.790 | 1.636 | 1.503 | -0.423 | *** | -0.287 | *** |
| <i>Panel C: Medium stocks</i> | | | | | | | | |
| Small | 2.396 | 1.737 | 1.309 | 1.004 | -1.088 | *** | -0.732 | *** |
| Medium | 3.130 | 2.652 | 1.927 | 1.647 | -1.203 | *** | -1.005 | *** |
| Large | 4.917 | 4.400 | 4.072 | 3.472 | -0.845 | *** | -0.928 | *** |
| <i>Panel D: Small stocks</i> | | | | | | | | |
| Small | 5.116 | 4.872 | 2.925 | 2.621 | -2.191 | *** | -2.251 | *** |
| Medium | 7.363 | 6.802 | 4.957 | 4.294 | -2.406 | *** | -2.508 | *** |
| Large | 11.918 | 11.122 | 10.317 | 9.159 | -1.600 | *** | -1.963 | *** |

Appendix 7: Price Improvement by *Qspread*

Overall, our findings show that effective spreads are lower on the dark venues than on the lit markets. However, the opposite result holds when quoted spreads are wide. Specifically, Table 2, Panel A shows that quoted spreads are 23.9% and 18.3% higher on lit markets than dark venues in the two lowest *qspread* categories. In contrast, traders pay 3.5% more to trade on dark venues when *qspread* is wide. One reason for this finding is that lit markets are able to compete for order flow by offering price improvement through mid-point peg orders when quoted spreads are wide.

More specifically, the amount of price improvement offered by lit markets is compared to that of dark venues based on the prevailing *qspread* at the time of the trade. To calculate price improvement, we compute the distance between the trade price and the prevailing NBBO price depending on whether the trade is buyer or seller initiated (see Section 2.2.1 for details). We define 13 price improvement levels and the cross-sectional frequencies of trades occurring at each level are reported in Table A7. When spreads are narrow, the results in Panel A show that dark liquidity providers are able to lower transaction costs by offering sub-penny price improvement; 43% of transactions in dark venues are price improved while only 4.8% of transactions in lit markets are price improved. When quoted spreads are wide, the difference in the frequency of trades receiving price improvement in lit and dark venues is much smaller. Panel C shows that 45% of lit trades and 59% of dark trades are price improved. Furthermore, we find that the amount of price improvement offered by lit markets is larger than the amount offered by dark venues. Approximately all of transactions receiving price improvement in lit markets are improved by 1 cent or more while only 58% of trades that are price improved receive 1 cent or more in dark venues. These results are consistent with the observation that transaction costs are lower in lit markets relative to dark venues when quoted spreads are wide. In wide spread environments, sub-penny pricing is less valuable to dark venues, allowing lit markets to more successfully compete for order flow.

Table A7. Price improvement by *Qspread*

This table contains a comparison of price improvement between lit and dark markets. Trade and quote data of 116 stocks listed on NASDAQ and NYSE are examined over the period January 3 2011 to March 31 2011. All transactions reported within the sample period are ranked into terciles based on the size of the prevailing quoted spread (*qspread*) at the time of the trade for every stock. Price improvement is calculated by comparing the transaction prices with the prevailing NBBO and classified into 13 levels based on the magnitude of improvement. For each stock, the frequency of transactions with price improvement falling into each level is calculated for the lit and dark markets. The mean and median of the frequencies for each price level across stocks are reported.

| Level | Price improvement (cents) | Lit | | Dark | |
|------------------------|---------------------------|-------|--------|-------|--------|
| | | Mean | Median | Mean | Median |
| <i>Panel A: Low</i> | | | | | |
| 1 | 0 | 95.22 | 97.59 | 57.06 | 56.82 |
| 2 | $0 < x \leq 0.10$ | 0.00 | 0.00 | 11.50 | 11.36 |
| 3 | $0.10 < x \leq 0.20$ | 0.00 | 0.00 | 2.63 | 2.31 |
| 4 | $0.20 < x \leq 0.30$ | 0.00 | 0.00 | 4.04 | 3.98 |
| 5 | $0.30 < x \leq 0.40$ | 0.00 | 0.00 | 1.16 | 0.95 |
| 6 | $0.40 < x < 0.50$ | 0.00 | 0.00 | 0.49 | 0.34 |
| 7 | 0.5 | 2.05 | 1.97 | 18.51 | 19.26 |
| 8 | $0.50 < x < 0.60$ | 0.00 | 0.00 | 0.03 | 0.00 |
| 9 | $0.60 \leq x < 0.70$ | 0.00 | 0.00 | 0.08 | 0.00 |
| 10 | $0.70 \leq x < 0.80$ | 0.00 | 0.00 | 0.11 | 0.00 |
| 11 | $0.80 \leq x < 0.90$ | 0.00 | 0.00 | 0.11 | 0.00 |
| 12 | $0.90 \leq x < 1.00$ | 0.00 | 0.00 | 0.02 | 0.00 |
| 13 | $1.00 \leq x$ | 2.73 | 0.00 | 4.25 | 0.00 |
| <i>Panel B: Medium</i> | | | | | |
| 1 | 0 | 84.30 | 85.90 | 50.55 | 49.76 |
| 2 | $0 < x \leq 0.10$ | 0.00 | 0.00 | 11.28 | 10.94 |
| 3 | $0.10 < x \leq 0.20$ | 0.00 | 0.00 | 2.63 | 2.22 |
| 4 | $0.20 < x \leq 0.30$ | 0.00 | 0.00 | 2.80 | 2.53 |
| 5 | $0.30 < x \leq 0.40$ | 0.00 | 0.00 | 1.12 | 0.98 |
| 6 | $0.40 < x < 0.50$ | 0.00 | 0.00 | 0.50 | 0.39 |
| 7 | 0.5 | 1.47 | 0.97 | 13.18 | 12.11 |
| 8 | $0.50 < x < 0.60$ | 0.00 | 0.00 | 0.14 | 0.00 |
| 9 | $0.60 \leq x < 0.70$ | 0.00 | 0.00 | 0.33 | 0.06 |
| 10 | $0.70 \leq x < 0.80$ | 0.00 | 0.00 | 0.49 | 0.12 |
| 11 | $0.80 \leq x < 0.90$ | 0.00 | 0.00 | 0.35 | 0.16 |
| 12 | $0.90 \leq x < 1.00$ | 0.00 | 0.00 | 0.18 | 0.00 |
| 13 | $1.00 \leq x$ | 14.23 | 12.61 | 16.46 | 13.10 |

Table A7 – Continued

| Level | Price improvement (cents) | Lit | | Dark | |
|----------------------|---------------------------|-------|--------|-------|--------|
| | | Mean | Median | Mean | Median |
| <i>Panel C: High</i> | | | | | |
| 1 | 0 | 54.83 | 56.20 | 41.13 | 41.66 |
| 2 | $0 < x \leq 0.10$ | 0.00 | 0.00 | 10.83 | 10.19 |
| 3 | $0.10 < x \leq 0.20$ | 0.00 | 0.00 | 2.12 | 2.07 |
| 4 | $0.20 < x \leq 0.30$ | 0.00 | 0.00 | 1.41 | 1.39 |
| 5 | $0.30 < x \leq 0.40$ | 0.00 | 0.00 | 1.12 | 0.95 |
| 6 | $0.40 < x < 0.50$ | 0.00 | 0.00 | 0.38 | 0.27 |
| 7 | 0.5 | 0.54 | 0.23 | 5.44 | 3.66 |
| 8 | $0.50 < x < 0.60$ | 0.00 | 0.00 | 0.24 | 0.15 |
| 9 | $0.60 \leq x < 0.70$ | 0.00 | 0.00 | 0.67 | 0.54 |
| 10 | $0.70 \leq x < 0.80$ | 0.00 | 0.00 | 0.94 | 0.87 |
| 11 | $0.80 \leq x < 0.90$ | 0.00 | 0.00 | 1.03 | 0.88 |
| 12 | $0.90 \leq x < 1.00$ | 0.00 | 0.00 | 0.46 | 0.27 |
| 13 | $1.00 \leq x$ | 44.63 | 43.13 | 34.24 | 35.50 |

Appendix 8: Hasbrouck (1995) Information Shares

Table A8-1. Hasbrouck Information Shares (10 second)

This table reports the information shares for the 116 stocks in our sample. Information shares are estimated daily using 10 lags at 10 second sampling intervals. *Lit* and *Dark* represent the average between the maximum and minimum market contributions based on the ordering of the variables in the Cholesky factorization.

| Symbol | Lit | Dark | Symbol | Lit | Dark | Symbol | Lit | Dark | Symbol | Lit | Dark |
|--------|-------|-------|--------|-------|-------|--------|-------|-------|--------|-------|-------|
| AA | 0.593 | 0.407 | CELG | 0.778 | 0.222 | FL | 0.839 | 0.161 | MDCO | 0.908 | 0.092 |
| AAPL | 0.580 | 0.420 | CETV | 0.886 | 0.114 | FMER | 0.895 | 0.105 | MELI | 0.866 | 0.134 |
| ABD | 0.908 | 0.092 | CKH | 0.936 | 0.064 | FPO | 0.853 | 0.147 | MFB | 0.911 | 0.089 |
| ADBE | 0.728 | 0.272 | CMCSA | 0.628 | 0.372 | FRED | 0.855 | 0.145 | MIG | 0.810 | 0.190 |
| AGN | 0.887 | 0.113 | CNQR | 0.947 | 0.053 | FULT | 0.826 | 0.174 | MMM | 0.824 | 0.176 |
| AINV | 0.791 | 0.209 | COO | 0.930 | 0.070 | GAS | 0.911 | 0.089 | MOD | 0.901 | 0.099 |
| AMAT | 0.617 | 0.383 | COST | 0.855 | 0.145 | GE | 0.578 | 0.422 | MOS | 0.686 | 0.314 |
| AMED | 0.881 | 0.119 | CPSI | 0.807 | 0.193 | GENZ | 0.760 | 0.240 | MRTN | 0.775 | 0.225 |
| AMGN | 0.746 | 0.254 | CPWR | 0.731 | 0.269 | GILD | 0.714 | 0.286 | MXWL | 0.882 | 0.118 |
| AMZN | 0.683 | 0.317 | CR | 0.954 | 0.046 | GLW | 0.605 | 0.395 | NC | 0.745 | 0.255 |
| ANGO | 0.761 | 0.239 | CRI | 0.911 | 0.089 | GOOG | 0.784 | 0.216 | NSR | 0.907 | 0.093 |
| APOG | 0.866 | 0.134 | CRVL | 0.619 | 0.381 | GPS | 0.667 | 0.333 | NUS | 0.901 | 0.099 |
| ARCC | 0.777 | 0.223 | CSCO | 0.660 | 0.340 | HON | 0.831 | 0.169 | NXTM | 0.895 | 0.105 |
| AXP | 0.697 | 0.303 | CSE | 0.718 | 0.282 | HPQ | 0.596 | 0.404 | PBH | 0.851 | 0.149 |
| AYI | 0.943 | 0.057 | CSL | 0.945 | 0.055 | IMGN | 0.878 | 0.122 | PFE | 0.596 | 0.404 |
| AZZ | 0.771 | 0.229 | CTRN | 0.876 | 0.124 | INTC | 0.608 | 0.392 | PG | 0.652 | 0.348 |
| BAS | 0.923 | 0.077 | CTSH | 0.864 | 0.136 | IPAR | 0.769 | 0.231 | PNC | 0.815 | 0.185 |
| BHI | 0.789 | 0.211 | DCOM | 0.782 | 0.218 | ISIL | 0.773 | 0.227 | PNY | 0.910 | 0.090 |
| BIIB | 0.873 | 0.127 | DELL | 0.600 | 0.400 | ISRG | 0.863 | 0.137 | PPD | 0.625 | 0.375 |
| BRCM | 0.675 | 0.325 | DIS | 0.672 | 0.328 | JKHY | 0.913 | 0.087 | PTP | 0.893 | 0.107 |
| BRE | 0.940 | 0.060 | DK | 0.775 | 0.225 | KMB | 0.819 | 0.181 | RIGL | 0.855 | 0.145 |
| BXS | 0.888 | 0.112 | DOW | 0.707 | 0.293 | KNOL | 0.846 | 0.154 | ROC | 0.935 | 0.065 |
| BZ | 0.764 | 0.236 | EBAY | 0.658 | 0.342 | KR | 0.642 | 0.358 | ROCK | 0.854 | 0.146 |
| CB | 0.882 | 0.118 | EBF | 0.828 | 0.172 | LANC | 0.851 | 0.149 | ROG | 0.828 | 0.172 |
| CBEY | 0.825 | 0.175 | ERIE | 0.672 | 0.328 | LECO | 0.858 | 0.142 | RVI | 0.897 | 0.103 |
| CBT | 0.923 | 0.077 | ESRX | 0.799 | 0.201 | LPNT | 0.912 | 0.088 | SF | 0.940 | 0.060 |
| CBZ | 0.738 | 0.262 | EWBC | 0.873 | 0.127 | LSTR | 0.913 | 0.087 | SFG | 0.904 | 0.096 |
| CCO | 0.870 | 0.130 | FCN | 0.934 | 0.066 | MAKO | 0.837 | 0.163 | SJW | 0.678 | 0.322 |
| CDR | 0.816 | 0.184 | FFIC | 0.748 | 0.252 | MANT | 0.871 | 0.129 | SWN | 0.763 | 0.237 |

Table A8-2. Hasbrouck Information Shares (1 minute)

This table reports the information shares for the 116 stocks in our sample. Information shares are estimated daily using 10 lags at 1 minute sampling intervals. *Lit* and *Dark* represent the average between the maximum and minimum market contributions based on the ordering of the variables in the Cholesky factorization.

| Symbol | Lit | Dark | Symbol | Lit | Dark | Symbol | Lit | Dark | Symbol | Lit | Dark |
|---------------|------------|-------------|---------------|------------|-------------|---------------|------------|-------------|---------------|------------|-------------|
| AA | 0.521 | 0.479 | CELG | 0.574 | 0.426 | FL | 0.633 | 0.367 | MDCO | 0.822 | 0.178 |
| AAPL | 0.513 | 0.487 | CETV | 0.817 | 0.183 | FMER | 0.783 | 0.217 | MELI | 0.764 | 0.236 |
| ABD | 0.849 | 0.151 | CKH | 0.864 | 0.136 | FPO | 0.822 | 0.178 | MFB | 0.849 | 0.151 |
| ADBE | 0.540 | 0.460 | CMCSA | 0.537 | 0.463 | FRED | 0.785 | 0.215 | MIG | 0.786 | 0.214 |
| AGN | 0.674 | 0.326 | CNQR | 0.831 | 0.169 | FULT | 0.709 | 0.291 | MMM | 0.599 | 0.401 |
| AINV | 0.679 | 0.321 | COO | 0.839 | 0.161 | GAS | 0.831 | 0.169 | MOD | 0.815 | 0.185 |
| AMAT | 0.516 | 0.484 | COST | 0.616 | 0.384 | GE | 0.517 | 0.483 | MOS | 0.539 | 0.461 |
| AMED | 0.805 | 0.195 | CPSI | 0.783 | 0.217 | GENZ | 0.675 | 0.325 | MRTN | 0.768 | 0.232 |
| AMGN | 0.556 | 0.444 | CPWR | 0.620 | 0.380 | GILD | 0.567 | 0.433 | MXWL | 0.810 | 0.190 |
| AMZN | 0.535 | 0.465 | CR | 0.866 | 0.134 | GLW | 0.537 | 0.463 | NC | 0.709 | 0.291 |
| ANGO | 0.667 | 0.333 | CRI | 0.812 | 0.188 | GOOG | 0.592 | 0.408 | NSR | 0.830 | 0.170 |
| APOG | 0.787 | 0.213 | CRVL | 0.650 | 0.350 | GPS | 0.559 | 0.441 | NUS | 0.798 | 0.202 |
| ARCC | 0.616 | 0.384 | CSCO | 0.574 | 0.426 | HON | 0.596 | 0.404 | NXTM | 0.796 | 0.204 |
| AXP | 0.532 | 0.468 | CSE | 0.615 | 0.385 | HPQ | 0.520 | 0.480 | PBH | 0.774 | 0.226 |
| AYI | 0.850 | 0.150 | CSL | 0.861 | 0.139 | IMGN | 0.798 | 0.202 | PFE | 0.551 | 0.449 |
| AZZ | 0.715 | 0.285 | CTRN | 0.839 | 0.161 | INTC | 0.539 | 0.461 | PG | 0.522 | 0.478 |
| BAS | 0.829 | 0.171 | CTSH | 0.633 | 0.367 | IPAR | 0.674 | 0.326 | PNC | 0.580 | 0.420 |
| BHI | 0.568 | 0.432 | DCOM | 0.759 | 0.241 | ISIL | 0.621 | 0.379 | PNY | 0.857 | 0.143 |
| BIIB | 0.628 | 0.372 | DELL | 0.551 | 0.449 | ISRG | 0.764 | 0.236 | PPD | 0.661 | 0.339 |
| BRCM | 0.534 | 0.466 | DIS | 0.538 | 0.462 | JKHY | 0.816 | 0.184 | PTP | 0.832 | 0.168 |
| BRE | 0.856 | 0.144 | DK | 0.731 | 0.269 | KMB | 0.583 | 0.417 | RIGL | 0.772 | 0.228 |
| BXS | 0.769 | 0.231 | DOW | 0.540 | 0.460 | KNOL | 0.826 | 0.174 | ROC | 0.799 | 0.201 |
| BZ | 0.704 | 0.296 | EBAY | 0.523 | 0.477 | KR | 0.530 | 0.470 | ROCK | 0.783 | 0.217 |
| CB | 0.648 | 0.352 | EBF | 0.809 | 0.191 | LANC | 0.783 | 0.217 | ROG | 0.818 | 0.182 |
| CBEY | 0.835 | 0.165 | ERIE | 0.680 | 0.320 | LECO | 0.810 | 0.190 | RVI | 0.797 | 0.203 |
| CBT | 0.811 | 0.189 | ESRX | 0.587 | 0.413 | LPNT | 0.820 | 0.180 | SF | 0.869 | 0.131 |
| CBZ | 0.717 | 0.283 | EWBC | 0.702 | 0.298 | LSTR | 0.838 | 0.162 | SFG | 0.819 | 0.181 |
| CCO | 0.833 | 0.167 | FCN | 0.806 | 0.194 | MAKO | 0.729 | 0.271 | SJW | 0.659 | 0.341 |
| CDR | 0.768 | 0.232 | FFIC | 0.747 | 0.253 | MANT | 0.795 | 0.205 | SWN | 0.562 | 0.438 |

Appendix 9: O’Hara and Ye (2011) Replication

We replicate the tests by O’Hara and Ye (2011) with our dataset. Following their study, we calculate the daily *TRF_ratio* as the ratio of dark volume on the overall market trading volume. The remaining variables are defined in Section 2.4. Table A9 reports the results of the two-stage Heckman correction model.

Table A9. O’Hara and Ye (2011) Replication

This table reports the estimates for the two-stage Heckman correction model based on the model specification in O’Hara and Ye (2011). Trade and quote data of 116 stocks listed on the NASDAQ and NYSE are examined over the period January 3 2011 to March 31 2011. The dependent variable for the first stage probit is *TRF_ratio*, which is calculated as the proportion of total trading volume on dark venues. The dependent variable for the second stage OLS is *Eff_spread*, which is the daily value weighted relative effective spread. *Lambda* is the inverse Mills ratio obtained from the first stage probit model. *Price* is the log of the daily value-weighted average price. *Trade_size_ratio* is the ratio of the average trade size on day *t* and the average trade size for the whole sample period for each sample stock. *Total_trades* is the log of the daily total number of trades. *Total_volume* is the log of the daily total trading volume. *Mcap* is the log of market capitalization on 3 January 2011. In the second-stage OLS, all coefficients except for *Trade_size_ratio* are scaled by a factor of 10,000. Standard errors reported in second stage OLS are corrected for double clustering by date and symbol (Thompson, 2011). ***, ** and * indicate significance levels of 0.1%, 1% and 5% respectively

| | First-stage OLS | | | Second-stage OLS | | |
|------------------|-----------------|--------|-----|------------------|--------|-----|
| | Coefficient | StdErr | | Coefficient | StdErr | |
| TRF_ratio | | | | -3.0628 | 1.1994 | ** |
| Lambda | | | | -3.2307 | 1.5036 | * |
| Price | 0.0448 | 0.0067 | *** | -0.9843 | 0.2919 | *** |
| Trade_size_ratio | 6,312 | 265.3 | *** | 9.4459 | 2.1731 | *** |
| Total_trades | | | | -0.5381 | 0.1219 | *** |
| Total_volume | 0.1015 | 0.0024 | *** | | | |
| Mcap | -0.1491 | 0.0055 | *** | | | |
| NASDAQ | | | | 0.1015 | 0.2374 | |
| Intercept | -0.1649 | 0.0591 | ** | 15.4000 | 2.3101 | *** |
| Adj-R | 0.2924 | | | 0.6565 | | |

Consistent with O’Hara and Ye (2011, p. 468, Table 6), our results show that *TRF_ratio* is negative and significant, indicating that market transaction costs decreases with dark trading. The signs of all other variables are also the same as those reported by O’Hara and Ye (2011). Specifically, in the first-stage model, the *TRF_ratio* is negatively correlated with *Price* and

Mcap, and positively related to *Trade_size_ratio*; in the second-stage model, *Eff_spread* is negatively related to *Price* and *Ntrades*, and positively related to *Trade_size_ratio*. However, we do find that λ is negative and significant at the 5% level, which means that we cannot reject the hypothesis of no selection bias in our data. In addition, *Eff_spread* is positively related to *Total_volume* while the relationship between *Eff_spread* and *Nasdaq* is insignificant. In summary, our results indicate that it is critical to control for the level of adverse selection risk in the market when examining the impact of dark fragmentation.

Appendix 10: Policy Recommendations

We study the effects of the growing level of trading by market centers which are not full participants in the National Market System (NMS). These dark venues differ from lit markets in a number of dimensions most notably in whether they must provide fair-access and pre-trade transparency and restrict sub-penny trading increments. Our results have important implications for the integrity of the current US equities markets. We find that transaction costs increases and price efficiency decreases as the fraction of trading on dark venues increases. Our results also show that dark venue trading adversely affects investors trading on both lit and dark markets.

The increase in transaction costs and reduction in price efficiency can have long-term consequences on investor confidence. Among all investors, the negative effects are stronger for liquidity-motivated and long-term investors since these investors trade infrequently and hence, rely more on market efficiency. Traders pursue statistical arbitrage or market making strategies exploit short run market inefficiencies and consequently are less likely to be disadvantaged. In fact, short-term market inefficiencies and higher transaction costs may represent potential profit-generating opportunities for professional traders whose activities are generally viewed with skepticism by long term investors. Losing the confidence of long-term investors can have significant negative consequence including increases in cost of capital and destabilisation of financial markets.

Recent studies also find that trading on dark venues reduces market liquidity (Degryse, De Jong and Van Kervel, 2011; Sarkar, Schwartz, and Klagge, 2008), which support our finding that dark trading is associated with lower price efficiency. The increase in excessive short-term volatility may lead to a more profound consequence during volatile periods when liquidity is most needed. Since there is no time priority currently across different market centres, rational liquidity providers will refrain from trading while they wait for the volatility to settle without losing the opportunity to trade. The reduced liquidity will in term reduce price efficiency further, causing a cascading effect (see, Pagano, 1989b). The observation of reduction in dark market trading during the 2010 Flash Crash and market volatility of August 2011 is consistent with this analysis

Overall, our results support the theoretical predictions of Bolton, Santos and Scheinkman (2011). Specifically, trading in dark venues in the current form is detrimental to the market's central role of allocating efficiently scarce resources in the economy. Accordingly, we recommend the following policy changes.

1. There is an urgency to reduce the negative impact of dark venues.

From the previous analysis, the detrimental impact of dark trading is mainly driven by their ability to segment market participants through their exemptions from certain provisions of Regulation NMS. Therefore, it is important to allow equal market access, eliminate existing discrepancies in the minimum price increment, and reward for price discovery.

2. Expand the fair access requirements

Equal market access on dark venues can not only prevent order flow segmentation but also lead to a general improvement of investor welfare. Results in Table 2 show that about 70% of transaction costs on dark venues are charged by liquidity providers as market-making profits; while this ratio for lit markets is about 21% on average. There is a significant lack of competition in the supply of liquidity on dark venues. Unequal market access affects the entry of all willing liquidity providers, which intensifies liquidity competition and hence reduces total transaction costs for investors on dark venues.

Currently, alternative trading systems that execute less than 5% of trading volume in an lit security are exempted from several requirements of lit market centers. For example, these venues are not required to disclose their best priced orders for inclusion in the public quotation data (Rule 301(b)(3)(ii)) and are exempted from fair access regulations (Rule 301(b)(5)(ii)(B)). While no individual market center exceeds the 5% threshold, dark venues as a group represent over 25% of the total market volume on average. We suggest a reduction in the 5% threshold in order to prevent the collectively significant negative impact from dark venues.

3. Adoption of a tick size table to allow for sub-penny pricing

The sub-penny rule affects a minimum tick size of \$0.01 for stocks priced equal to or greater than \$1.00. Operating as broker-dealers, dark venues are able to offer sub-penny executions,

which allow them to attract uninformed orders by offering minimal price improvement. We propose a harmonization in minimum tick size, which is particularly important for tick constrained stocks; we find sub-penny pricing is most beneficial to dark venues when stocks are trading at low quoted spreads. Consistent with this proposal, Multilateral Trading Facilities (MTFs) and exchanges under MiFID agreed to a harmonized tick size regime for the most liquid stocks on European markets in June 2009.⁹ We believe a similar tick size regime in the U.S. equities markets will increase the market efficiency by enhancing the competitiveness of lit markets.¹⁰

4. Implementation of a “trade-at” rule

Our analysis indicates that there are significant costs to providing liquidity in lit markets and benefits to providing liquidity on dark venues. Since lit markets set the benchmark used for trading on both lit and dark markets more market centers should be encouraged to display liquidity and operate in a way which gives priority to displayed liquidity. Recently the SEC proposed a “trade-at” rule¹¹ Orders received by trading centers not displaying the NBBO at the time the order is received must be executed with *significant* price improvement or routed to a market center displaying the NBBO.

There are two elements to the proposal. The first element is based on our demonstrating that price improvement allows dark venues to cream-skim uninformed order flow at minimal cost; we document a large number of transactions receiving minimal price improvement (i.e. < 0.10 cent). By requiring significant price improvement, the trade-at rule increases the cost of attracting orders and places lit markets in a better position to compete for orders.

⁹ See “European exchanges introduce harmonized tick size regimes in Europe”, FESE. Available from: http://www.fese.be/_mdb/pressdocs/European%20exchanges%20introduce%20harmonised%20tick%20size%20regimes%20in%20Europe.pdf, accessed on October 23 2011. For the remaining stocks, exchanges choose one of four tick size tables with up to 17 tick size bands based on stock price. MTFs apply the tick size table adopted by the listing venue for the underlying shares.

¹⁰ In his response to the Pan Europe Tick Size Harmonization Plans of the FESE, Tamas Madlena, CEO of Quote MTF, commented that “The commoditization of tick sizes across the European equities market is to the benefit of all participants and investors by encouraging efficiency, consistency and clarity.” (Quote MTF, Press Release on 28 September, 2010).

¹¹ SEC Concept Release No. 34-61358, p. 70.

The second element rewards an orders displaying at the NBBO. While lit markets provide priority to displayed order over non-displayed orders there is currently no display priority across market centers. As a result, an order can be executed at the NBBO price on the dark venues ahead of orders on the lit markets even when the lit orders are displayed. Pre-trade opacity in dark venues allows traders to free ride on prices discovered on lit markets. Since liquidity provision is costly due to adverse selection risk, a display priority in place is important to encourage liquidity providers to compete for execution and therefore, enhance market liquidity and price discovery.

These policy recommendations are essential to improving the competitive landscape of U.S. equity markets. Without these policies in place it is difficult for lit exchanges to compete with the dark without compromising, to some extent, their public obligations. For example, the NYSE recently proposed a Retail Liquidity Program where potential price improvement is given to orders deemed to originate from retail investors. This may contradict the requirement for a national security exchange as “the rules of the exchange ... are not designed to permit unfair discrimination between customers, issuers, brokers, or dealers ...” (Security Exchange Act of 1934, Section 6(b)(5)).¹²

In 1975, Congress established the framework for a National Market System to connect together a growing number of different markets. Our policy recommendations promote the interaction of informed and uninformed order flow among these markets in working towards ‘efficient, competitive, fair and orderly markets’ (SEC, Reg NMS, Release No. 34-51808) Today such market centers are especially important for the restoration of confidence in the financial markets.¹³

¹² In its proposal the NYSE particularly defended its position. See SEC Release No. 34-65672.

¹³ At the time of this study, investor confidence in the stock market has dropped to 16%, the same level after the collapse of Lehman Brothers. See “Buy Low Sell High? Not In This Market”, *The Wall Street Journal Asia*, 12 April 2012.