Trade Size, High Frequency Trading, and Co-Location Around the World*

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Abstract

We examine the impact of changes in market microstructure, particularly algorithmic trading (AT) and high frequency trading (HFT), on trade size across 24 stock exchanges around the world. Using colocation services as a proxy for AT and HFT, we find mixed results on the impact of AT and HFT on the average trade size. Furthermore, we test whether the presence of HFT leads to the introduction of colocation services. The data are consistent with the view that HFT pre-dates colocation by at least 8 months on most exchanges, and has strong power in explaining the introduction of colocation services. In effect, our results show that colocation services do not properly measure effective AT and HFT; rather, colocation services are the result of HFT. Exchanges choose to offer colocation services due to the fact HFT requires higher speed transactions. Finally, we show there have been substantial changes in trade size in other countries such as China where there is no HFT, and offer explanations for these changes and suggest avenues for future research.

Keywords: Trade size, High frequency trading, Colocation, International market microstructure

JEL Codes: G12, G14, G18

1. Introduction

The number of shares traded (hereafter, "trade size") potentially contains important information. For example, insiders who have private information will prefer to trade larger amounts of shares at any given price (Easley and O'Hara, 1987, Kim and Verrecchia, 1991). Larger trade size will have a more pronounced price impact on the underlying asset. However, informed traders can disguise such private information by trading multiple smaller trades (Kyle, 1985; Chan and Fong, 2000). In doing so, their trading may reflect higher trade counts along with smaller trade sizes. Smaller trade sizes along with higher trade counts could impact market quality in different exchanges around the world. Furthermore, with the development of Algorithmic Trading (AT) and High Frequency Trading (HFT), we observe both higher numbers of trades and smaller trade sizes in many countries. HFT encompasses thousands of trades in a second, and as such, trade size contains less information, yet still impact the underlying asset.

In this paper, we seek to understand whether or not changes in market microstructure have an impact on the trade size, particularly with the rise of AT and HFT. Further, we address the companion issue of whether or not the introduction of colocation (where exchanges allow traders to physically locate their servers within the exchange's office) is a suitable proxy for the start date of HFT trading activities on different exchanges around the world. AT refers to the use of electronic platforms for entering trading orders with an algorithm, typically without human intervention (Prix et al., 2007). Algorithms are used to execute pre-programmed trading instructions for executing an order, in terms of time, price, and quantity. These instructions can be based on a variety of factors depending on the trading strategy. HFT is a subset of AT where orders are entered very quickly (microseconds) and where speed is critically important in order to take advantage of new information and/or mispriced securities. HFT, as the term suggests,

involves rapidly trading in and out of positions thousands of times a day without holding positions at the end of the day, and realizing consistent, albeit small, profits on each trade.

HFT has become a common strategy used by traders on many exchanges around the world. Depending on the data considered, studies have found that HFT now accounts for more than half of traded shares in the United States, 35% to 40 % in the United Kingdom and Canada, respectively (Grant, 2011; O'Reilly, 2012). It has been argued that HFT might affect a number of market attributes including the degree to which markets can be manipulated, their liquidity, and the cost of equity capital (Biais and Wooley, 2011; Cumming et al., 2012; Goldstein et al., 2011; Hendershott and Riordan, 2010; Hendershott, Jones and Menkveld , 2011). We believe these issues are highly topical. Likewise, HFT has caught the attention of regulators. For example, in Europe there have been recent proposals to compel HFT traders to disclose the contents of their algorithms.[1] As at January 31, 2013, these proposals were put on hold until regulators gather more evidence about the impact of HFT on exchanges and financial marketplaces more generally.

In order to ascertain the effect of HFT on exchanges and financial marketplaces, it is of course necessary to identify the start-date of HFT on different exchanges. Oddly enough, there is no established start-date of HFT for different exchanges around the world, and this makes empirical work on the impact of HFT difficult, if not impossible. On approach based on two studies (Boehmer, et al. 2012a, 2012b) is to use the date that an exchange offers colocation services as a proxy for the start time of HFT. To this end, we manually collect the date that an exchange offers colocation services in order to see whether trade size has significantly reduced after this date. However, the data generally do not support the view that colocation appropriately measures the start of AT and HFT, counter to the Boehmer et al. (2012a, 2012b) studies.

[1] http://www.reuters.com/article/2013/01/28/germany-regulation-idUSL5N0AX9DV20130128

The results in this paper strongly indicate that colocation is not a good proxy for the start date for AT and HFT on different exchanges around the world. Colocation involves an exchange renting a space to the trading firm next to the trading facility, which provides added speed for the flow of time-sensitive information as the traders' high speed servers are as closely linked to the exchange infrastructure as geographically possible. HFT firms are also known to seek microsecond speed advantage by physically relocating their servers as close as possible to the exchange. The data are consistent with the view that exchanges offered colocation services in response to HFT demands for higher transaction speeds, and consequently the introduction of colocation services significantly lagged HFT. Since colocation start dates may not be a proper proxy for the time at which AT and HFT began on an exchange, we test whether a 'market-base' approach to identify the effective time HFT in the market leads to the introduction of colocation services. Our empirical results show pronounced reductions in trade size that occurred long before the introduction of colocation services (we estimate it was at least 8 months across the exchanges in our sample).

Using the market-based approach to identifying AT and HFT start dates have significant power in explaining whether or not exchanges offer colocation services. Our results show that the demand for speed, proxied by reductions in trade size, has significant power in explaining whether exchanges offer colocation services. In our most conservative estimate, an exchange is 27.6% more likely to offer colocation services when HFT is present. In our least conservative estimate, an exchange is 44.5% more likely to offer colocation services when HFT is present. All of our results are statistically significant at least at the 5% level.

Overall, our study contributes to the literature in the following ways. First, we provide arguments about the impact of HFT on trade size. A commonly used HFT characteristic is a

high number of orders with short holding period, suggesting that markets with HFT should experience drops in average trade size. With manually collected colocation dates, we use colocation as proxy for the start date of HFT and test if the introduction of colocation services has significant impact on the trade size. We do not find consistent evidence in support of the view that colocation causes trade size changes.

Second, we test the hypothesis that exchanges endogenously choose to offer colocation services. Based on a somewhat unique international dataset, we use a "market-based" approach to identify the presence of HFT in a particular market. Then, we use this as a proxy for demand for colocation services and seek to understand whether exchanges offers colocation services in order to meet the demand for faster transaction speed. The data indicate that both the change in the average trade size and HFT have a very strong impact on an exchange's decision to offer colocation services.

Finally, we believe our study has useful policy implications, particularly insofar as since studies on the impact of AT and HFT depend critically on appropriate identification of the exact time at which AT and HFT began in the first place. International start dates of AT and HFT are not well delineated and hard to determine even by stock exchange themselves. Nevertheless, choosing the correct start date is important especially to the study on the impact of HFT. Our study provides a new approach to identify the presence of HFT in a market place.

The rest of the paper is organized as follows. Section 2 examines the relationship between the introduction of colocation services and its impact on trade size. Section 3 develops a 'market-based' approach to identifying AT and HFT starts date based on the changes in trade size. Section 4 presents the empirical data used in our study. Section 5 presents the univariate comparison and Section 6 provides the multivariate analyses of the relationship between

colocation and trade size, and the relationship between trade size, HFT and colocation services. Concluding remarks follow in the last section.

2. Colocation services and trade size

Markets with HFT are characterized by higher trading volumes with smaller trade sizes due to the fact that HFT involves a large number of smaller orders and short-term holding positions without overnight holdings (Aldridge, 2009; Henrikson, 2011; Brogaard, 2010). Studies on HFT are typically hindered by the difficulty in identifying HFT trades and orders. Many studies focus on one exchange during a particular short period of time, depending on the data provided to identify HFT trading activities. Further, several studies (Boehmer, et al. 2012a, 2012b) have used colocation start dates as a proxy for AT and HFT.

In this section we first examine, in subsection 2.1, issues with colocation start dates as proxies for AT and HFT start dates. Thereafter in subsection 2.2 we examine issues pertinent to the use of colocation dates in econometric work on the impact on market efficiency and quality.

2.1. Colocation Start Dates

Recent work has examined the relationship between international differences in the start of AT and its effect on liquidity (Boehmer, et al., 2012a) and firms' equity capital (Boehmer, et al., 2012b). In this work, the way the start time of HFT is identified is based on when the exchange first offers colocation service. Colocation involves an exchange renting a space to the trading firm next to the trading facility, which ensures geographic proximity in relation to computing infrastructure therefore providing added micro-second speed for the flow of time-sensitive information. We believe there are several drawbacks to the use of colocation start-dates

as the time at which AT and HFT began on an exchange. First, there are discrepancies on the start date of colocation services. When one asks the directors of the exchange themselves, it becomes quite clear that the precise start date is not always known due to the differential timing and ambiguous presence of AT and HFT orders in the market. Second, our study finds that AT and HFT orders in almost all countries began years in advance of colocation. High frequency traders themselves are widely known to have physically located themselves as close as possible if not next to the exchange in order to obtain time advantages, and established such proximate location long before colocation started. Moyer and Lambert (2009) reported that "6 square feet of space in the data center where the big exchanges also house their computers goes for $2000 a month" and "It is not unusual for trading firms to spend 100 times that to house their server" as close as possible to the stock exchange[2]. Even with this price rush, "the number of firms that co-locate at NASDAQ has doubled over the last year"[3]. Third, colocation is not a pre-requisite for AT or HFT. It takes time for exchanges to have all the necessary resources to offer colocation services. In the meantime, the exchange could offer alternatives for traders who require the speed advantage. For example, the London Stock Exchange (LSE) offered 'Exchange Hosting' services to accommodate the demand of HFT firms in September 2009. It officially introduced the colocation services to vendors and services provider on October 18, 2010. While "colocation" was introduced by the LSE in September 2009, clearly HFT traders had physically established themselves in locations proximate to the exchange prior to the date thereby giving rise to large reductions in trade size on the LSE long before September 2009. The situation is nicely summarized as follows:

[2] See http://www.forbes.com/forbes/2009/0921/revolutionaries-stocks-getco-new-masters-of-wall-street.html
[3] See Arnuk, S. L. and Saluzzi, J. (2008). Toxic Equity Trading Order Flow on Wall Street. http://www.themistrading.com/article_files/0000/0348/Toxic_Equity_Trading_on_Wall_Street_12-17-08.pdf

> "So, barring any new breakthroughs in physics, we are in the final stages of a trend that began when the Rothschilds, by legend, used carrier pigeons to trade on the outcome of the Battle of Waterloo. For roughly a century leading up to 1970, the state of the art in financial communication was the telegraphic stock ticker (for receiving data) and the telephone (for transmitting orders). Now it is the high-speed server linked to a financial exchange by fiber-optic cable as short as physically possible, because each mile adds about eight microseconds of latency. There is so much money to be made that any expenditure on research and infrastructure to shave those microseconds is worth it."

The importance of trading firms locating themselves next to exchanges, as opposed to physical colocation within the exchange, was especially important given the fact that colocation services appeared to be significantly restricted at the outset; see, for example, the NYSE Euronext announcement in April 2008 provided in the Appendix of this paper below. In short, it is clear that "colocation" (with firms locating themselves next to or across the street from the exchange) was taking place well before the exchanges themselves saw this as a revenue making activity and formally introduced it.

Similarly, the OLSO Stock Exchange, for example, does not officially offer colocation services but it has a strategic cooperation agreement with LSE. Anyone who can co-locate at the LSE also has the access to the OLSO stock market. OLSO does not offer colocation services independently. However, OLSO uses trading platform developed by LSE group, and highlight that "[a] common trading platform with LSE further strengthens the collaborative agreement signed in 2009. It also allows for "Co Location" in the LSE data center for those members who require the shortest possible distance to the trading engine located in London."[4]

If HFT requires a speed advantage, these firms could locate their servers in the place close to the trading engine of the exchange. In those cases, using a colocation date to identify AT or

[4] http://www.oslobors.no/ob_eng/Oslo-Boers/Trading/Trading-systems/Partnership-with-LSEG

HFT activities will not correctly reflect the correct start date for the market. Figure 1 illustrates this point. Before LSE offered colocation services on September 2009, the average trading size had already start to decline dramatically. As discussed further in the next section below, average trading size is expected to fall in conjunction with the introduction of HFT given HFTs rapidly trade in and out of positions thousands of times a day and with typically much smaller average trade sizes.

[Insert Figure 1 Here]

2.2. Colocation Dates in Econometric Studies

Colocation dates are used by Boehmer, Fong and Wu. (2012a,b) to infer the impact on various aspects of market efficiency and quality, similar to those outcomes appropriately identified and used in other microstructure studies (e.g., Coughenour and Shastri, 1999). A market is a collection of choices about a series of sub-systems including technology, regulation, information, participants and instruments and each of these subsystems individually and in combination with other elements can impact market quality. Given that colocation is a technology decision it clearly can have a direct impact on market quality and is therefore not exogenous. Therefore, colocation services may reduce trade size. Trade size, however, with HFT, may also have the power of explaining why exchanges offer colocation services. In order to test the hypothesis of whether or not the introduction of colocation services reduce trade size, we hand collect all known start dates of colocation services in our sample. Many exchanges publish the date that they offer colocation on the exchanges' website. For those which did not have such

information online, we contacted the exchange directly and requested this information directly. The list of colocation services and their start dates are listed in Table 2.

3. Market-Based Approaches to Identifying AT and HFT Start Dates

'Market-based' approaches to identifying AT and HFT start dates refer to examining the effect of HFT on an exchange. Of course, for the purpose of carrying out econometric work to study whether or not HFT had an impact on the exchange, it is tautological to use the outcome in question on the exchange to identify the AT and HFT start date. As such, researchers need to pick an effect of AT and HFT on an exchange that is unrelated to the outcome of interest. For example, if one is interested in examining whether or not AT and HFT affected liquidity, it would be inappropriate to examine changes in bid-ask spreads or trading volume as a way to identify the start date of AT and HFT.

One universally accepted characteristic of AT and HFT is the much smaller average trade sizes with such orders. HFT's involve "minimizing risk and posting small deal sizes that enable [high frequency traders] to move in and out of trades extremely quickly, arbitraging between spreads available on different exchanges and platforms, and even between the speed of trading available on them."[5] A simple examination of trade size, therefore, is one candidate for a proxy to identify AT and HFT start dates.

In Figure 1, we plot changes in average trade size over time among exchanges widely known to have HFT. We mark the expected HFT start date based on a 4 continuous drop in average trade size. The effective HFT start dates based on trade size typically begin a couple of

[5] Michael Mackenzie, "High Frequency Trading Dominates the Debate," Financial Times, Oct. 20, 2009, at 3, available at http://www.ft.com/cms/s/0/fa347c26-bc41-11de-9426-00144feab49a.html

years prior to colocation dates, which is expected as high frequency traders established themselves at locations proximate to exchanges well in advance of the provision of colocation services, as discussed above in section 2. Based on what we have learned from our conversations with exchange directors and exchange participants, the effective HFT start dates based on average trade size appear to be reasonable, and certainly are verified by the data as dates where there was sharp and unusual and otherwise unexplained drop in trade size. We indicate the HFT start dates based on average trade size in Table 2.

We compare the average trade size among HFT exchanges in Figure 1 to exchanges widely known to not have HFT (due to, for instance, the absence of direct market access) in Figure 2. Exchanges without HFT either do not experience a large drop in average trade size, or if they do, it is temporary and associated with the financial crisis or some other alternative plausible explanation.

[Insert Figures 2 Here]

4. Data and Summary Statistics

The data used in this paper contains 24 stock exchanges in 19 countries, including Australia, Canada, China (Shanghai and Shenzhen), Germany, Hong Kong, India (Bombay and the National Stock Exchange of India), Japan, Malaysia, New Zealand, Norway, Saudi Arabia, Singapore, South Korea (KOSPI and KOSDAQ), Sweden, Switzerland, Taiwan, the U.K. (LSE and ChiX- London), United Arab Emirates (Dubai Financial Market) and the U.S. (NASDAQ and NYSE). The original data used in this paper covers the period of January 2003 to December 2011 and are from Thomson Reuters. We access the data through Capital Market Cooperative

Research Centre (CMCRC). The definitions and source of the variables used in the analysis are provided in Table 1. Two main dependent variables are the average trade size and the colocation dummy.

[Insert Table 1 here]

We collect monthly data on total trading volume and total number of trades from CMCRC. In our paper, we define the trade size (TS_{jt}) as

$$TS_{jt} = \frac{V_{jt}}{N_{jt}}$$

where V_{jt} is the total trading volume in the exchange j at month t and N_{jt} is the total number of trades in the exchange j at month t.

Our study investigates whether the changes in market microstructure could have an impact on the trade size. Particularly we are interested in whether or not the colocation services provided by the exchange could significantly reduce the trade size. The HFT effective date is from Cumming, et al. (2012). Table 2 lists both HFT effective dates and colocation start dates.

[Insert Table 2 here]

La Porta, et al. (1998, 2006) find a positive relationship between security law and financial market development. In addition, Cumming, et al. (2011, 2012) find that exchange regulations significantly increases liquidity and reduces insider trading activities. As one example, exchange trading rules changed a great deal in Europe in this period, and these changes have been empirically shown to greatly impact liquidity (Cumming, et al. 2011; see also Cumming and Johan, 2008, regarding surveillance). Liquidity could increase trading activities and thus have an impact on trade size as well. We gather several legal indices such as insider trading, efficiency of

the judiciary, rule of law, risk of expropriation, anti-director index and disclosure index from La Porta et al. (1998, 2006).

Many exchanges also have requirements on the price limit or circuit breakers to prevent over-reaction or huge movements in stock price. The trading interference hypothesis indicates that these price limits or trading halts prevent continuous trading thus reduce stock liquidity, and lead to a higher trading volume and volatility in the following days (Kim and Ree, 1997; Lehmann, 1989). Kim and Ree (1997) test the trading interference hypothesis on individual stocks at the Tokyo Stock Exchange from 1989 to 1992, and find that trading volume increases for the stocks with price limits on the day after the price reaches its limit. To test whether trading interference could have impact on the average trade size in our sample, we create a dummy variable to identify if the exchange has a price limit rule or circuit breakers. We collect the price limit information from Gan and Li (2001) and Kim and Part (2010). In our sample, we found 6 countries/regions (9 out of 24 exchanges) have the price limit rule and 4 countries/regions (6 out of 24 exchanges) have circuit breakers. This information is also presented in Table 1.

Other than legal and exchange regulation, several additional factors could also affect trading volume thus impacting average trade size. Odean, et al. (1999) and Chui, et al. (2010) find investors in with a culture of individualism tend to trade more and the trades lead to lower returns. In the same spirit, we use Hofestede's (2001, 2005) individualism versus collectivism (IDV) index as a proxy for individualism culture. Higher values in the individualism index represents a higher value of individualistic culture.

Figure 1 and Figure 2 present the average market trade size for both HFT and non-HFT countries. From these figures, we can clearly observe a time trend in the average trade size. This

trend is stronger in HFT countries than that of non-HFT countries. Nevertheless, it is difficult to develop a simple model to capture the time series properties of trade size. Empirically, we tried to include several lags of trade size as well as seasonal effects such as January and December. Also, we observe some sudden drops in trade size for non-HFT countries during the financial crisis, especially for the Shanghai Stock Exchange in China. Therefore, we control the effect of the financial crisis and country effect of China in our regression analysis.

Many studies have already established a positive relationship between trading volume and stock returns. Therefore, both past return and market condition could affect individual investor trading behavior thus affect the trade size. We collect country level MSCI indices to proxy past returns. Also, we use the market-cap weighted volatility as a proxy for market condition. The market-cap weighted volatility is also from CMCRC.

Several economic and market level variables for each exchange are also used in our analysis. The market capitalization at the end of each month is measured as the market capitalization of all listed companies in the exchange. We also collect annul gross domestic product per capita from Global Insight.

Table 3 presents the descriptive statistics for the full sample of the data. The summary statistics show that there is a sizable variation among shares per trade from month to month in different exchanges. The average trade size per month is around 13,001.50 shares with a range from 146 shares per trade to a total of 393,172 shares per trade.

[Insert Table 3 here]

5. Univariate Tests

Table 4 provides a comparison of mean and median test of trade size for HFT and non-HFT countries (Panel A), comparison of trade size for both the Shanghai Stock Exchange and Shenzhen Stock Exchange in China before and after February 2007 (Panel B), and for HFT countries with various cut off values, which are the colocation start dates and our 'market-approach' HFT dates (Panel C).

[Insert Table 4 here]

Panel A of Table 4 reports difference in means and medians of trade sizes between non-HFT countries and HFT countries. HFT countries are defined as countries with HFT activities which are identified by our 'market-approach' method. The mean (median) value of trade size are 26,667.65 (8,581.5) shares per trade for non-HFT countries. The mean (median) value of trade size are 2,919.92 (1,389.5) shares per trade for HFT countries. From these raw numbers, we can clearly see that the trade size is much smaller in HFT countries than that of none HFT countries. The difference tests show that in both mean and median value, HFT countries have significant lower trade sizes than that of non-HFT countries.

From Figure 2, we observe a sudden drop in trade size around February 2007 and after that, the Shanghai Stock Exchange doesn't seem to return to its previous trading levels. This may be due to speculative traders pushing the stock to an unreasonably high level. At one point, the turnover in Shanghai Stock Exchange exceeds Japan and UK[6]. In Panel B of Table 4, we test whether or not there are drops in trade size before and after February 2007 for both the

[6] http://www.thisismoney.co.uk/money/investing/article-1610369/China-share-turnover-exceeds-UK.html

Shanghai and Shenzhen Stock Exchange in China. The results show that before and after February 2007, the mean (median) value of trade size for Shanghai stock exchange are 6,460.51 (6,545) and 2,336.70 (1,591) shares. The difference between the two exchanges is significantly different. However, the mean (median) value of trade size for Shenzhen Stock Exchange are 5,585.69 (5,353) and 5,529.56 (5,390) shares before and after February 2007 and we were unable to find any differences between them.

The last panel in Table 4, Panel C, we compare whether the trade size is different after the appearance of HFT (I), after the exchange offers colocation services (II), and before and after the colocation services after the HFT date (III). The mean (median) value for trade size before and after HFT effective date are 4,847.14 (2,812) and 2,253.90 (1,213.5). The mean (median) value for trade size before and after the exchanges offer colocation services are 2,312.0 (3,933) and 1,273.35 (860). Finally, the mean (median) value for trade size after the HFT date but before and after the exchanges offer colocation services are 2,830.77 (1,864) and 1,273.36 (860). All difference tests are significant at least at the 5% level.

Overall, these comparison tests support the view that there are differences among trade sizes across different regions. Particularly, a micro-structure change in the market has impact on the trade size. Results in Panel C Table 4 show that both our 'market-approach' identifying HFT and colocation services actually offered by the exchanges can capture such influences. Nevertheless, these tests are not fully informative since there are other factors that could have impact on the trade size. In the empirical test, we include different control variables in order to isolate the unique marginal impact of AT and HFT, proxied by colocation services. We also try to detangle whether or not the exchanges offer colocation services due to the fact there are demands for such services from high frequency traders.

Table 5 presents a correlation matrix for the main variable used in the multivariate tests. The correlations among several variables are high in which collinearity is potentially problematic. In next section, we present several alternative specifications with and without collinear variable in order to show our results are robust.

[Insert Table 5 here]

6. Multivariate analyses

In this section, we conduct empirical tests showing that AT and HFT, proxied by colocation services, have an impact on trade size after controlling for behavior/cultural and legal differences, and market/economic factors. More specifically, we test seven regressions between trade sizes and colocation services with various cluster controls. In additional, we run six models of logistic regressions to see whether or not lagged trade size and HFT can predict whether or not exchanges offer colocation services.

Table 6 illustrates the regression results between trade size and AT and HFT, proxied by colocation services. The dependent variable in Table 6 is trade size. Model 1 tests the relationship directly between trade size and colocation dummy. Model 2 shows the results with additional macro-economic control variables. Model 3 shows the results with individualism index. Model 4 controls for the time series properties. Model 5 shows the results with exchange trading regulation such as insider trading rule index, volume manipulation rule index, and legal index such as efficiency of the judiciary, rule of law, risk of expropriation, anti-director index disclosure index, and price limit/circuit breaker dummy. Model 6 shows the results with China dummy and finally, Model 7 shows the results with all joint variables.

The results in Table 6 show a mixed result that AT and HFT, proxied by the colocation services have an impact on the trade size. The colocation services are statistically significant at 1% in model 2 and at 10% in model 1, 3. We find no statistically significant relationship between trade size and colocation in model 4, 5, 6, and 7. Nevertheless, all models show that after the exchange offers colocation services, the trade size decreases. Using model 3 as an example, after an exchange offers colocation services, there is a 57.05%[7] reduction in trade size. Even in model 4, there is a 6.97% reduction in trade size after the colocation services.

Besides the main variable of interest, colocation services, results in Table 6 also show some interesting findings. First, we find that trade size are highly correlated with previous trade size. Second, overconfident investors may trade more frequently (Odean, et al., 1999; Chui, et al., 2000) but have fewer shares per trade. Third, both exchange regulations and legal environment have an impact on trade size. Finally, we find some evidence that market/macro-economic condition influence the trade size but these results are not consistent.

[Insert Table 6 here]

These mixed results between trade size and colocation services raise the question of whether colocation service is a good proxy for AT and HFT. From both Figure 1 and Figure 2, we observe a clear drop in trade size. In such cases, stock exchanges may choose to offer colocation services after it observes that there is a demand for increasing transaction speed.

To test whether or not exchanges offer colocation services to meet the demand of high frequency traders, we perform a logistic regression and the results are shown in Table 7. The dependent variable in Table 7 is whether or not the exchange offers colocation services (0/1).

[7] 7417.8/13001.5=0.5705

We test 6 different models. Model 1 tests whether past trade size has an impact on exchanges choosing to offer colocation services. Model 2 test whether the 'market- based' approach identifying HFT has an impact on exchanges choosing to offer colocation services. Model 3 tests the HFT and lagged trade size jointly. Model 4 and model 5 show the results after controlling for legal/law environments and after controlling for macro-economic factors, respectively. Model 6, the last model, shows the results of all variables jointly.

The results in Table 7 consistently indicate that both past trade size and the presence of high frequency traders have a strong influence on whether exchanges offer colocation services. In our most conservative estimate (Model 6), with the presence of HFT, the exchange is 27.6% more likely to offer colocation services. In the least conservative estimate (Model 4), with the presence of HFT, the exchange is 44.5% more likely to offer colocation services.

[Insert Table 7 here]

7. Conclusion

In this paper we examined the impact of AT and HFT on trade size across 24 stock exchanges around the world. The data examined are consistent with the view that HFT pre-dates collocation by at least a year on most exchanges. In effect, HFT has strong predictive power in explaining the introduction of colocation services. Our results are consistent with the view that colocation services do not properly measure effective AT and HFT; rather, colocation services are the result of HFT. Exchanges choose to offer colocation services due to the fact HFT requires higher speed transactions.

Further, in this paper we showed there have been substantial changes in trade size in other countries, particularly China, where there is no HFT. One explanation for the large reduction in trade size in China is the high volatility observed in the Shanghai and Shenzhen market. Future research on the causes and consequences of such dramatic changes in trade size is warranted.

Appendix. Announcement from NYSE Euronext

9 April 2008

PROJECT: Colocation service

Colocation service now available for Euronext Cash Markets

NYSE Euronext is pleased to announce the **introduction of a colocation service for its European cash markets**.

This new offer is part of NYSE Euronext's high capacity trading services, and complements other access solutions to Euronext's cash markets. It has been created as a result of evolutions in trading patterns, and is particularly suited to algorithmic trading, for which **extremely low latency** is key.

The colocation service allows the lowest possible latency to the NSC® trading engine, by letting members co-locate their servers within NYSE Euronext's data centre in Paris.

This new offer reinforces NYSE Euronext's commitment to meet its customers' need for speed, flexibility, capacity and reliability. It is available on an optional basis to all Euronext members.

Members will be able to place orders until 21 April 2008 for the first round of colocation cabinets.

Due to capacity constraints in NYSE Euronext's Paris data centre, **only one cabinet per member can be ordered**.

Technical details of the colocation service

As part of NYSE Euronext's high capacity trading services, colocation builds upon the same technical components as Multi-Market Broadband Access (MMBA), including the same market data and web stat services, with the specificity of the member's servers being located within NYSE Euronext Paris' cash markets data centre. **Colocation cabinet**	Standard rack with 36 units for member equipment
Power supply	4kW power to the cabinet with dual resilient 10 way power strips
Lines	2 x 100Mb line
Link to NSC® trading engine	Direct cross connect link (2 x 100Mb) for connectivity to Euronext order processing servers and Market Data Feed reception
Cash services*	2 order processing servers, with a total capacity of 1000 messages per second 1 server for Validation, Market Data Services and Web Stat services

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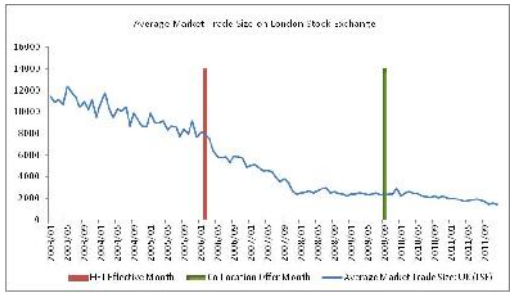
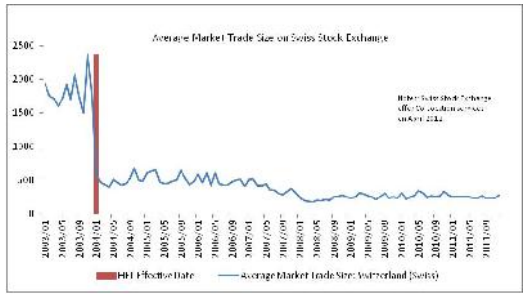
Figure 1. Plot of Average Market Trade Size for HFT Countries

The red line indicates the HFT Effective Date and the green line indicates the colocation start month. For NASDAQ, XETRA Germany, the HFT Effective Date is January 2003 and for ChiX London the HFT Effective Date is January 2007. The colocation start month for New Zealand Stock Exchange is not available from public records.

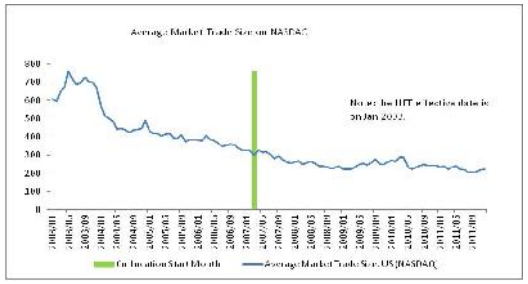


London Stock Exchange

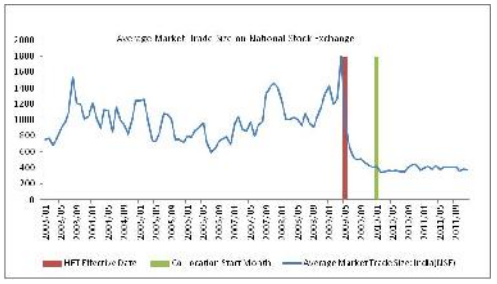


Swiss Stock Exchange

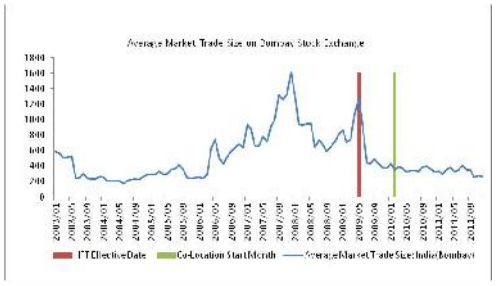
Toronto Stock Exchange



NASDAQ



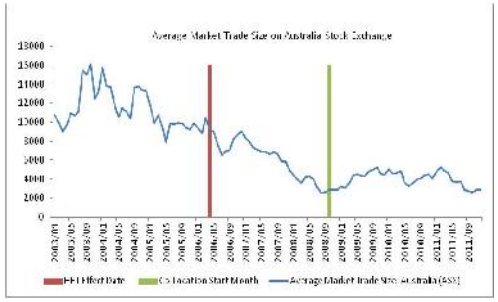
National Stock Exchange (India)



Bombay Stock Exchange

Figure 1. (Continued)

Tokyo Stock Exchange

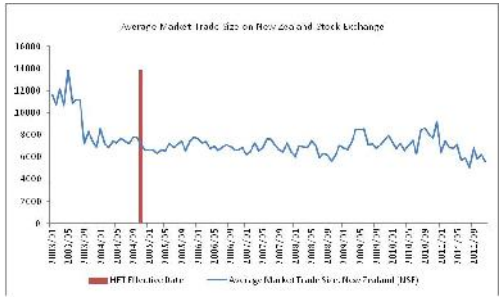


Australian Stock Exchange

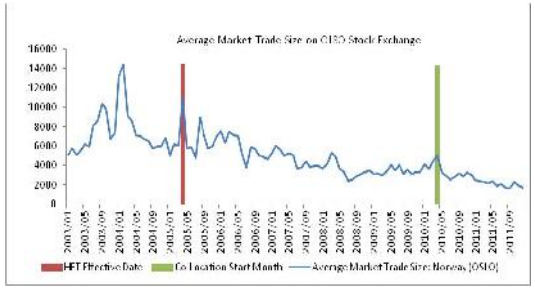
XETRA

NYSE

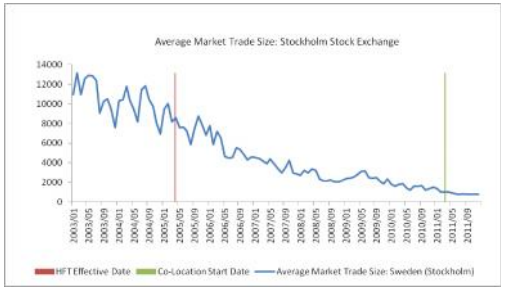
Chi-X London



New Zealand Stock Exchange



OSLO Stock Exchange



Stockholm Stock Exchange

Figure 2: Plot of Average Market Trade Size for non HFT Countries.

Dubai Stock Exchange

Bursa Malaysia

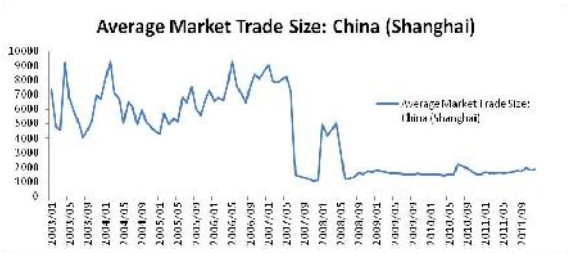
Hong Kong Stock Exchange

Korea (KOSAQ)

Korea (KOSPI)

Singapore Stock Exchange

Figure 2 (Continued)



Shanghai Stock Exchange

Shenzhen Stock Exchange

Taiwan Stock Exchange

Saudi Arabia Stock Exchange

Table 1: Definition of Variables

This table defines the dependent, independent and control variables.

Variable Name	Definition
Trade Size	Total Trading Volume (Shares) / Total Number of Trades. Source: Capital Markets Corporative Research Center (CMCRC).
HFT	Dummy variable indicates when HFT starts in the market, First, Cumming, et al. (2012) check whether the exchange in our sample offers direct market access (DMA). Second, Cumming, et al. (2012) obtained the monthly on market trading volume and number of trade for each exchange from January 2003 to December 2011 and calculate the average monthly market trading size as the monthly total on market trading volume over the monthly total number of trades. They define the start month of HFT influence on the market as the first of four continuously declining months in average market trading size or the biggest single drop from previous month. They also looked at both the three-month and five-month continuous declines in average market trading size and found the results to be similar. Few exchanges have continuous declines in trading size over five months. Source: Cuming, et al. (2012).
Colocation	Dummy variable indicates when the exchange starts to offer the colocation services, as listed in Table A2 in the Appendix.
January	A dummy variable equals to 1 if the month is January.
December	A dummy variable equals to 1 if the month is December.
Financial Crisis	A dummy variable equals to 1 if the year is 2008.
Culture and Law Index	
Individualism Index	The high side of this dimension, called Individualism, can be defined as a preference for a loosely-knit social framework in which individuals are expected to take care of themselves and their immediate families only. Its opposite, Collectivism, represents a preference for a tightly-knit framework in society in which individuals can expect their relatives or members of a particular in-group to look after them in exchange for unquestioning loyalty. A society's position on this dimension is reflected in whether people's self-image is defined in terms of "I" or "we." Source: http://geert-hofstede.com/dimensions.html
Insider Trading Rule Index	Sum of dummy variables for Front-running, Client precedence, Trading ahead of research reports, Separation of research and trading, Broker ownership limit, Restrictions on affiliation, Restrictions on communications, Investment company securities, Influencing or rewarding the Employees of Others, and Anti-intimidation / Coordination. Source: Cumming et al. (2011).
Volume Manipulation Rule Index	Sum of dummy variables for Churning and Wash trade. Source: Cumming et al. (2011).
Efficiency of Judiciary	Assessment of the ''efficiency and integrity of the legal environment as it affects business, particularly foreign firms'' produced by the country risk rating agency Business International Corp. It ''may be taken to represent investors' assessments of conditions in the country in question.'' Average between 1980 and 1983. Scale from zero to 10; with lower scores, lower efficiency levels Assessment of the efficiency and integrity of the legal environment. Scale from zero to ten; with lower scores, lower efficiency levels. Source: La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998).
Rule of Law	Assessment of the law and order tradition in the country produced by the country risk rating agency International Country Risk (ICR). Average of the months of April and October of the monthly index between 1982 and 1995. Scale from zero to 10, with lower scores for less tradition for law and order (we changed the scale from its original range going from zero to six). Original data comes from International Country Risk guide. Source: La Porta, Lopez-de-Silanes, Shleifer and Vishny (1998).
Risk of Expropriation	ICR's assessment of the risk of "outright confiscation" or "forced nationalization." Average of the months of April and October of the monthly index between 1982 and 1995. Scale from 0 to 10, with lower scores for higher risks. Original data come from International Country Risk Guide. Source: La Porta et al. (1998).
Anti-Director Index	An index aggregating the shareholder rights we labeled as ''antidirector rights.'' The index is formed by adding 1 when (1) the country allows shareholders to mail their proxy vote to the firm, (2) shareholders are not required to deposit their shares prior to the general shareholders' meeting, (3) cumulative voting or proportional representation of minorities in the board of directors is allowed, (4) an oppressed minorities mechanism is in place, (5) the minimum percentage of share capital that entitles a share-holder to call for an extraordinary shareholders' meeting is less than or equal to 10 percent (the sample median), or (6) shareholders have pre-emptive rights that can be waived only by a shareholders' vote. The index ranges from zero to six. Source: La Porta, Lopez-de-Silanes, Shleifer, and Vishny (1998)
Disclosure Index	The Index of disclosure equals the arithmetic mean of (1) prospectus; (2) compensation; (3) shareholders; (4) inside ownership; (5) contracts irregular; and (6) transactions. Source: La Porta et al., Lopez-De-Silanes and

	Shleifer (2006).
Price Limit/Circuit Breaker	A dummy variable indicates whether the exchange has a regulation on stock price limit/circuit breaker. In our sample, there are 6 countries/regions (9 exchanges) have price limit: Malaysia, India, Japan, Korea, China, and Taiwa. There are 4 countries/regions (6 exchanges) have circuit breaker in place: Swiss, Canada, United Kingdom and United States. Source: Gan and Li (2001) and Kim and Part (2010).
Market/Economic Variables	
Log(Market Capitalization)	Log of market capitalization in US millions. Source: Capital Markets Corporative Research Center (CMCRC).
Log(Volatility)	Log of market volatility in the lagged period. Source: Capital Markets Corporative Research Centre (CMCRC).
Log (MSCI)	Log of MSCI index in the lagged period. Source: DataStream.
Log(GDPPC)	Log of gross domestic product (GDP) per capita in the lagged period. Source: GlobalInsight.

Table 2: Proximity Hosting/Colocation Offer Time

Exchange Name	HFT Start Date*	Colocation Start Date
Stockholm Stock Exchange	2005/04	2011/03
Swiss Stock Exchange	2004/01	2012/04
Toronto Stock Exchange	2005/05	2008/04
NASDAQ	2003/01	2007/03
Bursa Malaysia	N/A	N/A
NSE India	2009/05	2010/01
Bombay Stock Exchange	2009/05	2010/02
Tokyo Stock Exchange	2005/05	2010/01
Australia Stock Exchange	2006/04	2008/Fourth Quarter
XETRA Germany	2003/01	2006/08
NYSE	2003/05	2008/04
London Stock Exchange	2006/02	2009/09
Chix London	2007/01	2008/11
Hongkong Stock Exchange	N/A	2012/Fourth Quarter
KOSDAQ	N/A	N/A
Korea Stock Exchange	N/A	N/A
Singapore Stock Exchange	N/A	2011/07
Shanghai Stock Exchange	N/A	N/A
Shenzhen Stock Exchange	N/A	N/A
Taiwan Stock Exchange	N/A	2010/Fourth Quarter
New Zealand Stock Exchange	2004/11	N/A
OLSO Norway	2005/04	2010/04
Dubai Stock Exchange	N/A	N/A
Saudi Arabia Stock Exchange	N/A	N/A

*HFT start date are from Cumming, D., Zhan, F., and Aitken, M. (2012). High Frequency Trading and End-of-Day Price Dislocation.

Table 3: Descriptive Statistics

This table present statistics for the full sample of exchange-month observations in the dataset. The data span from January 2003 to December 2011 and the exchanges are listed in Table 2.

Variable Name	Mean	Median	Standard Deviation	Minimum	Maximum	Number of Observations
Trade Size	13001.50	2482.50	37027.12	146.00	393172.00	2544
HFT	0.43	0.00	0.49	0.00	1.00	2544
Colocation	0.17	0.00	0.38	0.00	1.00	2544
January	0.08	0.00	0.28	0.00	1.00	2544
December	0.08	0.00	0.28	0.00	1.00	2544
Individualism Index	52.66	48.00	28.83	17.00	91.00	2220
Insider Trading Rule Index	3.06	3.00	2.30	0.00	10.00	2328
Volume Manipulation Rule Index	1.09	1.00	0.71	0.00	2.00	2328
Efficiency of the Judiciary	9.08	10.00	1.37	6.00	10.00	2112
Rule of Law	8.32	8.98	2.00	4.17	10.00	2112
Risk of Expropriation	9.17	9.40	0.79	7.75	9.98	2112
Anti-Director Index	3.82	4.00	1.24	1.00	5.00	2112
Disclosure Index	0.79	0.75	0.16	0.42	1.00	2112
Price Limit/Circuit Breaker	0.62	1.00	0.49	0.00	1.00	2544
Log(Market Capitalization)	29.59	29.07	2.59	24.21	38.56	2513
Log(Volatility)	0.03	0.01	0.01	0.00	0.20	2508
Log (MSCI)	0.01	0.01	0.07	-0.41	0.31	2204
Log(GDPPC)	9.58	10.15	1.35	6.14	11.44	2436

Table 4 : Comparison Test

This table presents the comparison of mean and median test for the trade size between HFT and none HFT countries (Panel A), trade size in both Shanghai Stock Exchange and Shenzhen Stock Exchange (Panel B)[before and after Feb 2007], and for HFT countries. (Panel C) [before and after the HFT start date (I), before and after Colocation start date (II), and before and after Colocation start date after the HFT start date (III)]. The *, ** and *** denote the significance at 10%, 5% and 1% level, respectively.

Panel A: Trade Size between HFT and none HFT countries			**Panel B: Trade Size in China (Shanghai Stock Exchange and Shenzhen Stock Exchange)**			
	Country Level		**Shanghai Stock Exchange**		**Shenzhen Stock Exchange**	
	none HFT country	**HFT country**	**Before Feb 2007**	**After Feb 2007**	**Before Feb 2007**	**After Feb 2007**
Group	0	1	0	1	0	1
Number of Observations	1080	1464	49	59	49	59
Mean	26667.65	2919.92	6460.51	2336.70	5585.69	5529.56
Median	8581.5	1389.5	6545	1591	5353	5390
Standard Deviation	53783.14	3183.50	1413.23	1887.27	1571.23	1428.46
Difference in Mean (0-1)	16.8557***		12.6310***		0.1943	
Difference in Median (0-1)	p=0.000***		p=0.000***		p= 0.847	

Panel C: Trade Size in HFT countries						
	I		**II**		**III**	
	Before HFT	**After HFT**	**Before Colocation**	**After Colocation**	**Before Colocation**	**After Colocation**
Group	0	1	0	1	0	1
Number of Observations	376	1088	1061	403	685	403
Mean	4847.14	2253.90	2312.00	1273.36	2830.77	1273.36
Median	2812	1213.5	3933	860	1864	860
Standard Deviation	4414.67	2277.71	3470.14	1174.97	2556.07	1174.97
Difference in Mean (0-1)	14.5666***		12.8640***		11.5341**	
Difference in Median (0-1)	p=0.000***		p=0.000***		p=0.000***	

Table 5: Correlation Matrix

This table presents Pearson coefficient for the full sample of data used in this paper. The * indicate the correlations are statistically significant at the 5%.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1)	Trade Size	1															
(2)	HFT	-0.283*	1														
(3)	Colocation	-0.156*	0.449*	1													
(4)	Price Limit/Circuit Breaker	-0.306*	-0.107*	0.0564*	1												
(5)	Individualism Index	-0.304*	0.717*	0.303*	-0.0896*	1											
(6)	Financial Crisis	-0.0680*	0.0585*	-0.0423	-0.0136	0.00985	1										
(7)	Insider Trading Rule Index	-0.307*	0.307*	0.158*	0.236*	0.391*	0.0163	1									
(8)	Volume Manipulation Rule Index	0.135*	-0.0207	0.0175	0.132*	0.166*	-0.00072	0.0148	1								
(9)	Efficiency of the Judiciary	0.142*	0.483*	0.161*	-0.459*	0.635*	0.00775	0.208*	-0.0805*	1							
(10)	Rule of Law	0.0323	0.524*	0.161*	-0.449*	0.601*	0.00952	0.160*	-0.0924*	0.716*	1						
(11)	Risk of Expropriation	-0.195*	0.625*	0.219*	-0.249*	0.667*	0.00847	0.192*	-0.022	0.588*	0.892*	1					
(12)	Anti-Director Index	0.157*	0.124*	0.0608*	0.234*	0.382*	0.00102	0.167*	0.201*	0.522*	0.0885*	0.00414	1				
(13)	Disclosure Index	0.167*	-0.217*	-0.0318	0.476*	-0.0617*	-0.00959	0.275*	0.291*	0.0949*	-0.213*	-0.265*	0.739*	1			
(14)	Log(Market Cap)	-0.0475*	-0.0643*	-0.0561*	0.551*	-0.182*	0.00299	-0.229*	0.183*	-0.318*	-0.382*	-0.177*	0.00236	0.0485*	1		
(15)	Log(Volatility)	-0.0382	-0.206*	-0.118*	0.253*	-0.277*	0.157*	-0.0594*	0.200*	-0.349*	-0.397*	-0.331*	0.00969	0.160*	0.228*	1	
(16)	Log (MSCI)	0.0401	-0.0602*	-0.0710*	0.0000832	-0.0249	-0.368*	-0.0185	-0.00336	-0.0242	-0.0355	-0.04	-0.00492	0.00502	-0.0126	-0.0433	1
(17)	Log(GDPPC)	0.0568*	0.419*	0.140*	-0.393*	0.364*	0.0481*	0.0906*	0.164*	0.457*	0.845*	0.815*	-0.178*	-0.299*	-0.144*	-0.229*	-0.0604*

Table 6: Panel Regression

This table presents panel regression of determinate of average trade size. Variables are defined in Table 1. Model 1 presents results with Colocation dummy. Model 2 presents results with Colocation and China dummy. Model 3 presents a regression results with both lagged trade size and January and December dummy. Model 4 presents the results with lagged trade size, January and December, as well as indicator for financial crisis. Model 5 presents the results with Insider Trading Rule Index, Volume Manipulation Rule Index, Efficiency of the Judiciary, Risk of Expropriation, Anti-director, Disclosure index and Price Limit/Circuit dummy. Model 5 presents the results with macro-economic and market condition variables. Model 6 presents the results with China indicator and Model 7 presents the results with all joint variables. The *, **, and *** are statistically significant at the 10%, 5%, and 1% level, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Colocation	Macro-Economic Variables	Individualism Index	Time Series Properties	Legal Index	China	All Jointly
Constant	15273.9**	-5005.0	681.4	1262.8	213799.4*	3030.8	5574.6
	[2.19]	[-0.70]	[0.01]	[1.30]	[1.77]	[0.06]	[1.83]
Colocation	**-12846.6***	**-16256.2*****	**-7417.8***	**-906.1**	**-3930.6**	**-3928.8**	**28.05**
	[-1.87]	**[-8.35]**	**[-1.78]**	**[-1.39]**	**[-1.27]**	**[-1.10]**	**[0.07]**
China						**-10282.0****	
						[-2.23]	
Time Series Properties							
Lag Trade Size (-1)				0.958***			0.895***
				[46.61]			[11.71]
Lag Trade Size (-2)				-0.0193			
				[-1.20]			
January				-594.6			
				[-0.43]			
December				-662.3			
				[-1.33]			
Financial Crisis (y2008)				-1802.5*			
				[-1.68]			
Culture and Law Index							
Individualism Index			-533.4*			-504.2**	-30.18
			[-1.79]			[-2.15]	[-1.25]
Insider Trading Rule Index					-5242.8**		-274.5
					[-2.30]		[-1.76]
Volume Manipulation Rule Index					8906.6		
					[1.36]		
Efficiency of the Judiciary					4416.1		
					[0.89]		
Rule of Law					14920.4*		1394.3*
					[1.90]		[2.07]
Risk of Expropriation					-43234.6**		-3706.4*
					[-2.10]		[-2.14]
Anti-Director Index					-5482.5		
					[-1.41]		
Disclosure Index					88850.4**		10219.1*
					[2.17]		[1.88]
Price Limit/Circuit Breaker					-16006.7*	-31442.0	-3635.8*
					[-1.71]	[-1.33]	[-2.01]
Macro-Economic Variable							
Log (Market Cap)		-426.3**	-763.6			1646.4	377.6*
		[-2.68]	[-0.65]			[0.66]	[1.92]
Log (Volatility)		-80722.3	-314893.3*			-192176.5	-13669.6
		[-0.59]	[-1.71]			[-1.26]	[-0.42]
Log (MSCI)		17297.1	17323.3			16371.3	1909.9
		[1.60]	[1.32]			[1.11]	[0.69]
Log(GDPPC)		3744.5***	7540.2			1567.3	383.9
		[5.48]	[1.58]			[0.89]	[1.23]
Cluster Control	Exchange and Year	Year	Exchange and Year	Exchange and Year	Exchange and Year	Exchange and Year	Year
Observations	2544	2182	2077	2542	2112	2077	1869
R-squared	0.018	0.038	0.137	0.887	0.416	0.223	0.891

Table 7: Logistic Regression Results for Colocation

This table presents panel logistic regression of determinate of Colocation. Marginal effect coefficients are shown in the. The dependent variable is Colocation dummy. All variables are defined in Table 1. Standard errors are clustered by year. Model 1 presents results with Lagged Trade Size. Model 2 presents results with HFT dummy. Model 3 presents a regression results with both lagged trade size and HFT dummy. Model 4 present the results with Insider Trading Rule Index, Market Manipulation Rule Index, Efficiency of the Judiciary, Risk of Expropriation, Anti-director and Disclosure index. Model 5 presents the results with macro-economic and market condition variables. Model 6 present the results with all joint variables. The *, **, and *** are statistically significant at the 10%, 5%, and 1% level, respectively. T-statistics are in square brackets.

	(1)	(2)	(3)	(4)	(5)	(6)
	Trade Size	HFT	HFT+Trade Size	Law Index	Macro-Economic Variable	All Jointly
HFT		**0.338*** **	**0.282*** **	**0.445*** **	**0.313*** **	**0.276** **
		[3.23]	**[2.64]**	**[4.26]**	**[3.35]**	**[2.18]**
Lag Trade Size						
Log (Trade Size (-1))	-0.053**		-0.003			-0.057
	[-2.03]		[-0.17]			[-1.30]
Log (Trade Size (-2))	-0.011		-0.022			-0.045*
	[-0.55]		[-1.10]			[-1.80]
Law Index						
Insider Trading Rule Index				0.008*		-0.030*
				[1.61]		[1.88]
Volume Manipulation Rule				-0.001		-0.086
Index				[-0.02]		[-1.50]
Efficiency of the Judiciary				-0.052**		
				[-2.05]		
Rule of Law				0.006		
				[0.29]		
Risk of Expropriation				-0.050		-0.205*
				[-1.10]		[-1.71]
Anti-Director Index				0.012		
				[0.55]		
Disclosure Index				0.071		0.042
				[0.62]		[1.22]
Macro-Economic/Market Condition						
Log(Market Cap)					-0.0005	-0.018**
					[-0.09]	[-2.10]
Log(Volatility)					-0.469	-3.307
					[-0.23]	[-0.81]
Log(MSCI)					-0.182	-0.109
					[-0.80]	[-0.65]
Log(GDPPC)					0.015	0.144*
					[1.16]	[1.85]
Observations	2542	2544	2542	2112	2182	1973
Pseudo R2	0.0822	0.221	0.2361	0.2041	0.2182	0.3303