Online Appendix for:

Risk and Return in High-Frequency Trading

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November 14, 2017

Online Appendix

A1. TRS Data Processing

This appendix presents a summary of our data processing. There are on average 8.56 million entries in each month of the TRS data. Post-processing, the number of observations is on average 6.16 million per month.

(a) Time stamp adjustment

The firms reporting to TRS operate in different time zones and the database does not have a built-in functionality to adjust the trade times to a common time zone. To adjust the time stamps we record in which hour the first and last exchange-transaction is executed at NASDAQ OMX Stockholm or at one of the multilateral trading facilities for each firm in each day. All the exchanges open at 8 am (GMT) and close at 4:30 pm (GMT). We adjust the time stamps of firms that do not have their median first and last trades in sync with the opening hours. For example, for a firm with the median first trade hour in a month being 7 am and the median last trade hour being 3 pm, we adjust all transaction time stamps by +1 hour.

(b) Matching to TRTH data

TRS transactions are matched to TRTH transactions using information on stock, trading venue, date, time, price, buy/sell, and quantity. The time stamps of the two databases are allowed to differ by no more than one second. Where trader IDs are available in the TRTH data (for NASDAQ OMX Stockholm only), they are added to the matching criterion. TRTH trades are split into two transactions, one for the buyer and one for the seller. If there are several matches to one transaction, the transaction closest in time is considered to be the closest match. To the extent that there are multiple TRTH trades in the same second, same stock, at the same trading venue, with the same price and quantity, and with different sub-second time stamps, this approach may introduce noise in the time stamps. This potential problem applies only where trader IDs are unavailable in TRTH, and it is more likely at the most active trading venue, for example December 2014 at

NASDAQ OMX Stockholm. For that subset, 6.5 % of all transactions have a potentially noisy sub-second time stamp. The time stamp noise due to this problem is however unlikely to influence DECISION_LATENCY, see discussion in footnote 16.

(c) Firms

We analyze trading revenues at the corporation level rather than the branch or division level. Accordingly, we truncate BIC codes (11-letter identifiers of the financial institutions reporting to TRS) to the first four letters that are unique to each corporation. For various reasons, such as mergers and acquisitions, the same corporation may span several (truncated) BIC codes. For example, GETCO acquired Knight Trading in August 2013. We thus treat the (truncated) BIC codes GEEU (GETCO) and NITE (Knight Trading) as separate for the period preceding the merger and as one corporation for August 2013 onwards.

(d) Filtering of trades

We exclude transactions where the trade price is more than 5% lower than the official low price of the stock-day, or more than 5% higher than the official high price of the day. The official statistics do not consider OTC transactions, so prices outside the High-Low interval are possible, but deviations of more than 5% are considered erroneous. TRS transactions that are flagged as derivative-related either in TRS or in the TRTH entry that it is matched to are also excluded.

Non-proprietary transactions frequently generate more than one entry in TRS. For example, if a broker buys 100 shares on behalf of a client, it may be reported as two transactions in TRS: one transaction where the reporting firm purchases 100 shares at the exchange, and one off-exchange transaction where the reporting firm sells 100 shares to its client.[1] As firms differ in how they report their transactions we need to process the data to make transactions comparable.

[1] In a memorandum on transaction reporting FI provides numerous examples on how different types of trades on behalf of clients may be reported. The memo may be retrieved at http://www.fi.se/upload/90_English/90_Reporting/TRS/memo_transaction_reporting_ver_1_7_2014-03-07.pdf

For each transaction we seek to retain one representative TRS entry and to attach an entry of the *end investor* associated with that transaction. The *end investor* assignment is done differently depending on the type of trade.

We define *primary transaction* as TRS entries where the counterparty of the trade is a clearing house or the same as the trading venue for the transaction **or** the owner of the trading venue (in the case of dark pools). The definition is motivated by the fact that all exchange transactions must be done through central counterparty (CCP) clearing. All other TRS entries are defined as *secondary transactions*. Of all TRS entries, 81.5% are considered primary transactions.

(i) Primary transaction matched to a secondary transaction of the same firm

To account for several entries reported for the same transaction, we match primary and secondary transactions by *reporting firm*, *stock*, *price*, *quantity*, *date*, and *time*. The time stamps are allowed to differ by no more than one second. The end investor of primary trades matched in this way is set to the client of the secondary trade, if available, and otherwise to the counterparty of the secondary trade. The matched secondary trades are then discarded. Of all primary transactions, 26 % are matched to a secondary transaction in this way.

(ii) Primary transaction matched to a secondary transaction of another firm

To account for the case that the same transaction is reported by both counterparties, we match the reporting firm of primary transactions to the counterparty of secondary transactions. The other matching criteria include *stock*, *price*, *quantity*, *date*, and *time*. As above, the time stamps are allowed to differ by no more than one second. The end investor of primary trades matched in this way is set to the client of the secondary trade, if available, and otherwise to the *reporting firm* of the secondary trade. The matched secondary trades are then discarded. Of all primary transactions, 12 % are matched to a secondary transaction in this way.

(iii) Primary transaction that is not matched to a secondary transaction

Primary transactions that are not matched to a secondary transaction are considered to be on behalf of a client if a client reference is available, and otherwise proprietary. For client (proprietary) trades, the end investor is set equal to the client reference (the reporting firm).

(iv) Secondary transaction that is not matched to a secondary transaction

Secondary transactions that are not matched to a primary transaction, are considered to be on behalf of a client if a client reference is available, and otherwise proprietary. For client (proprietary) trades, the end investor is set equal to the client reference (the reporting firm).

(v) Secondary transactions where the counterparty does not report to TRS

To capture firms that are not obliged to report to TRS, but that still trade our sample stocks, we look for firms that are reported as counterparties but that not show up as reporting firms. For all secondary transactions where such firms appear as counterparties, we create a new entry with the same properties but with opposite direction of trade and with counterparties reversed. This is a way to detect HFT firms that connect to the market through direct market access or sponsored access. Of all secondary transactions, 16 % are subject to this procedure.

A2. Descriptive Statistics for the Cross-Section of Stocks

Table A1 reports descriptive statistics for the sample stocks. MARKET_CAPITALIZATION is measured at closing prices on December 31, 2014. DAILY_TRADING_VOLUME refers to trading at NASDAQ OMX Stockholm only and is reported in MSEK. DAILY_TURNOVER is the DAILY_TRADING_VOLUME divided by MARKET_CAPITALIZATION, expressed in percentage points. TICK_SIZE is the average minimum price change. QUOTED_SPREAD is the average bid-ask spread prevailing just before each trade; and EFFECTIVE_SPREAD is the trade value-weighted average absolute difference between the trade price and the bid-ask midpoint. All spread measures are based on continuous trading at NASDAQ OMX Stockholm, expressed relative to the bid-ask spread midpoint, and presented in basis points. The TICK_SIZE and the QUOTED_SPREAD are halved to be comparable to the EFFECTIVE_SPREAD. The DAILY_TURNOVER across stocks is 0.60% and the QUOTED_ SPREAD and EFFECTIVE_SPREAD vary between 2 and 6 bps. The TICK_SIZE for many stocks is close to the QUOTED_SPREAD, indicating that market tightness is frequently bounded by the tick size. Finally, we report VOLATILITY, the average 10-second squared basis point returns, calculated from bid-ask midpoints; and an index for the degree of volume fragmentation. The FRAGMENTATION_INDEX is defined as the inverse of a Herfindahl index of trading volumes across the five largest trading venues (BATS, Burgundy, Chi-X, NASDAQ OMX Stockholm, and Turquoise). The procedure implies that fragmentation is measured on a scale from one to the number of trading venues considered, which in our case is five.[2]

INSERT TABLE A1 ABOUT HERE

A3. HFTs Active at NASDAQ OMX Stockholm

Due to confidentiality requirements, we cannot report the full list of names of the 25 HFTs covered in the proprietary data set. However, in Table A2, we use public trading records to report the names of 19 HFTs who trade at NASDAQ OMX Stockholm as members. The HFTs not listed in Table A2 therefore trade only at other trading venues or as clients of other members at NASDAQ OMX Stockholm.

INSERT TABLE A2 ABOUT HERE

A4. Comparison of HFT Revenue Calculation Methods

We compare four methods of calculating trading revenues. As explained in the main text, adjustments are needed because small data errors in inventory can accumulate over time, leading to large and persistent (unit root) errors in computing position that can persist indefinitely throughout the sample if

[2] If there are *N* trading venues and they all have equal shares of the trading volume, the index takes its maximum value *N*. If all trading volume is concentrated to one venue the index takes its minimum value, which is 1. The index design is similar to the Fidessa Fragmentation Index, more details of which can be found at http://fragmentation.fidessa.com/faq/#faq2

left uncorrected. The four methods are as follows. *No adjustment* is calculated by cumulating daily inventory positions over the full sample. *Method 1: Benchmark* is the method used throughout the paper that zeros the end-of-day position daily for each HFT firm (equivalent to assuming that each firm liquidates any remaining end-of-day position at the daily closing price). *Method 2: Intraday Revenues* assumes a first-in-last-out inventory accounting. That is that any remaining end-of-day positions were never purchased in the first place. *Method 3: Intraday Revenues Plus Revenues from Inventory Sold* is similar to *Method 2* but adds back in the revenues from closing end-of-day positions that are in opposite direction of previous day end-of-day inventory. That is, the end-of-day inventory is marked to market only if an offsetting position exists in the previous end-of-day inventory.

Table A3 reports the firm cross-sectional distribution of HFT trading revenues using the four different methods for calculating trading revenues. It shows that inventory adjustments do not alter the main results of the paper in the sense that the mean, median, and distribution are roughly similar across the different methods. As a result, marking-to-market end-of-day inventory positions is relatively innocuous.

INSERT TABLE A3 ABOUT HERE

A5. Construction of Daily Fama-French Plus Momentum Factors for Swedish Equities

We construct daily Fama-French and momentum factors for Swedish equities. The data used to construct the factors (using the variables: daily total excess returns, shares outstanding, and quarterly book values) come from Compustat Global and covers the period January 2010 to December 2014. We exclude stock-day observations in which the total market capitalization falls below 100 MSEK (about 10.5 million USD as of the exchange rate of December 2014). The four factors (excess market return, small minus large [SML], value minus growth [HML], winner minus loser [WML]) are constructed according to the specifications used to create U.S. factors, as specified on Kenneth French's website: the value-weighted portfolios consist of top-30%, middle 40%, and bottom-30% of stocks (by market capitalization, book to market, and past-12-month returns for SML, HML and WML, respectively) and are re-sorted every July 1 using data from the previous year's performance.

Table A4 reports summary statistics corresponding to these traded risk factors for Swedish equities. The statistics include the mean daily log excess return (annualized), its standard error, and the number of observations (i.e., the number of trading days), and are reported for each portfolio. The annualized excess returns on the four portfolios (market excess return, SMB, HML, WML) are 0.160, 0.176, 0.039, and 0.028, respectively, which are all positive, as expected.

INSERT TABLE A4 ABOUT HERE

A6. Comparison of Trading Revenues to Trading Profits Based on Public Filings

The data do not convey trading fees or other operational costs and so we are unable to directly calculate trading profits. However, regulatory filings of five major HFT firms (Virtu, 2011-2015; Knight Capital Group, 2013-2015; GETCO, 2009-2012; Flow Traders, 2012-2015; and Jump, 2010) allow a comparison of trading revenues and trading profits. A potential concern in our analysis of HFT performance is that firms with higher trading revenues may have higher fixed costs. That is, firms with higher trading revenue may also incur higher costs to produce better performance. If true, then trading revenues may not be a good proxy for firm profitability. We show that this is not likely the case.

Table A5 reports trading revenue, trading costs, trading profit margins, and trading returns calculated from annual reports, IPO prospectuses, and SEC disclosures for five HFT firms for which public data is available.[3] Trading costs are broken down into several categories such as trading and clearing fees, data costs, financing costs, equipment and technical costs, all expressed as a percent of trading revenues. Trading costs also include depreciation and amortization. This serves as a control for investments that a firm may have undertaken in years preceding the public data coverage.

[3] Jump Trading was never a public company like the other four but nevertheless filed publicly available SEC disclosures containing trading revenues and profits for 2010 (see, https://www.bloomberg.com/news/articles/2014-07-23/don-t-tell-anybody-about-this-story-on-hft-power-jump-trading).

INSERT TABLE A5 ABOUT HERE

We make two observations. First, trading profit margins are high, ranging between 27.4% and 64.5% of trading revenue for all four firms. Approximately 40-80% of the HFT costs are per-trade fees: brokerage fees, exchange and clearance fees, and financing costs. The fixed (i.e. not per-trade) costs, including communications and data processing, equipment, administrative and technology costs, make up only 15-30% of the total costs. As a result, we conclude that fixed costs, which include costs related to technological investment and colocation services, are small relative to trading revenues, making it unlikely that firms with the highest trading revenues face higher investments costs that would substantially reduce their net profits.

Second, as a percentage of trading revenues, the fixed costs do not vary substantially across firms, suggesting that revenues are not correlated with fixed costs in percentage terms. For example, in 2014, KCG had double the trading revenue of Virtu and five times the trading revenue of Flow Traders, but the total fixed costs as a percentage of trading revenue show no pattern (22.7% for KCG; 17.7% for Virtu; 27.2% for Flow Traders). There is also no clear time trend in fixed costs within each firm to suggest that higher trading revenues periods might be correlated with higher fixed costs. All else being equal, the stability of the fixed costs suggests that firms with higher trading revenues also have higher profits. As such, HFT revenue variation is likely a close proxy for variation in HFT profits.

Table A5 reports trading returns. Trading returns are calculated in two ways based on different capitalization measures: trading revenue / (trading assets minus trading liabilities) and (trading revenue / book equity). From these public filings in which capitalization is directly observable, we find trading returns to range from 60% to almost 237%, depending on the firm. This suggests the returns computed in Section III.A are of a reasonable magnitude.

A7. Exchange Fees, Liquidity Rebates, and their Potential Effect on Trading Performance

Table A6 reports exchange fees in 2014 for three stock exchanges (NASDAQ OMX Stockholm, BATS, and Chi-X) trading Swedish equities. Fees range from 0 to 0.325 bps over these selected venues.

Exchange fees depend on the side of the trade: “maker” fees are less than “taker” fees (for example, 0.13 vs. 0.325 bps for NASDAQ OMX S30 stocks), and, at Chi-X, makers receive liquidity rebates (negative fees) of about 0.225 bps. For NASDAQ OMX Stockholm, we report the fees for S30 stocks, which are lower than for other stocks; all the stocks in our sample fall into this category.

INSERT TABLE A6 ABOUT HERE

While NASDAQ OMX Stockholm grants preferential prices for liquidity provision under its Liquidity Provider Scheme (LPS), BATS and Chi-X do not (a designated liquidity provider program exists but does not yield lower fees). Although BATS and Chi-X merged in November 2011, with technology integration complete by April 2012, the trading platforms continue to implement different pricing structures.

Table A7 analyzes HFT performance after accounting for potential maker-taker fees and liquidity rebates and shows that even accounting for the most conservative possible fees and/or rebates does not qualitatively change the results.

INSERT TABLE A7 ABOUT HERE

Table A7 is similar to Table 1 but adjusts for potential maker-taker fees and liquidity rebates. Panel A reports trading revenues under the assumption of the maximum possible maker-taker fees on NASDAQ OMX Stockholm (0.325 bps taker fees; 0.125 bps maker fees), and Panel B uses the maximum possible on the Chi-X exchange, which features a liquidity rebate (0.30 bps taker fees; 0.225 bps liquidity rebate).

Accounting for the most conservative possible fees and/or rebates does not qualitatively change the results. For example, though trading performance for the entire distribution is shifted down slightly, the sign of REVENUES does not change for any HFT firm. We additionally confirm (not reported in the table) that the performance results are still positively skewed, with the same HFTs at the top strongly outperforming their competitors.

A8. Trading Performance and Latency of the Five Fastest HFTs

Table A8 is similar to Table 2 but breaks down the TOP5 dummy variables into individual dummy variables for the fastest HFTs: RANK1, RANK2, RANK3, RANK4, and RANK5. It shows that even among the top five HFTs the faster firm tends to perform better and that performance is monotonic in latency.

INSERT TABLE A8 ABOUT HERE

A9. Alternative Identification Strategies

In this Appendix section, we present two alternative identification strategies to assess the relationship between latency and trading performance. While our analysis of colocation upgrades in Section IV is the strongest identification strategy considered in this paper, the two alternative strategies considered here yield similar results and thus show that the colocation upgrade results are robust to alternative settings. First, we re-estimate Table 2 with HFT firm fixed effects to control for firm-specific characteristics and to better isolate the effect of changes in latency rank. Second, we select all instances in which an HFT increases or decreases in latency rank, and analyze the subsequent change in HFT performance.

Firm fixed effects. In Table A9, we re-estimate the main regression reported in Table 2, which links trading performance to latency, but we estimate it this time with HFT firm fixed effects to control for firm-specific characteristics. By controlling for firm-specific characteristics, this specification helps overcome concerns that other factors than relative latency (but correlated with it) may determine HFT performance. The specification in Table A9 effectively looks at switches between ranks (i.e. the coefficient on the TOP1 dummy reflects, for a given HFT, time-series changes in performance when that HFT enters or leaves the Top 1 position). We choose, however, not to use Table A9 as our main specification because it eliminates comparisons across firms, and explaining the cross-sectional differences in performance is one of the main purposes of our study.

INSERT TABLE A9 ABOUT HERE

The estimates in Table A9 are qualitatively similar to those in Table 2. Note that the control variables, the same as in Table 2, are time-varying characteristics of HFT firms and are thus not absorbed by the firm fixed effects. Thus, we conclude that the main results in Table 2 are robust to this alternative specification holding fixed firm-level characteristics.

Increases and decreases in latency rank. A second strategy involves an event-study-like analysis measuring the change in HFT performance when an HFT switches rank. Before describing the methodology and presenting the results, we first document a latency-rank transition matrix, which shows how the latency rank of HFT firms evolves on a monthly basis. This transition matrix is presented in Table A10. The rows correspond to the latency rank (ranked monthly based on DECISION_LATENCY) in a given month *t*, and the columns correspond to the latency rank in the subsequent month (*t*+1). Each cell in the matrix represents the frequency with which HFTs transition from one rank to another on a monthly basis. The sample consists of 16 HFT firms and 60 months of trading (January 2010 to December 2014).

INSERT TABLE A10 ABOUT HERE

From Table A10, we can see that while rank order is generally persistent month-to-month (the diagonal cells), the off-diagonal cells show there are moderate numbers of rank shifts. Although some of these rank shifts may simply reflect noise (e.g., an HFT bouncing between rank 2 and 3), larger rank shifts are also evident. Latency rank thus appears contestable, and, as shown in the analysis of colocation upgrades in Section IV, such colocation upgrade events can drastically change the competitive environment, allowing some firms to leap ahead in rank.

We next use these changes in rank to assess the effect on subsequent trading performance. Table A11 analyzes the change in HFT performance subsequent to increases and decreases in latency rank (with HFTs ranked monthly based on DECISION_LATENCY). Panel A considers “up-rank” events (an HFT increases in rank in the subsequent month), and Panel B considers “down-rank” events (an HFT decreases in rank in the subsequent month). We only consider moving up or down to the top 3 positions, as the effect is much attenuated for rank 4 and below. Within Panel A, the rows correspond to HFTs that increase in rank (compared to the previous month) to land in Rank 1, increase in rank to land in Rank 2, and increase in rank to land in Rank 3. Within Panel B, the rows correspond to HFTs that decrease in rank (compared to the previous month) to leave from Rank 1, decrease in rank to leave from Rank 2, and decrease in rank to leave from Rank 3. For each of these types of events, the mean change in performance is reported, with its standard error in parentheses underneath.

INSERT TABLE A11 ABOUT HERE

There are 40 total rank shifts into or out of the top 3 throughout our entire sample. For each, we compute the average change in performance in the three months subsequent to the rank shift, relative to the three months before. Panel A shows that HFTs that increase in rank see an increase in subsequent trading performance, with the magnitude largest for those becoming Top 1. Panel B shows that HFTs that decrease their rank see a decrease in subsequent trading performance, with the magnitude largest for those leaving the Top 1. These results are qualitatively consistent with those in the main analysis in Table 2.

Finally, because the sample size in Panels A and B is small, Panel C combines all the types of events reported in Panels A and B (reversing the sign of the performance measures for "down-rank" events in Panel B). The result, which is statistically significant, again confirms that HFTs that increase their rank see an increase in trading performance (and vice versa for decreases in rank).

A10. Alternative Latency Measures

In this Appendix section, we construct two alternative latency measures, QUEUING_LATENCY and MEAN_LATENCY, and re-estimate the results of Table 2.

To mitigate the time stamp noise of DECISION_LATENCY, we measure MEAN_LATENCY. We use the same distribution of latencies as for DECISION_LATENCY, but instead of calculating the 0.1% quantile, we define MEAN_LATENCY as the mean of all latencies that are shorter than one millisecond. By using a central moment rather than an extreme quantile, we expect the time-stamp noise to cancel out, relying on the central limit theorem. This approach comes at the cost of not picking the cases where HFTs operate at their very fastest speed.

Our second alternative latency measure, QUEUING_LATENCY, circumvents both the time stamp noise and the problem that DECISION_LATENCY relies on that HFTs use a mixture of active and passive trades. For this measure, we exploit price changes that lead to a gap in the limit order book. As modelled by Yueshen (2014), if the price change is viewed as temporary, fast traders rush in to capture the top-of-queue limit order position in the emerging gap. When the price changes and a new tick opens up, QUEUING_LATENCY measures how often each HFT firm submits the first limit order and thus gets to the top of the queue. A higher value corresponds to lower latency. Note that this measure does not use time stamps and, furthermore, that simply more trading or limit order submissions does not help one get to the top of the queue: given the brief window when a new tick opens up, the chances of a randomly submitted order ending up first is negligible.

The measurement procedure for QUEUING_LATENCY involves the following three steps. First, we identify trades that consumes all available liquidity at a price level (*gap-opening trades*). Second, for each gap-opening trade we identify the next trade at the same price level as the *gap-filling trade*. We retain the passive counterparty of all gap-filling trades that: (i) are in the same direction as the corresponding gap-opening trades; (ii) occur within 10 seconds after the corresponding gap-opening trades; (iii) do not have the same broker as buyer and seller; (iv) do not have the same passive counterparty as the corresponding gap-opening trades.[4]

We repeat the analysis in Table 2 for the two alternative measures of latency and report the findings in Table A12. As in Section IV.A, we use the alternative latency measures to rank HFTs by latency in each month and construct new TOP1 and TOP5 rank dummies. Note that in Panel A, which looks at QUEUING_LATENCY, we represent nominal latency with log(QUEUING_LATENCY + *1)*, so that we do not take the log of zero, which is the lowest possible value that QUEUING_LATENCY can attain.

INSERT TABLE A12 ABOUT HERE

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[4] The reasoning behind the criteria is as follows. (i) This criterion avoids cases where the market order leading to the gap-opening trade posts its residual volume as a limit order. That is a mechanical way to cease the top-of-queue position. Execution of such limit orders is however always in the opposite direction relative the gap-opening trade. (ii) This criterion ensures that there really is a race to capture the trading opportunity. (iii) This criterion avoids the influence of the *internal* priority rule at NASDAQ OMX Stockholm. Under this rule, a broker with a limit order posted at a given price level has priority to be executed if a market order from the same broker is executed at that price. (iv) This criterion ensures that we do not capture iceberg orders that automatically converts hidden liquidity to visible if the previously visible part of the order is executed.

Panel A reports the results for QUEUING_LATENCY. In Column 1, there is an association between nominal speed and trading performance. In contrast to Table 2, we expect a positive coefficient, since lower latency is represented by a higher value of QUEUING_LATENCY. In Columns 2 and 3, when the TOP1 and TOP5 rank dummies are added, the coefficient on nominal latency now becomes insignificantly different from zero, while the magnitudes of the estimates on the TOP1 and TOP5 rank dummies are large and significant. Thus, as before, relative latency is more important than nominal latency. Similar results can be seen for RETURNS, the SHARPE_RATIO, and TRADING_VOLUME. However, as usual for the quality measure, REVENUES_PER_MSEK_TRADED, the results are small in magnitude and not significant.

Panel B reports the results for MEAN_LATENCY and tells a similar story. The only main difference between Panel B and Table 2 is that the coefficient on the TOP5 rank dummy is generally statistically significant, but the one on TOP1 is not, although it is still generally positive and large in magnitude. So while being relatively fast according to this measure is still important, as reflected in the coefficient on the TOP5 dummy, MEAN_LATENCY may not be the best measure to capture the very fastest HFTs at their peak potential, when extreme low latencies are needed to outperform competitors. Nevertheless, as a central tendency and not an extreme value, MEAN_LATENCY is useful for assessing the robustness of our main measure, DECISION_LATENCY.

A11. Persistence in Performance

We test for persistence industry-wide and at the HFT firm-level. Firm-level performance persistence would show that something else than luck drives a firm's performance. Industry-wide persistence in performance would be consistent with competition on relative latency. Budish et al. (2015) argue one firms with a speed advantage can always adversely select slower traders. Furthermore, if competition on relative speed makes new entry difficult, as we show in Section VI.C, difficulty of new entry may keep aggregate HFT performance from declining.

To analyze firm-level persistence we regress measures of performance on their lagged values, on both the daily and monthly frequency. Measures of performance are standardized in the cross section (centered on the mean and scaled by the standard deviation across firms). The standardization controls for potential time-variation in the mean and variance of returns. We also estimate persistence regressions with rank-order performance, ranking the relative performance of firms as 1, 2, 3, etc., for each measure of performance on each day or month.

Results based on daily observations are reported in Table A13, Panel A, and those using monthly observations are reported in Panel B. Since each measure is standardized in the cross-section, the constant term in the regression model is mechanically zero. Coefficient estimates equal to one means perfect persistence and zero means no persistence. Standard errors are clustered by firm and day in Panel A and by firm and month in Panel B.

INSERT TABLE A13 ABOUT HERE

We find that HFTs have statistically significant daily persistence coefficients of 0.235 for REVENUES and 0.387 for RETURNS. On the monthly frequency, we find higher persistence coefficients: 0.631 for REVENUES, 0.763 for the SHARPE_RATIO, and 0.446 for RETURNS. Performance is more persistent at the monthly level, which is likely due to the higher idiosyncratic risk in daily observations. The rank order analysis shows similar persistence. Consistent with our earlier argument that REVENUES_PER_MSEK_TRADED may be a less relevant performance metric for HFTs, we find lower persistence in this measure.

Consistent with these predictions, we find that the HFT industry-wide performance is relatively stable over the five-year sample. Table A14, Panel A, reports average daily statistics aggregated across all HFTs and all stocks and reported in half-year intervals. The statistics include TOTAL_ DAILY_REVENUES (REVENUES summed across all HFTs), AVERAGE_DAILY_REVENUES (the TOTAL_DAILY_REVENUES averaged across HFTs), DAILY_TRADING_VOLUME (the TRADING_ VOLUME summed across all HFTs and reported in MSEK), and AVERAGE_REVENUES_

PER_MSEK_TRADED (the ratio of TOTAL_DAILY_REVENUES and DAILY_TRADING_ VOLUME).

INSERT TABLE A14 ABOUT HERE

Our results show that TOTAL_DAILY_REVENUES and AVERAGE_DAILY_REVENUES are relatively stable over the five-year period.[5] Interestingly, as shown in Figure 2, Panel B, DAILY_TRADING_VOLUME_PER_FIRM trends up while AVERAGE_REVENUES_PER_MSEK_ TRADED trends down, but the ratio of the two, HFT_REVENUES_PER_FIRM, is stable. One possible interpretation is that as HFTs are presumably competing more by increasing trading volume and pursuing ever-lower latencies, they are chasing the same number of profit opportunities, so the resulting HFT revenues per firm is the same.

To formally test the movement of the trends, we estimate the following OLS regression on daily observations:

$$\text{PERFORMANCE}_t = \alpha + \beta\,(\text{YEAR} - 2010) + \epsilon_t, \qquad \text{(A1)}$$

where PERFORMANCE_t is one of the performance measures described above, and *year* is a continuous variable (e.g., YEAR would take on the approximate value of 2014.25 on March 31, 2014). A positive (negative) coefficient on the $(\text{YEAR} - 2010)$ variable corresponds to an increasing (decreasing) trend in the HFT industry-wide performance over the period 2010-2014. Newey-West standard errors with 30-day lags are used. The coefficient estimates are presented in Table 13, Panel B.

The tests statistically confirm the aforementioned trends. However, there is statistical evidence that trading revenues are slightly increasing over the sample period: a yearly increase of 22,682 SEK for TOTAL_DAILY_REVENUES, relative to a baseline of 166,484 SEK in the first half of 2010. This increase is however not statistically significant in terms of AVERAGE_DAILY_REVENUES, which takes the number of HFTs in the industry into account.

[5] Returns slightly trend down, but, given the relative stability of revenues per firm, this mechanically must mean that average firm capitalization is slightly increasing over the sample.

We also examine the time trend in the COST_OF_HFT_INTERMEDIATION_FOR_NONHFTS (defined as in Section VII and measured on a daily frequency). Table A14, Panel B, indicates a small upward time trend in the cost of HFT intermediation, starting from around 0.13 bps and increasing by about 0.06 on average per year.

Table A1: Stock Characteristics

This table reports summary statistics of the 25 Swedish stocks in the sample. MARKET_CAPITALIZATION is based on the closing price on December 31, 2014 (expressed in MSEK). All other statistics are calculated as averages across trading days in December 2014. Because *SCVb* is delisted in May 2014, the metrics for that stock are based on April 2014. DAILY_TRADING_VOLUME refers to trading at NASDAQ OMX Stockholm only and is reported in MSEK. DAILY_TURNOVER is the DAILY_TRADING_VOLUME divided by MARKET_ CAPITALIZATION, expressed in percentage points. TICK_SIZE is the average minimum price change; QUOTED_SPREAD is the average bid-ask spread prevailing just before each trade; and EFFECTIVE_SPREAD is the trade value-weighted average absolute difference between the trade price and the bid-ask midpoint. All spread measures are based on continuous trading at NASDAQ OMX Stockholm, expressed relative to the bid-ask spread midpoint, and presented in basis points. The Tick Size and the Quoted Spread are halved to be comparable to the Effective Spread. VOLATILITY is the average 10-second squared returns, calculated from bid-ask midpoints. The FRAGMENTATION_INDEX is the inverse of a Herfindahl index of trading volumes across the five largest trading venues (BATS, Burgundy, Chi-X, NASDAQ OMX Stockholm, and Turquoise); a higher value signifies greater fragmentation. The table is sorted by MARKET_CAPITALIZATION.

Stock Ticker	MARKET_ CAP. (MSEK)	DAILY_ TRADING _VOL. (MSEK)	DAILY_ TURNOVER (%)	TICK_ SIZE (bps)	QUOTED_ SPREAD (bps)	EFF_ SPREAD (bps)	VOLATILITY (sq. bps)	FRAGMENT_ INDEX
HMb	475,595	1,358	0.29	1.57	2.06	2.26	2.94	2.11
SHBa	228,731	757	0.33	1.38	2.17	2.36	4.08	2.30
SWEDa	221,307	1,011	0.46	2.58	2.90	3.21	5.69	2.00
SEBa	216,025	771	0.36	2.67	3.19	3.30	5.20	1.93
ATCOa	183,324	839	0.46	2.32	3.04	3.23	5.12	2.29
ASSAb	145,878	529	0.36	1.23	2.36	2.51	3.52	2.28
VOLVb	136,816	1,099	0.80	2.98	3.24	3.34	5.71	1.91
INVEb	129,676	590	0.46	1.79	2.43	2.62	4.12	1.80
SCAb	104,559	632	0.60	2.91	3.42	3.59	5.13	2.13
SAND	95,835	798	0.83	3.27	3.67	3.74	6.55	2.12
SCVb	78,800	825	1.05	2.65	3.66	4.75	6.75	1.91
ATCOb	78,395	262	0.33	2.55	3.88	4.09	5.52	1.85
SKFb	68,879	684	0.99	3.14	3.63	3.85	6.07	2.24
ELUXb	68,807	471	0.68	2.24	3.16	3.29	5.05	2.31
SKAb	67,160	320	0.48	3.07	3.63	3.77	4.89	1.90
ALFA	62,205	463	0.75	3.42	4.06	4.10	6.04	2.05
KINVb	60,097	337	0.56	1.95	3.61	3.98	7.95	2.26
SWMA	49,082	337	0.69	2.04	3.10	3.32	4.38	2.24
TEL2b	40,403	334	0.83	2.64	3.21	3.51	5.97	2.12
GETIb	39,540	221	0.56	2.91	3.81	4.21	4.25	1.99
LUPE	34,964	586	1.68	4.08	5.65	5.68	16.53	1.91
BOL	34,326	538	1.57	4.05	4.87	4.90	7.88	2.06
SECUb	32,861	169	0.51	2.73	3.66	3.88	3.75	2.32
MTGb	15,369	155	1.01	2.05	4.07	4.77	7.46	2.17
SSABa	13,877	370	2.67	1.61	3.82	4.14	8.89	1.76

Table A2: HFTs Active at NASDAQ OMX Stockholm

This table shows a list of HFTs who according to public trading records are active at NASDAQ OMX Stockholm for at least one month of our sample period (January 2010 to December 2014). The list contains 19 of the 25 firms identified as HFTs in our sample. We can only show the public record for confidentiality reasons. HFTs that are not listed do not trade as members at NASDAQ OMX Stockholm, but may trade at other trading venues or as clients of other members at NASDAQ OMX Stockholm. The HFTs are presented in alphabetical order.

Algoengineering
All Options International
Citadel Securities
Flow Traders
GETCO[a]
Hardcastle Trading
IMC Trading
International Algorithmic Trading (SSW Trading)
Knight Capital [a]
Madison Tyler[b]
MMX Trading
Optiver
Spire
Susquehanna Int. Sec.
Timber Hill
WEBB Traders
Virtu Financial[b]
Wolverine Trading UK

[a] Knight Capital merged with GETCO in July 2013
(https://www.sec.gov/Archives/edgar/data/1569391/000119312513279128/d559202d8k12g3.htm)
[b] Madison Tyler merged with Virtu Financial in July 2011
(https://www.sec.gov/Archives/edgar/data/1592386/000104746914002070/a2218589zs-1.htm)

Table A3: Comparison of HFT Revenue Calculation Methods

This table reports the firm cross-sectional distribution of HFT trading revenues (as in Table 1) using four different methods for calculating trading revenues. *No adjustments* is calculated by cumulating daily inventory positions over the full sample; *Method 1: Benchmark* is the method used throughout the paper that zeros the end-of-day position daily for each HFT firm (equivalent to assuming that each firm liquidates any remaining end-of-day position at the daily closing price); *Method 2: Intraday Revenues* assumes that any remaining end-of-day positions were never purchased in the first place (assuming first-in-last-out inventory accounting); *Method 3: Intraday Revenues Plus Revenues from Inventory Sold* is similar to *Method 2* but adds back in the revenues from closing end-of-day positions that are in opposite direction of previous day end-of-day inventory (that is, the end-of-day inventory is marked to market only if an offsetting position exists in the previous end-of-day inventory).

	Mean	St.Dev.	p10	p25	p50	p75	p90
No adjustments							
REVENUES	20,824	25,149	-6,788	277	10,037	45,082	65,415
SHARPE_RATIO	4.07	5.16	-0.76	0.80	2.81	6.04	10.89
REV_PER_MSEK_TRADED	159.42	326.12	-201.36	27.00	59.05	217.77	443.20
Method 1: Benchmark							
REVENUES	18,181	29,519	-7,572	-487	6,990	31,968	61,354
SHARPE_RATIO	4.16	6.58	-1.47	0.33	1.61	7.02	11.14
REV_PER_MSEK_TRADED	153.25	504.78	-257.94	-43.71	56.45	147.24	472.16
Method 2: Intraday Revenues							
REVENUES	18,069	29,527	-7,554	-577	7,095	31,972	61,243
SHARPE_RATIO	4.15	6.50	-1.47	0.33	1.61	7.01	11.14
REV_PER_MSEK_TRADED	146.98	476.65	-255.17	-24.76	55.54	147.03	469.27
Method 3: Intraday Revenues Plus Revenues from Inventory Sold							
REVENUES	21,128	25,451	-2,036	2,026	11,408	32,193	66,835
SHARPE_RATIO	3.34	3.80	-0.09	0.75	1.93	4.90	9.37
REV_PER_MSEK_TRADED	265.14	535.64	-200.68	9.13	88.62	367.66	1,160.62

Table A4: Daily Fama-French Plus Momentum Factors for Swedish Equities

This table reports summary statistics corresponding to daily Fama-French plus momentum factors created for Swedish equities. The mean daily log excess return (annualized), its standard error, and the number of observations (i.e., number of normal trading days) are reported for each of the portfolios. The four factors are constructed according to the specifications used to create U.S. factors, as specified on Kenneth French's website: the value-weighted portfolios consist of top-30%, middle 40%, and bottom-30% of stocks and are re-sorted every July 1 using data from the previous year's performance. The data (daily total excess returns, shares outstanding, and quarterly book values) come from Compustat Global and covers the period January 2010 to December 2014.

	Mean	S.E.	Daily observations
log market excess returns	0.160	0.083	1255
log large-cap returns	0.152	0.085	1255
log medium-cap returns	0.231	0.070	1255
log small-cap returns	0.347	0.063	1255
log SML returns	0.176	0.068	1255
log growth returns	0.161	0.088	1255
log neutral returns	0.143	0.084	1255
log value returns	0.206	0.090	1255
log HML returns	0.039	0.054	1255
log winner returns	0.171	0.095	1255
log neutral returns	0.155	0.084	1255
log loser returns	0.136	0.088	1255
log WML returns	0.028	0.065	1255

Table A5: Trading Revenues, Costs, and Profits from Public Filings

This table reports trading revenues, trading costs, trading profit margins, and trading returns calculated from annual reports and IPO prospectuses for five high-frequency trading firms for which public data is available. Trading costs are broken down into several categories, all expressed as a percent of trading revenues. Trading profit margin is calculated as (1 - trading costs), and trading returns are calculated two ways based on two capitalization measures: as trading revenues / (trading assets minus trading liabilities) and as (trading revenues / book equity). All quantities are in million USD, except for the firm Flow Traders, which is in million EUR.

	Virtu					KCG			GETCO				Flow Traders				Jump
	2015	2014	2013	2012	2011	2015	2014	2013	2012*	2011	2010	2009	2015	2014	2013	2012	2010
Trading Revenues (in millions)	757.5	685.2	623.7	581.5	449.4	1,179.9	1,274.4	903.8	526.6	896.5	865.1	955.2	400.1	240.8	200.5	125.1	511.6
-- % of revenue from proprietary trading	95.1%	98.5%	98.4%	100%	100%	73.8%	68.5%	67.0%	89.9%	94.2%				100%	100%	100%	
Trading Costs (as % of Trading Revenue)	54.7%	60.0%	57.8%	72.6%	62.1%	51.3%	52.4%	59.0%	62.5%	48.5%	48.6%	40.4%	35.5%	41.6%	43.7%	47.5%	
-- Brokerage, exchange and clearance fees	30.7%	33.7%	31.3%	34.5%	32.9%	22.5%	23.9%	27.3%	35.3%	32.2%	35.1%	32.1%	{ 14.2%	15.7%	15.8%	14.8%	
-- Communication and data processing	9.0%	10.0%	10.4%	9.5%	10.3%	11.8%	11.8%	13.7%	17.2%	9.7%	7.1%	4.5%					
-- Equipment rentals, depreciation and amortization	4.4%	4.5%	4.0%	15.7%	11.1%	10.2%	10.4%	11.0%	9.1%	6.2%	6.2%	3.8%	1.6%	1.8%	1.9%	2.4%	
-- Net interest & dividends on securities paid (on credit lines, securities borrowing, etc.)	7.1%	8.6%	7.8%	7.1%	6.0%	6.1%	5.4%	6.5%	1.0%	0.3%	0.1%	0.0%	9.7%	12.5%	12.8%	12.3%	
-- Other trading costs (administrative & technical costs, other overhead, etc.)	3.4%	3.2%	4.4%	5.8%	1.8%	0.7%	0.8%	0.5%	0.0%	0.0%	0.0%	0.0%	10.1%	11.5%	13.3%	18.0%	
Trading Profit Margin	45.3%	40.0%	42.2%	27.4%	37.9%	48.7%	47.6%	41.0%	37.5%	51.5%	51.4%	59.6%	64.5%	58.4%	56.3%	52.5%	52.3%***
Trading Revenue / (Trading Assets Minus Trading Liabilities)**	183%	228%	196%	184%		96%	96%	60%	62%				114%	118%	119%	103%	237%
Trading Revenue / (Book Equity)	136%	135%	138%	84%		82%	84%	60%	80%				162%	169%	146%	123%	222%

* Does not include any costs associated with the December 19, 2012 merger agreement with Knight (e.g., costs related to the Knight August 1, 2012 incident)
** Trading asset include cash and cash equivalents, financial instruments owned, receivables from broker-dealers and clearing organizations, and collateralized agreements. Trading liabilities include short-term borrowings, collateralized financing, financial instruments sold and not yet purchased, payables to broker-dealers and clearing organizations, and other accounts payable.
*** Total profit margin

Table A6: Exchange Fees for Three Exchanges Trading Swedish Equities

This table reports exchange fees in 2014 for three stock exchanges (NASDAQ OMX Stockholm, BATS, and Chi-X) trading Swedish equities. Exchange fees depend on the side of the trade: "maker" fees are less than "taker" fees, and, at Chi-X, makers receive liquidity rebates (negative fees). NASDAQ OMX Stockholm fees are lower for S30 stocks; all the stocks in this study fall into this category. While NASDAQ OMX Stockholm grants preferential prices for liquidity provision under its Liquidity Provider Scheme (LPS), BATS and Chi-X do not (a designated liquidity provider program exists but it does not have lower fees). Although BATS and Chi-X merged in November 2011, with technology integration complete by April 2012, the trading platforms continue to implement different pricing structures.

	NASDAQ OMX Stockholm for S30 stocks	NASDAQ OMX Stockholm Liquidity Provider Scheme (LPS) for S30 stocks	BATS*	Chi-X*
Maker	0.125 bps	0 bps	0 bps	-0.15 to -0.225 bps**
Taker	0.325 bps	0.5 bps	0.15 bps	0.30 to 0.24 bps

* For non-hidden limit orders
** The exact price within this range depends on volume. The lowest fees are given after total monthly trading volume exceeds 16 billion EUR. Negative values represent liquidity rebates.

Table A7: HFT Performance after Accounting for Potential Maker-Taker Fees

This table is similar to Table 1 but adjusts for potential maker-taker fees and liquidity rebates. Panel A reports trading revenues under the assumption of the maximum possible maker-taker fees on NASDAQ OMX Stockholm (0.325 bps taker fees; 0.125 bps maker fees), and Panel B uses the maximum possible on the Chi-X exchange, which features a liquidity rebate (0.30 bps taker fees; 0.225 bps liquidity rebate).

Panel A: Using Maker-Taker Fees on NASDAQ OMX Stockholm

	Mean	St.Dev.	p10	p25	p50	p75	p90
REVENUES (SEK)	12,012	18,688	-2,228	-1,212	5,124	19,346	52,553
REV_PER_MSEK_TRADED	31.87	207.36	-209.56	-39.64	34.68	66.04	330.17
RETURNS	0.22	0.33	-0.08	0.00	0.08	0.45	0.81
SHARPE_RATIO	3.40	5.41	-1.50	0.00	1.66	6.20	10.49
1_FACTOR_ALPHA	0.22	0.33	-0.07	0.00	0.08	0.45	0.82
3_FACTOR_ALPHA	0.22	0.33	-0.06	0.01	0.08	0.45	0.80
4_FACTOR_ALPHA	0.22	0.33	-0.06	0.01	0.08	0.45	0.80

(N = 16 firms)

Panel B: Using Taker Fees & Liquidity Rebates on Chi-X

	Mean	St.Dev.	p10	p25	p50	p75	p90
REVENUES (SEK)	17,525	24,207	-1,230	-327	5,252	36,366	56,420
REV_PER_MSEK_TRADED	50.41	208.01	-198.67	-22.39	59.28	83.61	362.39
RETURNS	0.34	0.52	-0.08	0.01	0.08	0.48	1.11
SHARPE_RATIO	4.74	7.61	-1.45	0.40	1.69	6.56	13.53
1_FACTOR_ALPHA	0.34	0.53	-0.07	0.01	0.08	0.48	1.12
3_FACTOR_ALPHA	0.34	0.54	-0.06	0.02	0.09	0.48	1.11
4_FACTOR_ALPHA	0.34	0.54	-0.06	0.02	0.09	0.48	1.11

(N = 16 firms)

Table A8: Trading Performance and Latency of the Five Fastest HFTs

This table is similar to Table 2 but breaks down the TOP5 dummy variable into individual dummy variables for the fastest HFTs: RANK1, RANK2, RANK3, RANK4, and RANK5. As in Table 2, it reports coefficients estimated from equation (1) for five performance measures as dependent variables: REVENUES, RETURNS, SHARPE_RATIO, TRADING_VOLUME, and REVENUES_PER_MSEK_TRADED (all defined as in Table 1). The independent variables considered are as follows: log(DECISION_LATENCY) is the natural logarithm of DECISION_LATENCY (defined as in Table 1). RANK1, RANK2, RANK3, RANK4, and RANK5 are indicator variables for whether a given firm is ranked as the top 1, 2, 3, 4, or 5 firms by DECISION_LATENCY in a given month. The control variables, whose estimated coefficients are omitted to conserve space, are the same as in Table 2. All continuous independent variables are in units of standard deviations. *, ** and *** correspond to statistical significance at the 10%, 5%, and 1%, respectively. Standard errors are double clustered by firm and month and are reported in the parentheses. The sample consists of 25 Swedish stocks and 60 months of trading (January 2010 to December 2014).

	REVENUES			RETURNS			SHARPE_RATIO			TRADING_VOLUME (x 10^{-6})			REVENUES_PER_ MSEK_TRADED		
$\log(DECISION\_LAT_{i,t})$	-14020***	1275	11334	-.221***	-.0297	.0174	-4.38***	-.395	2.34	-247***	-54.5	32.6	-19.4	-6.68	102**
	(4311)	(6837)	(10708)	(.0483)	(.063)	(.0797)	(.632)	(1.34)	(1.5)	(43.7)	(64.7)	(77.8)	(57.5)	(69.3)	(40.6)
$RANK1_{i,t}$		58288***	44007***		.626***	.604***		12.2***	10.8***		693***	545***		33.9	106*
		(15035)	(11886)		(.152)	(.166)		(3.63)	(3.7)		(160)	(145)		(103)	(57.4)
$RANK2_{i,t}$		40358***	29165***		.396***	.361***		9.01**	6.98**		496***	371***		26.7	56.3
		(15163)	(10847)		(.15)	(.134)		(3.55)	(3.12)		(143)	(101)		(116)	(83.8)
$RANK3_{i,t}$		35262*	24967*		.575***	.534***		12.1**	9.91**		563**	446***		23.8	33.9
		(21206)	(14052)		(.212)	(.19)		(5.17)	(4.22)		(232)	(169)		(98.2)	(63.2)
$RANK4_{i,t}$		23756**	16243**		.441**	.414**		8.89**	7.01**		249*	159		78.3	90.5***
		(11854)	(7722)		(.21)	(.182)		(3.51)	(2.88)		(136)	(108)		(88)	(33.5)
$RANK5_{i,t}$		11588	5422		.106	.0955		2.92	2.21		117	48.6		-25.9	14.8
		(7457)	(7618)		(.0952)	(.0838)		(1.8)	(1.62)		(87.5)	(79)		(102)	(73.7)
Constant	20278***	6993*	9568**	.254***	.0852	.0885*	5.1***	1.55	1.92	313***	147***	177***	35.2	24.4	6.17
	(6973)	(3874)	(4393)	(.0579)	(.0564)	(.0463)	(1.26)	(1.28)	(1.21)	(75.9)	(55.8)	(52.4)	(57.3)	(82.2)	(11.9)
Controls	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Month FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.123	0.168	0.263	0.198	0.233	0.269	0.207	0.254	0.361	0.294	0.362	0.454	0.080	0.080	0.148
N	737	737	737	737	737	737	737	737	737	737	737	737	737	737	737

Table A9: Trading Performance and Latency with Firm Fixed Effects

This table is similar to Table 2 but is estimated with HFT firm fixed effects to control for firm-specific characteristics. The control variables, which vary across both HFT firm and month, are the same as in Table 2. All continuous independent variables are in units of standard deviations. *, ** and *** correspond to statistical significance at the 10%, 5%, and 1%, respectively. Standard errors are double clustered by firm and month and are reported in the parentheses. The sample consists of 25 Swedish stocks and 60 months of trading (January 2010 to December 2014).

	REVENUES			RETURNS			SHARPE_RATIO			TRADING_VOLUME (x 10^{-6})			REVENUES_PER_ MSEK_TRADED		
log(DECISION_LAT$_{i,t}$)	-4288	-2620	5293	-.0891	-.0466	-.0267	-1.55	-.777	1.02	-149***	-115**	-61.1	66.5	85.6	134**
	(7373)	(6424)	(6078)	(.11)	(.107)	(.126)	(1.14)	(1.36)	(1.49)	(53.6)	(54.5)	(52.1)	(56.1)	(64.5)	(56.7)
TOP1$_{i,t}$		22673**	21246**		.159	.159		3.47*	3.21*		296***	283***		41.2	53.7
		(9844)	(8875)		(.127)	(.126)		(1.79)	(1.75)		(79.3)	(75.6)		(26.3)	(33.8)
TOP5$_{i,t}$		-1278	-1846		.082	.0875		1.32	1.33		18.6	11.2		44.9	69.1
		(4072)	(3993)		(.106)	(.105)		(2.15)	(1.96)		(76.8)	(69.7)		(67.7)	(50.4)
END_OF_DAY_INV.$_{i,t}$			3426			.075			2**			-4.78			266
			(3001)			(.0632)			(.775)			(8.66)			(190)
MAX_INTRADAY_INV$_{i,t}$			-14678**			*[omitted]*			-3.06***			-90.8***			-56.8
			(7185)						(1.1)			(34.6)			(166)
INVEST_HORIZON$_{i,t}$			-4351			-.0435			-1.03			-53.3**			7.98
			(3105)			(.06)			(.709)			(25.7)			(29.4)
AGGRESSIVE_RATIO$_{i,t}$			2375			-.0418			.0923			20.8			-104
			(3352)			(.0899)			(1.04)			(30.2)			(116)
Constant	-3259	-4712	29.7	.0067	-.0312	.0373	-1.86**	-2.55**	-.848	149***	119***	145***	-439***	-456***	-286***
	(6505)	(6047)	(5896)	(.11)	(.108)	(.0803)	(.931)	(1.25)	(1.08)	(44)	(44.5)	(55.9)	(85.8)	(53.9)	(98.4)
Month and Firm FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.431	0.442	0.462	0.360	0.364	0.373	0.463	0.470	0.503	0.685	0.706	0.716	0.149	0.149	0.185
N	737	737	737	737	737	737	737	737	737	737	737	737	737	737	737

Table A10: Latency-Rank Transition Matrix

This table is a transition matrix showing how the latency rank of HFT firms evolves on a monthly basis. The rows correspond to the latency rank (ranked monthly based on DECISION_LATENCY) in a given month t, and the columns correspond to the latency rank in the subsequent month (t+1). Each cell in the matrix represents the frequency with which HFTs transition from one rank to another on a monthly basis. The sample consists of 16 HFT firms and 60 months of trading (January 2010 to December 2014).

		Rank t+1						
		1	2	3	4	5	>5	Exit sample
Rank t	1	**52.54%**	18.64%	8.47%	11.86%	5.08%	3.39%	0%
	2	22.03%	**30.51%**	22.03%	10.17%	5.08%	10.17%	0%
	3	10.17%	22.03%	**42.37%**	13.56%	5.08%	6.78%	0%
	4	1.69%	16.95%	10.17%	**37.29%**	16.95%	16.95%	0%
	5	6.78%	6.78%	10.17%	8.47%	**33.90%**	33.90%	0%
	>5	0.67%	0.45%	0.89%	2.45%	4.45%	**83.96%**	7.13%
	Enter sample	2.78%	2.78%	0%	0%	0%	94.44%	

Table A11: Change in HFT Performance Subsequent to Latency Rank Changes

This table analyzes the change in HFT performance subsequent to increases and decreases in latency rank (with HFTs ranked monthly based on DECISION_LATENCY). Panel A considers "up-rank" events (an HFT increases in rank in the subsequent month), and Panel B considers "down-rank" events (an HFT decreases in rank in the subsequent month). Within Panel A, the rows correspond to HFTs that increase rank (compared to the previous month) to land in Rank 1, increase rank to land in Rank 2, and increase rank to land in Rank 3. Within Panel B, the rows correspond to HFTs that decrease rank (compared to the previous month) to leave from Rank 1, decrease rank leave from Rank 2, and decrease rank to leave from Rank 3. For each of these types of events, the mean change in performance is reported, with its standard error in parentheses underneath. Panel C combines all the types of events reported in Panels A and B (reversing the sign of the performance measures for "down-rank" events in Panel B). *, ** and *** correspond to statistical significance at the 10%, 5%, and 1%, respectively.

Panel A: Change in HFT Performance due to "Up-Rank" Events

REVENUES	RETURNS	SHARPE_RATIO	TRADING_VOLUME (x 10^{-6})	REVENUES_PER_ MSEK_TRADED
Move from Rank >1 to Rank 1 (N = 11 events)				
26518**	.395**	8***	233**	23.5**
(11011)	(.169)	(1.32)	(93.8)	(10.4)
Move from Rank >2 to Rank 2 (N = 5 events)				
14786	.271	1.04	70.6	42.4
(24478)	(.266)	(1.93)	(139)	(32.2)
Move from Rank >3 to Rank 3 (N = 4 events)				
20050	.198	.591	259	38.6
(20810)	(.361)	(2.2)	(219)	(31.6)

Panel B: Change in HFT Performance due to "Down-Rank" Events

REVENUES	RETURNS	SHARPE_RATIO	TRADING_VOLUME (x 10^{-6})	REVENUES_PER_ MSEK_TRADED
Move from Rank 1 to Rank >1 (N = 11 events)				
-8719	-.12	-.671	-137**	25.3
(6400)	(.124)	(.818)	(66.4)	(24.9)
Move from Rank 2 to Rank >2 (N = 5 events)				
-6485	-.0109	-.0388	-59.2	34.4
(4338)	(.0454)	(1.03)	(67.2)	(54.3)
Move from Rank 3 to Rank >3 (N = 4 events)				
-4620	-.226	-1.56	-42.1	11.1
(7258)	(.215)	(1.39)	(71.1)	(97.7)

Panel C: Change in HFT Performance due to all Above Events Combined (N = 40, Signed):

REVENUES	RETURNS	SHARPE_RATIO	TRADING_VOLUME (x 10^{-6})	REVENUES_PER_ MSEK_TRADED
14021*	0.209*	2.44*	133.8***	0.1
(7850)	(0.121)	(1.28)	(47.9)	(27.2)

Table A12: Alternative Latency Measures

This table is similar to Table 2 but analyzes two alternative latency measures: QUEUING_LATENCY (Panel A), which counts the cases where an HFT firm captures the top-of-queue position in a limit-order book gap; and MEAN_LATENCY (Panel B), the mean of a distribution of latencies in each firm-month where a passive trade is followed by an active trade at the same venue, in the same stock, within one millisecond. The construction of these alternative latency measures is discussed in Appendix A10. The regression models estimated has the same specifications as in Table 2, except that all latency-related independent variables are based on QUEUING_LATENCY (Panel A) or MEAN_LATENCY (Panel B), rather than on DECISION_LATENCY. Nominal latency in Panel A is defined as the natural logarithm of QUEUING_LATENCY + 1.

Panel A: Queuing Latency and Trading Performance

	REVENUES			RETURNS			SHARPE_RATIO			TRADING_VOLUME (x 10^{-6})			REVENUES_PER _MSEK_TRADED		
log(QUEUING_LAT$_{i,t}$ +1)	16761***	4150	-8265	.281***	.176***	.121*	5.43***	2.94***	-.283	288***	133**	34.8	32.9	38.1	-95
	(4608)	(4907)	(11994)	(.0533)	(.0529)	(.0671)	(.72)	(1.12)	(1.43)	(39.6)	(56.7)	(102)	(58.6)	(77.1)	(62.1)
TOP1$_{i,t}$		50803***	51684***		.463**	.471**		11.9***	12.6***		601***	603***		-9.21	35.5
		(18676)	(15865)		(.228)	(.218)		(2.4)	(2.13)		(126)	(119)		(75.9)	(75.6)
TOP5$_{i,t}$		13698*	9563		.102	.127		2.13	2.39		176*	128		-9.11	87.7
		(7180)	(7400)		(.123)	(.136)		(1.74)	(1.88)		(99.9)	(87.4)		(125)	(66.2)
END_OF_DAY_INV.$_{i,t}$			2718			.0858*			1.95**			-32.5*			325*
			(3742)			(.0508)			(.767)			(18.1)			(170)
MAX_INTRADAY_INV$_{i,t}$			-19571**			*[omitted]*			-2.9**			-151**			-58.6
			(8658)						(1.25)			(68.5)			(129)
INVEST_HORIZON$_{i,t}$			-4950			.0917***			-1.96**			-60.5			-72.8
			(7114)			(.0333)			(.846)			(60.8)			(62.1)
AGGRESSIVE_RATIO$_{i,t}$			6664			.00695			-.442			60.3*			-51.4
			(4551)			(.0428)			(.617)			(33.9)			(65.8)
Constant	20223***	10893**	11153**	.252***	.176***	.16***	5.08***	3.32***	2.91**	313***	197***	203***	34.8	39.1	-7.21
	(6685)	(5372)	(4814)	(.0509)	(.0557)	(.0496)	(1.13)	(1.28)	(1.19)	(72.2)	(67.7)	(58.2)	(56.6)	(96.2)	(45.5)
Month FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.152	0.213	0.302	0.267	0.300	0.323	0.285	0.357	0.429	0.377	0.474	0.547	0.080	0.080	0.146
N	737	737	737	737	737	737	737	737	737	737	737	737	737	737	737

Panel B: Mean Latency and Trading Performance

	REVENUES			RETURNS			SHARPE_RATIO			TRADING_VOLUME (x 10^{-6})			REVENUES_PER _MSEK_TRADED		
log(*Mean Latency*$_{i,t}$)	-10796***	3261	7350	-.14***	.00246	.0247	-3***	-.0674	1.06	-160***	-32.7	17.7	-5.42	22.9	50.3
	(3456)	(6724)	(5858)	(.0523)	(.0918)	(.0913)	(.904)	(1.74)	(1.61)	(58.9)	(93.6)	(77.5)	(42.5)	(54)	(73.4)
TOP1$_{i,t}$		12076	19574		-.0658	.0144		-2.99	-.038		-220	-116		60.9	151
		(26687)	(20144)		(.274)	(.263)		(4.63)	(4.02)		(216)	(148)		(93.1)	(142)
TOP5$_{i,t}$		33497***	13819		.433***	.301**		9.69***	4.69*		465***	216**		49.4	-40.7
		(10315)	(10857)		(.148)	(.142)		(3)	(2.45)		(115)	(109)		(122)	(71.7)
END_OF_DAY_INV.$_{i,t}$			2352			.0737*			1.83**			-40.3**			322*
			(3909)			(.0442)			(.746)			(17.5)			(167)
MAX_INTRADAY_INV$_{i,t}$			-19668***			*[omitted]*			-3.65***			-217***			-52.1
			(6100)						(.999)			(51.1)			(117)
INVEST_HORIZON$_{i,t}$			-4960			-.171***			-2.19***			-82.3*			-69
			(5628)			(.0469)			(.743)			(46.1)			(61.1)
AGGRESSIVE_RATIO$_{i,t}$			6898**			-.0214			-.468			54.6**			-48.5
			(3469)			(.0521)			(.764)			(25.3)			(61.5)
Constant	20554***	7620	12494	.258***	.109	.137**	5.19***	1.96	3.14**	319***	170*	230***	35.7	13.3	32.6
	(7076)	(8590)	(8466)	(.0704)	(.0809)	(.0658)	(1.44)	(1.7)	(1.4)	(83.9)	(95.4)	(88.6)	(57.5)	(98.7)	(45)
Month FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.093	0.142	0.253	0.128	0.182	0.236	0.124	0.219	0.345	0.146	0.266	0.423	0.079	0.080	0.147
N	737	737	737	737	737	737	737	737	737	737	737	737	737	737	737

Table A13: Persistence of HFT Performance

This table analyzes persistence in HFTs' performance on both a daily (Panel A) and a monthly (Panel B) frequency by estimating the following equation using OLS: $\text{PERFORMANCE}_{i,t} = \beta\ \text{PERFORMANCE}_{i,t-1} + \epsilon_{i,t}$. PERFORMANCE can be one of the following dependent variables calculated on a daily basis for each HFT firm: REVENUES, RETURNS, SHARPE_RATIO, and REVENUES_PER_MSEK_TRADED (all defined as in Table 1). For the monthly frequency, each of the performance measures defined on a daily frequency are first averaged across trading days within each month. The SHARPE_RATIO is considered only for the monthly regressions and is based on mean and standard deviation of daily observations of REVENUES. The variables are either in units of standard deviations for each day or month (in each time period, firm-level performance is centered on the mean and scaled by standard deviation across HFTs) or on the rank order of the HFTs (from 1 to 16 based on performance). *, ** and *** correspond to p-values lower than 10%, 5%, and 1%, respectively. Standard errors are double clustered by firm and day (or month for Panel B) and are reported in parentheses. The sample consists of 25 Swedish stocks and 60 months of trading (January 2010 to December 2014).

Panel A: Daily Persistence

	Standardized			Rank order		
	REVENUES	RETURNS	REV_PER_ MSEK_TRADED	REVENUES	RETURNS	REV_PER_ MSEK_TRADED
Lag dependent variable$_{i,t}$	.235***	.387***	.023	.234***	.283***	.029*
	(0.087)	(0.085)	(0.020)	(0.067)	(0.064)	(0.018)
R-squared	0.057	0.157	0.016	0.114	0.143	0.076
N	10642	10642	10642	10642	10642	10642

Panel B: Monthly Persistence

	Standardized				Rank order			
	REVENUES	RETURNS	SHARPE_ RATIO	REV_PER_ MSEK_TRADED	REVENUES	RETURNS	SHARPE_ RATIO	REV_PER_ MSEK_TRADED
Lag dependent variable$_{i,t}$	.631***	.446***	.763***	.106	.464***	.539***	.196**	.134**
	(0.113)	(0.155)	(0.062)	(0.083)	(0.091)	(0.094)	(0.095)	(0.063)
R-squared	0.401	0.222	0.584	0.060	0.252	0.325	0.091	0.069
N	737	737	737	737	737	737	737	737

Table A14: Long-Run Trends in HFT Concentration and Industry-Wide Performance

This table reports long-run trends in various variables related to the HFT industry. TOTAL_DAILY_REVENUES (AVG_DAILY_REVENUES) is REVENUES summed (averaged) across all HFTs, reported in SEK; AVG_REVENUES_PER_MSEK_TRADED is daily REVENUES_PER_ MSEK_TRADED aggregated across HFTs; DAILY_TRADING_VOLUME is the daily TRADING_VOLUME summed across HFTs; COST_OF_HFT_INTERMEDIATION_ TO_NONHFTS is HFT REVENUES divided by non-HFT trading volume. The table also reports long-run trends in various variables measuring the HFT industry concentration in terms of revenues and trading volume. Specifically, the REVENUES_CONCENTRATION and TRADING_VOLUME_ CONCENTRATION is calculated as in equation (3). All measures are calculated on a daily frequency and reported in Panel A as the average across the trading days of each half-year period. Standard errors are given in parentheses. Panel A also reports *T,* the number of trading days in each half-year period. Panel B reports estimates of regressions aimed at identifying time trends, specified for each variable observed at daily frequency. The regression specification is given in equation (4). An estimated $\beta > 0$ indicates an increasing trend in the dependent variable. *, ** and *** correspond to p-values lower than 10%, 5%, and 1%, respectively. In Panel B, Newey-West standard errors (using 30 day lags) are in parentheses. The sample consists of 25 Swedish stocks and 60 months of trading (January 2010 to December 2014).

Panel A: Biannual Averages

	TOTAL_ DAILY_ REVENUES (SEK)	AVG_ DAILY_ REVENUES (SEK)	AVG_ REVENUES_ PER_MSEK_ TRADED (SEK)	DAILY_ TRADING_ VOLUME (MSEK)	COST_OF_HFT_ INTERMED_ TO_NONHFTS (bps)	TRADING_ VOLUME_ CONCENTR.	REVENUES_ CONCENTR.	T (days)
2010:1	166,484	19,694	99.71	1,626	0.132	0.292	0.351	124
	(19439)	(2256)	(10.74)	(57.03)	(0.014)	(0.059)	(0.083)	
2010:2	167,582	20,877	105.81	1,589	0.113	0.304	0.354	130
	(26100)	(3257)	(18.13)	(65.69)	(0.015)	(0.04)	(0.057)	
2011:1	348,282	29,299	80.93	4,512	0.274	0.282	0.327	124
	(79005)	(6577)	(13.36)	(148.62)	(0.049)	(0.025)	(0.067)	
2011:2	239,140	23,156	92.26	2,536	0.175	0.225	0.275	130
	(28225)	(2668)	(9.43)	(80.15)	(0.018)	(0.032)	(0.111)	
2012:1	265,916	21,868	65.78	4,167	0.351	0.199	0.282	123
	(34121)	(2879)	(7.4)	(88.5)	(0.056)	(0.044)	(0.098)	
2012:2	297,164	23,743	67.83	4,287	0.289	0.216	0.306	127
	(44538)	(3490)	(9.86)	(108.34)	(0.038)	(0.026)	(0.109)	
2013:1	256,618	20,898	43.92	5,665	0.426	0.206	0.334	122
	(30104)	(2375)	(4.57)	(108.73)	(0.045)	(0.02)	(0.135)	
2013:2	294,979	23,313	58.70	5,487	0.381	0.186	0.298	128
	(35315)	(2756)	(5.75)	(129.71)	(0.038)	(0.03)	(0.105)	
2014:1	348,687	32,937	74.56	4,280	0.372	0.269	0.328	121
	(69728)	(6069)	(10.27)	(144.08)	(0.059)	(0.024)	(0.105)	
2014:2	192,896	16,945	43.59	4,888	0.201	0.290	0.344	129
	(35573)	(3244)	(7.93)	(153.5)	(0.036)	(0.016)	(0.073)	

Panel B: Time Trend Regressions

	TOTAL_ DAILY_ REVENUES (SEK)	AVG_ DAILY_ REVENUES (SEK)	AVG_ REVENUES_ PER_MSEK_ TRADED (SEK)	DAILY_ TRADING_ VOLUME (MSEK)	COST_OF_HFT_ INTERMED_ TO_NONHFTS (bps)	TRADING_ VOLUME_ CONCENTR.	REVENUES_ CONCENTR.
(YEAR - 2010)	22682*	852.6	-11.61***	788.9***	.05635***	-.0092*	-.0022
	(12130)	(1128)	(3.124)	(117.4)	(.01138)	(.0049)	(.0034)
Constant	199748***	21123***	103.4***	1867***	.1266***	.271***	.325***
	(32304)	(3098)	(10.06)	(302.2)	(.02547)	(.0119)	(.0107)
R-squared	0.004	0.001	0.020	0.361	0.031	0.068	0.001
N	1255	1255	1255	1255	1255	1255	1255