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STUDY OF THE BEHAVIOUR OF HIGH-FREQUENCY TRADERS ON EURONEXT PARIS

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This study provides a descriptive summary of the activity of leading high-frequency traders (HFTs), including members of the SLP program[1] on Euronext Paris for the CAC 40 stocks. The aim of the AMF's study is to analyse liquidity provision and consumption by HFTs, who now act as leading market-makers[2] for liquid stocks on the French market, and to study their behavioural changes during highly stressed periods.

In recent years, the equity markets have experienced frequent periods of high volatility: volatility increased sharply in June 2016 due to the UK referendum; and the year had already started off on a volatile note amid concerns about China's economy and the risks associated with the sharp fall in oil prices. Such market conditions can have an impact on liquidity: amounts traded increase while, at the same time, market-makers face greater risks and therefore reduce their presence in the limit order book proportionally.

In order to analyse this environment, the AMF studied the activity of the leading HFTs, since they represent a significant share of the market-making activity on Euronext Paris liquid stocks. In this increasingly fast and fragmented market, HFTs are now the only market participants that are able to play this role, as they can perform efficient inventory management in a very fast-moving market environment.

Firstly, this paper focuses on order book liquidity theoretically provided by HFTs: HFTs' passive behaviour expressed as the quantity they offer at the three best price limits in the order book. Secondly, it turns to liquidity actually provided and consumed by HFTs: amounts traded and trade aggressiveness. In conclusion, the paper focuses on the two most volatile days of the period under study: December 3rd 2015 and June 24th 2016 (Brexit).

The period under study spans the nine-month period from November 2015 to July 2016, during which French equity market volatility swung widely: its rise through February 2016 was followed by a more stable period after March 2016. It is also worth noting that sharp price changes (price jumps[3]) occurred throughout the period, notably on December 3rd 2015 on an intraday basis (ECB announcement) and on June 24th 2016 before the market opening (Brexit announcement). Both days are examined in detail at the end of this paper.

[1] A description of the SLP program is provided in the appendix 1.
[2] A description of market-making activity can be found in the appendix 2.
[3] In the paper we refer as price jump for either a sharp increase or a sharp drop in price.

1. SCOPE OF ANALYSIS AND DESCRIPTION OF INDICATORS USED

1.1. SCOPE OF SECURITIES AND MARKET PARTICIPANTS CONSIDERED IN THE STUDY

For this study the AMF selected orders and trades from market participants that are either members of the SLP program on Euronext Paris (pure HFTs and investment banks carrying out hybrid activity, and henceforth are referred to as "mixed") or those classified as pure HFTs according to the classification presented in the appendix 3.

The study focuses on the most liquid French securities, specifically the CAC 40 stocks listed on Euronext Paris[4]. These securities are all liquid securities in the SLP program.

Lastly, since the amounts traded by HFTs during the auction phase represent only about 2% of their amount traded and a little less than 5% of amounts traded at auction, the analysis is confined to amounts traded during continuous trading phases.

Note: Throughout this paper, all metrics measured are averaged across all selected market participants. Nevertheless it should be noted that each market participant may behave quite differently and that even a single member's activity can have an impact on the averaged results.

1.2. VOLATILITY METRICS

In this analysis, the AMF measures market volatility in two different ways: overall market volatility and temporary volatility shocks (such as price jumps that often follow macro-economic announcements). The AMF thus makes a distinction between two volatility metrics:

- **Implied volatility:** a reflection of the estimated future price changes of an option's underlying assets. It is generally interpreted as the market's consensus estimate of the future risk and is derived from option prices. Implied volatility is used to identify **overall market volatility (or stress) at a given time**. The VCAC (the CAC 40 volatility index) is used as an estimator of this volatility.
- **Historical volatility**: this corresponds to the range of historical price changes over a given period. Its calculation is based on historical prices and **thus reflects actual price changes**. Historical volatility is used to identify sharp price changes throughout this paper and is calculated over a short time period. **Historical volatility provides a measure of local market volatility**.

These two metrics meet different needs: where historical volatility[5] captures temporary price shocks, implied volatility assesses the general level of market stress at times where historical volatility may be characterised by major temporary shocks[6].

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[4] Unibail, Arcelor Mittal, STMicroelectronics and Solvay are listed on Euronext Amsterdam or Euronext Brussels. The AMF does not have order book data for these exchanges. Alcatel-Lucent was included for only part of the analysis; it was replaced by Nokia on December 22nd 2015. It should be noted that amounts traded in CAC 40 securities represent more than 85% of total amounts traded in all French stocks.

[5] The historical volatility used in the study equates to the sum of the squared price deviations sampled every 15 seconds for 15 minutes (i.e. 60 measurements). This would appear to be an appropriate measure as it covers a short period of time and is representative of short-term price volatility. This measure appears to have little sensitivity to the sampling selected; from 15 seconds onward, the measure is not affected by the microstructure.

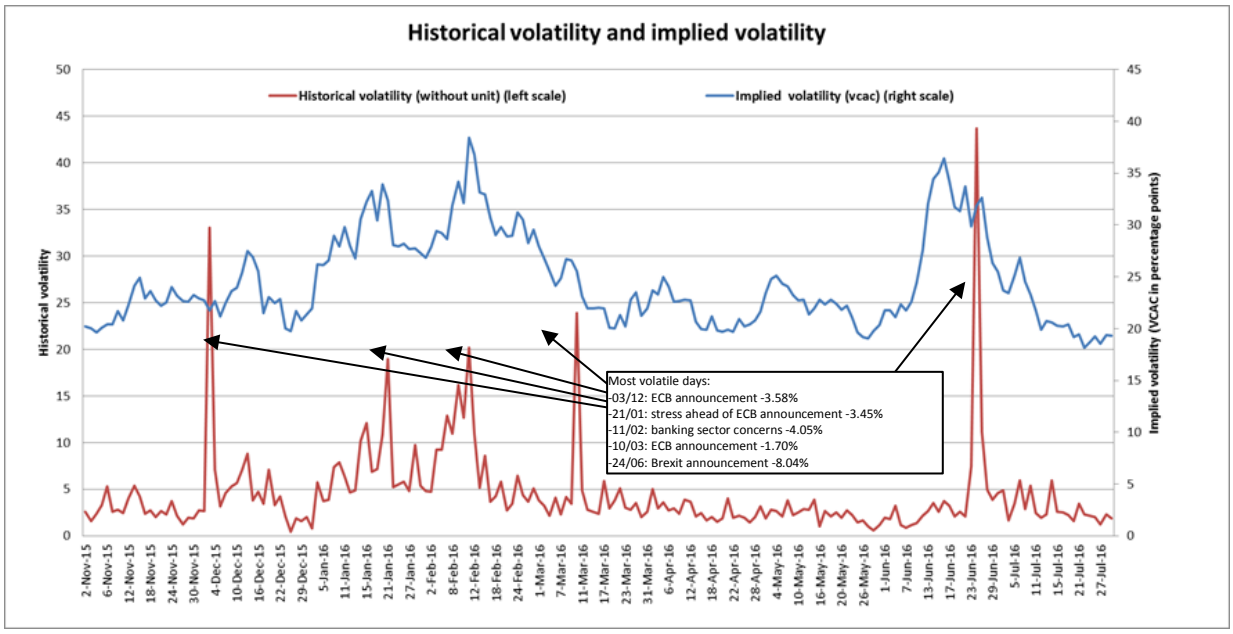

Figure 1: The two metrics varied widely over the period. Implied volatility illustrates the overall trend while historical volatility highlights the days when there were sharp price changes (notably December 3rd 2015 and June 24th 2016).

In résumé:

- An estimator of implied volatility: the VCAC, is used to identify overall volatility and expected risk in the market (the higher the VCAC, the greater the market stress).

- Historical volatility is used to identify sharp changes in prices over shorter periods of time.

Notes:

- Expected announcements affect historical volatility and implied volatility differently:
  - As implied volatility captures the expected risk of an announcement, it **decreases** automatically when new information reaches the market.
  - In contrast, a price move due to an announcement causes **historical volatility to rise**.

  This point is discussed in greater detail in appendix 4.
- These two metrics are clearly related, since periods of high implied volatility are generally characterised by a higher level of historical volatility. Therefore, the choice of the appropriate metric depends on what is to be measured: the impact of the risk, the impact of price changes, or the impact of an expected announcement.

The AMF favoured a measure over a short period (15 minutes) to reduce its lag (the measure increases more quickly after a price change, and hence a price change has an almost immediate impact on historical volatility).

[6] For example, historical volatility was very high on December 3rd, at a time when implied volatility remained at a lower level.

1.3. NOTABLE JUNCTURES IN THE DAY

For this analysis it is important to bear key figure publication times in mind and in particular macroeconomic announcements that are often accompanied by price moves:

- **9:00 a.m.:** Paris market opening and start of continuous trading following the opening auction.
- **11:30 a.m.**: European figures.
- **11:45 a.m. to 12:00 p.m.**: CAC 40 and Eurostoxx 50 Futures price auctions on the third Friday of the month (expiration).
- **1:00 p.m.**: German consumer confidence figures and UK monetary policy decisions
- **1:45 p.m.**: ECB announcements.
- **2:30 p.m.**: ECB press conferences and U.S. figures.
- **3:30 p.m.**: Opening of the U.S. Market.
- **4:00 p.m.**: U.S. figures.
- **5:30 p.m.**: End of continuous trading before the closing auction.

2. LIQUIDITY PROVISION BY HFTS

Firstly, the study focuses on orders placed by HFTs in the order book. As opposed to amounts traded, that represent consumed liquidity, these orders indicate **liquidity provided by HFTs in the order book**.

2.1. LIQUIDITY METRICS

Liquidity is assessed according to two key criteria:

- The cumulative amount placed at the best price limits[7] in the order book on average for all the securities analysed (referred to as "market depth" throughout the paper). This metric is used to quantify the actual passive presence of market participants in the order book.
- The spread[8], which reflects the cost of an aggressive trade. This metric is heavily influenced by HFTs and, in particular, by SLP program members, who are committed to be present at competitive prices.

In order to measure market quality, it is important to consider these two metrics. An upturn (resp. a downturn) in liquidity is characterised by either an increase (resp. decrease) of the market depth at best price limits while spreads stay constant (or tighten, resp. widen) or is characterised by spreads tightening (resp. widening) while market depth stays constant (or increase, resp. decreases).

On average for the whole period and for all the securities taken into account in the analysis, HFTs are present at the best ask or best bid 91% of the time and **the amount they offer at the best prices represents 70% to 80% of the total amount present at these limits** (excluding the RLP program[9]). Depending on the level of market depth studied, the amount ranges from EUR 41,000[10] (at best bid/ask limit) to EUR 225,000 (aggregated for the three best bid/ask limits) and thus it by far exceeds the average trade size, which ranges from EUR 8,000 to EUR 12,000 for these stocks. Orders therefore rarely breach the best limit: only 2.5% of aggressive orders hit at least two different price limits, and only 0.4% hit three different price limits.

The averaged HFTs' market share in terms of depth over the period is provided below:

Presence in the limit order book	Market share (relative measure)	Amount offered by HFTs (absolute measure)
At the best bid and offer prices	70,8%	40 826 €
At the two best price limits	77,3%	122 084 €
At the three best price limits	79,3%	224 774 €

Table 1: Average amounts, for all stocks, offered at the best price limit or cumulated for the two or three best bid/ask limits including HFTs' market share at these limits. HFTs show a slightly smaller presence in terms of market share at best limit. The amount offered (bid/ask average) ranges from EUR 41,000 to EUR 225,000.

[7] For each security, the *n* best price limits represent a range of different prices based on tick size; at times this must be taken into account to compare this metric across different stocks.
[8] Average spread for all securities. Expressed in ticks, spread can be compared from one stock to another; its average across all securities gives a relevant metric of the overall spread of the market.
[9] Retail Liquidity Provider: a liquidity program reserved for retail clients.
[10] This is the average of the amounts offered for purchase or sale (bid & ask).

The AMF uses the three best price limits metric throughout the analysis, as it cavitates to a lesser extent than the best price limit metric. The three best price limits metric is more stable than the best price limit metric and both sketch similar trends[11].

NB: Liquidity provision at the three best price limits is spread fairly evenly among the different market members identified as HFTs.

2.2. CHANGES IN LIQUIDITY OVER THE WHOLE PERIOD

In the first few months of the period under review, from November 2015 to February 2016, market depth[12] decreased sharply: it **plunged by more than 30% from its value at the beginning of the period while spreads widened only slightly[13].**

For the rest of the period under review, with the exception of the heightened uncertainty surrounding the Brexit announcement[14], volatility returned to levels close to those observed at the beginning of the period (the VCAC stood at 20), spreads were tighter (2.5 ticks on average) than at the beginning of the period, and order-book depth increased slightly, but did not return to the levels seen in November 2015.

For the entire period under review, excluding the two most volatile days (June 24th 2016 and December 3rd 2015), HFTs market share in the order book **remained almost constant[15]: close to 80% at the three best price limits.**

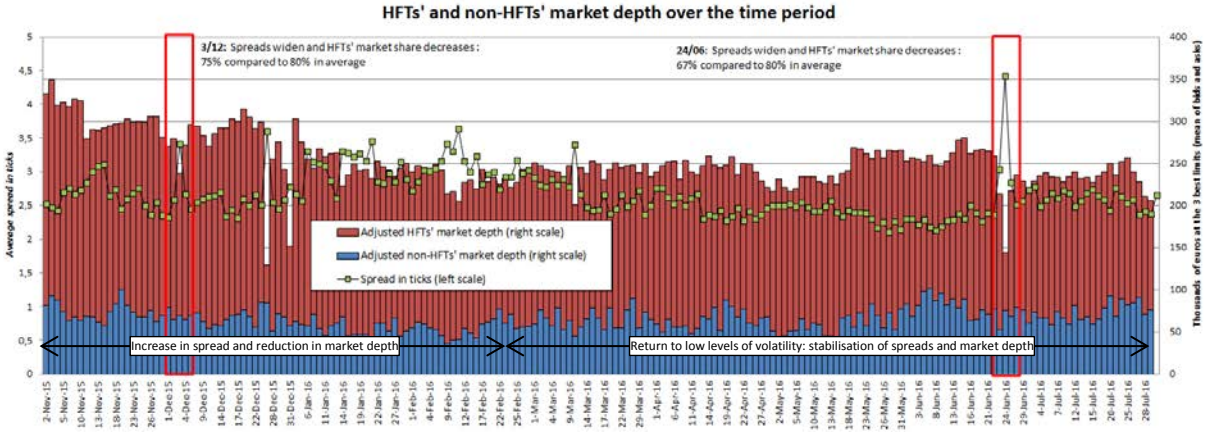

Figure 2: Adjusted depth[12] decreased sharply in the first part of the period (until February 2016) while spreads widened slightly, reflecting a downturn in liquidity. Then volatility decreased, as well as both depth and spreads stabilised near their beginning-of-period levels. Apart from two exceptional days (December 3rd and June 24th), HFTs' market share remained constant over the period at close to 80%.

[11] The choice of the number of limits considered for the market depth analysis is detailed in appendix 5.
[12] Market depth adjusted by multiplying it by the price changes of the CAC 40 so that it is not affected by the fall in prices in the first part of the period under review.
[13] Spread averaged 2.66 ticks in November 2015 versus 3.05 ticks in February 2016.
[14] A specific analysis of the behaviour of HFTs around the Brexit referendum result announcement is provided later in the paper.
[15] Although HFTs' presence in terms of market share was relatively constant for the entire period, the days December 3rd 2015 and June 24th 2016 showed a sharp decline in market depth provided by HFTs. These were the two most volatile days over the period but were nonetheless outliers (they are analysed at the end of this paper).

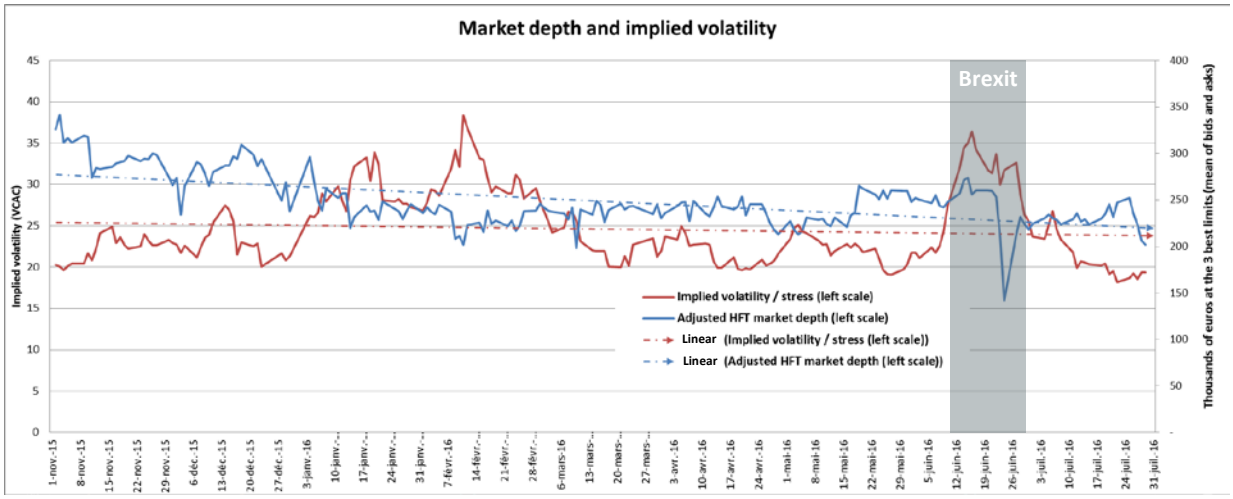

Figure 3: Except for the two-week period prior to the Brexit announcement, implied volatility and depth diverged: the higher the volatility, the smaller the quantity offered.

Market depth and implied volatility[16] follow opposite trends over the period: the higher the implied volatility (and thus the higher the risk), the lower the liquidity provision (shallower market depth and wider spreads). Conversely, market quality is better in lower volatility conditions: deeper market depth at the three best price limits and tighter spreads.

Implied volatility affects all market participants evenly. HFTs' market share in the order book remained constant during the whole period, close to 80% at the three best price limits.

Comment on market-makers' expected behaviour

The increase in implied volatility implies an increase in the risk of holding stocks on the market (the VIX index, from which the method for calculating the VCAC is derived, is also called the "fear index"), and therefore one would expect shallower market depth when volatility rises.

Since certain participants benefit from market-makers agreements which can include rebates, it may be feasible for these market members alone to maintain liquidity provision during periods of stress. Nevertheless, MiFID II encourages rewards rather than sanctions through RTS 8 on market-making[17], and requires that trading venues provide additional incentives during periods of stress.

[16] The result would have been very similar with historical volatility. Implied volatility was used here as market depth is linked to general market risk.

[17] Article 6, https://ec.europa.eu/transparency/regdoc/rep/3/2016/EN/3-2016-3523-EN-F1-1.PDF.

2.3. BREAKDOWN OF LIQUIDITY BY SECURITY

HFTs have a slightly greater presence (in terms of market share at the three best price limits) on the most actively traded securities, and in particular on highly liquid securities included in both the CAC 40 and the Eurostoxx 50 indices[18] (Figure 4 below). This can most likely be attributed to the greater arbitrage opportunities on these stocks[19].

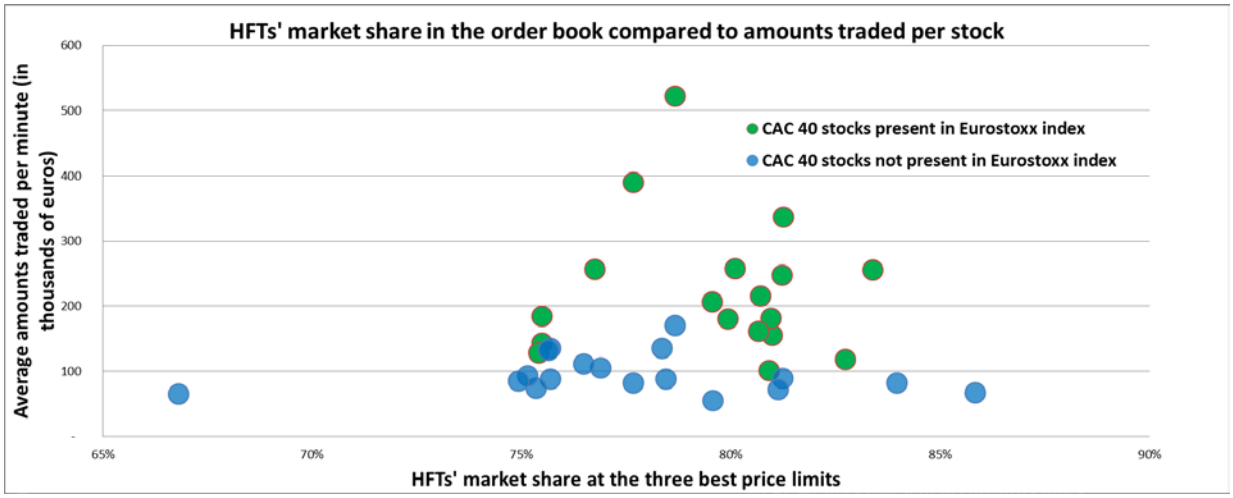

Figure 4: Scatter plot comparing market share in depth terms and average amounts traded in the securities. The market depth is slightly correlated to activity on the securities (amounts traded), and the presence of HFTs seems to depend primarily on inclusion in several indices.

The activity of HFTs varies widely from one stock to another but does not appear to be highly dependent on the amounts traded on these securities. In particular, HFTs have more of a presence in stocks that are included in several indices and for which there are more arbitrage opportunities.

2.4. INTRADAY ANALYSIS OF LIQUIDITY

The average intraday trend of market depth for the stocks analysed highlights wide disparities between **the behaviour of HFTs and non-HFTs**:

- **Non-HFTs have a relatively constant market share in the order book** throughout the day — except for the last 15 minutes of the day when the amount offered by non-HFTs increases quickly, driven by the strategy adopted by one market participant in particular.
- HFTs behave quite differently: both their market share in the order book and the amount they offer increase during the first hour of the day with a sharp rise at 10:00 a.m. linked to the arrival of one particular participant. The level remains stable during the day, albeit with **temporary declines** before the usual announcement times (identified by a fall in implied volatility in the charts below) and sometimes accompanied by spikes in historical volatility. At the end of the day, in market depth terms, market share and the amount offered decrease rapidly as HFTs do not generally hold overnight positions.

[18] Of the 20 securities on which HFTs have the highest market share in terms of market depth at the three best price limits, 13 are in both the CAC 40 and Eurostoxx 50.

[19] HFTs absolute presence (in terms of amount, rather than market share) moves in line with amounts traded: the more actively traded the security, the greater the market depth offered at best price limits (Figure 26 in appendix 6).

The two charts below show, respectively, the change in the market share of HFTs and non-HFTs on an intraday basis, compared with the change in spread, and the change in market depth, in terms of amount offered by HFTs and non-HFTs, compared with the VCAC (to identify expected announcements)[20].

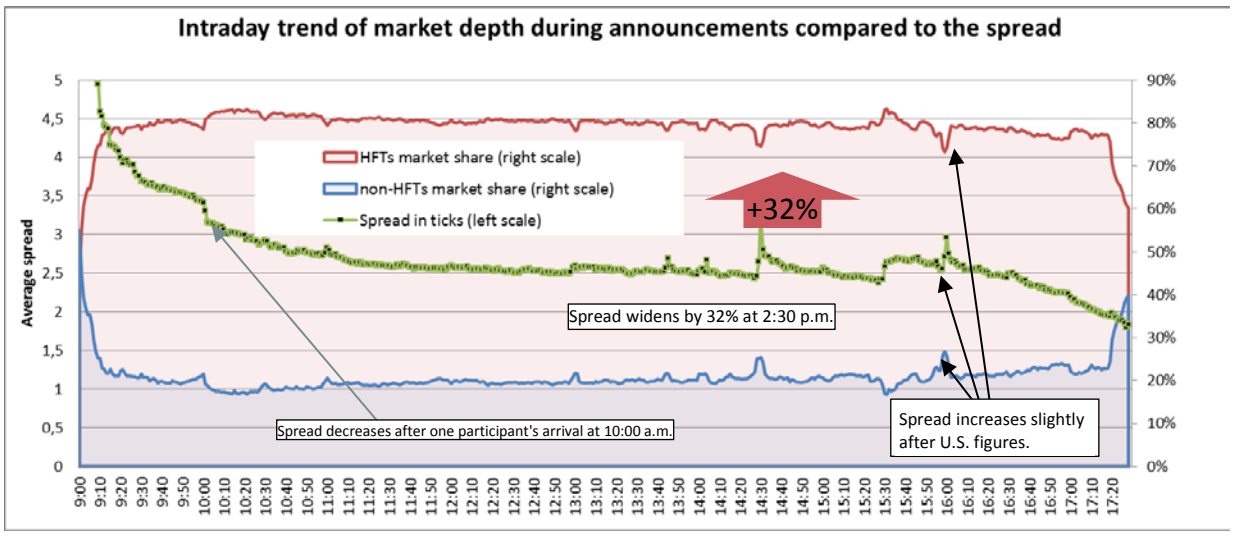

Figure 5: HFTs contribute to spread tightening at the beginning of the day (their market share increases while spread tightens); they withdraw their orders before announcements and at the end of the day.

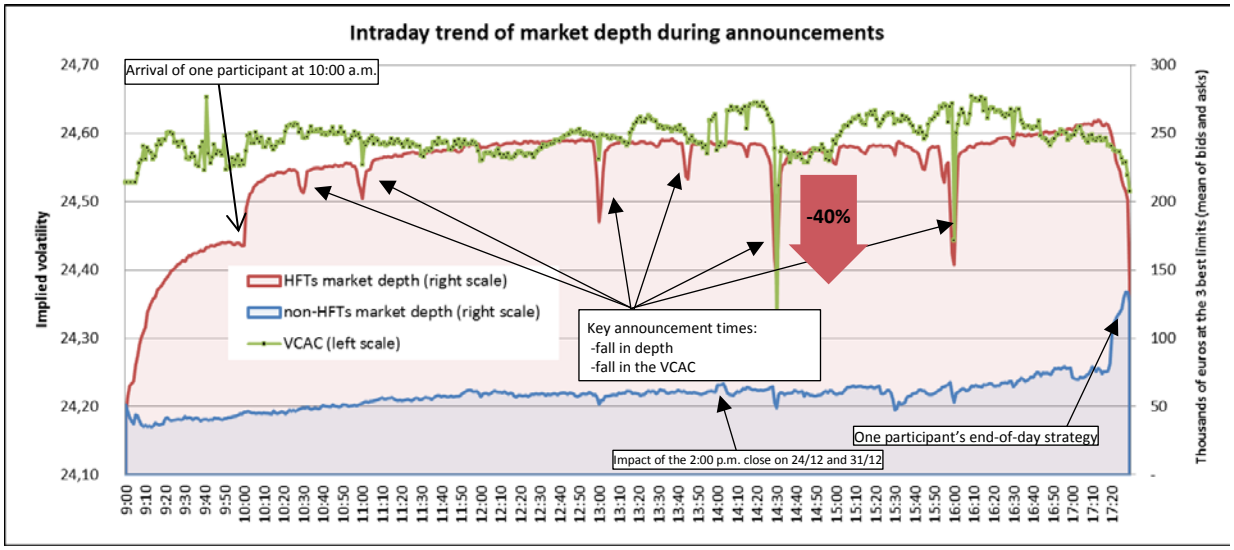

Figure 6: Market depth offered by HFTs increases at the beginning of the day and decreases at the very end of the day. HFTs withdraw their orders promptly before the announcements, which is hardly ever the case for non-HFTs: for example at 2:30 p.m., HFTs' presence falls by 40% from its value before the 2:30 p.m. announcements.

The two charts show that the market depth offered by HFTs thins out ahead of expected announcements that are likely to cause price shocks[21]: most of them sharply reduce their liquidity provision from the order book a few minutes before the announcements that could affect prices, mainly those occurring at 1:45 p.m., 2:30 p.m. and 4:00 p.m.[22], then HFTs re-enter the order book after the announcement (generally one or two minutes later).

[20] For each chart, the metrics are averaged by minute for all securities and all days.
[21] Expected announcements are marked by a fall in the VCAC.
[22] HFTs withdraw three minutes before the announcement; the impact on spreads can be seen in the minutes before the announcement.

HFTs' entry into the order book at the beginning of the day contributes to spread tightening, while their withdrawal before the announcement times contributes to spread widening.

HFTs' activity has a considerable impact on spreads: HFTs contribute to their tightening at the beginning of the day but they drive spread widening when they anticipate price jumps/falls related to expected announcements.

Liquidity diminishes sharply during periods of announcements that may have a material impact on prices[23]: HFTs sharply reduce their presence before the expected announcements, unlike other market participants, but return quickly after the announcements.

Comment on the market-makers expected behaviour

By definition, (non-directional) market-making strategies try to avoid sharp price moves; a withdrawal of HFTs' orders seconds before an expected announcement is therefore rational behaviour. However, this raises questions as to how this withdrawal affects post-announcement volatility. Attempts to require market-makers to maintain a presence during announcements to reduce volatility during these periods, which represent less than 2% of the total time the markets are open each day, have so far been unsuccessful: the time presence requirements provided in MiFID II for HFT market-makers leave significant scope for withdrawal from the order book.

[23] For example, at 2:30 p.m. the spread gains 32% while depth decreases by 40%.

Note: The AMF analysed the change in market depth after the 10 announcements at 2:30 p.m. that had the greatest impact on prices[24]. The results show a wider range of variation than in average market conditions, but are very similar to the general case described above: HFTs withdraw 80% of their orders starting at 2:28 p.m. and return to a nearly 80% market share starting at 2:35 p.m. **HFTs' withdrawal relative to other market participants during periods of volatility is significant but always temporary.**

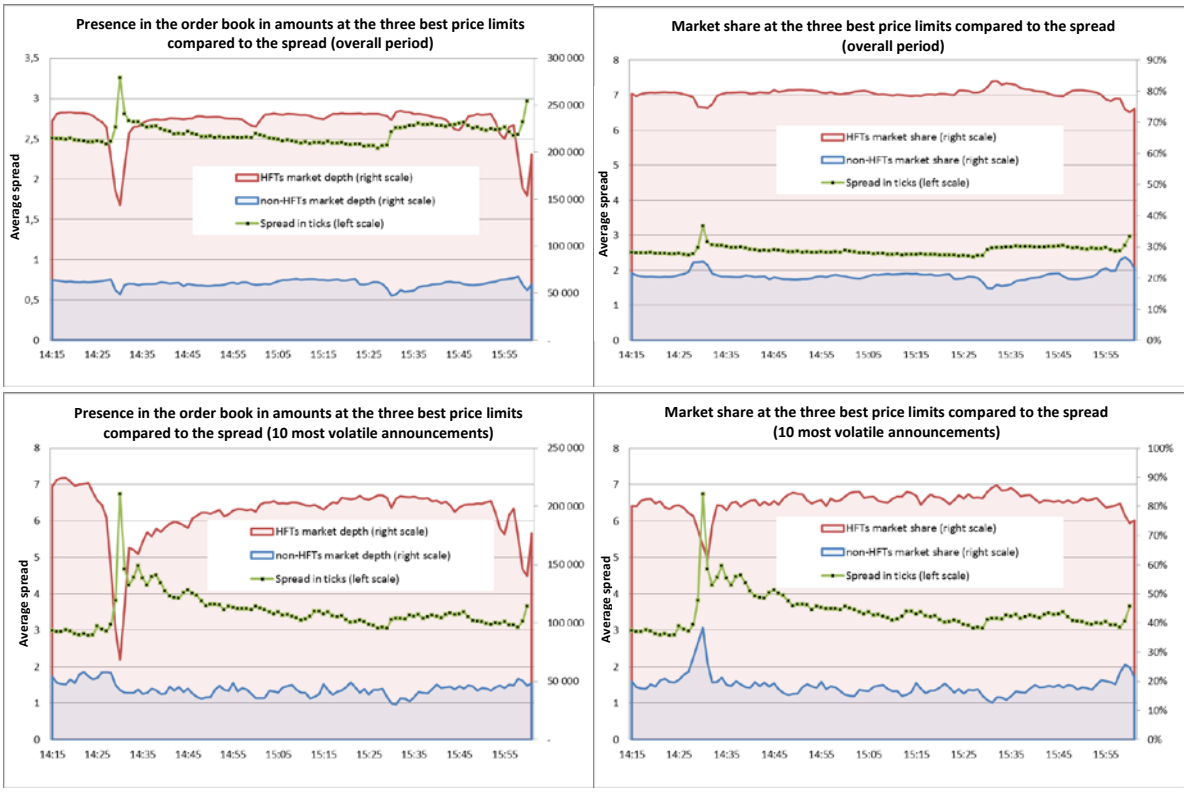

Figure 7: The same results are observed for the announcements at 2:30 p.m. that have a material impact on prices as in the general case: HFTs withdraw their orders before the announcements but are quick to return thereafter.

[24] The following days posted the highest historical volatility at 2:30 p.m.: 03/12, 21/01, 05/02, 08/07, 08/01, 04/12, 12/02, 10/03, 06/05 and 04/03.

3. TRADING ACTIVITY

3.1. DEFINITION OF METRICS USED

The first part of the analysis focused on the visible liquidity provided by HFTs in the order book (market depth and spread). This second part considers liquidity actually provided (passive trades) or consumed (aggressive trades) by HFTs.

An order is referred to as aggressive when it initiates a trade; it is the most recent order entered in the book before a trade. A passive order is the counterpart to any aggressive order. Liquidity is derived from the matching of aggressive orders with passive orders. Passive orders that are executed systematically provide liquidity, while the contribution to liquidity of an aggressive order is inversely proportional to how "informed[25]" it is.

A closer examination of HFTs' aggressive/passive ratio[26] establishes a link between the analysis of market depth and the analysis of amounts traded by HFTs. This ratio represents the share of liquidity consumed by HFTs (amounts traded aggressively) compared with the share of liquidity actually provided by HFTs as liquidity providers or consumers (total amounts traded aggressively and passively).

3.2. AMOUNTS TRADED

3.2.1. Analysis of the period under review

As price moves generally create opportunities for market participants, periods of sharp price changes are often characterised by large amounts traded. Accordingly, a comparison of amounts traded with historical volatility (a good estimator of actual price changes) shows, as expected, that amounts traded track the historical volatility trend.

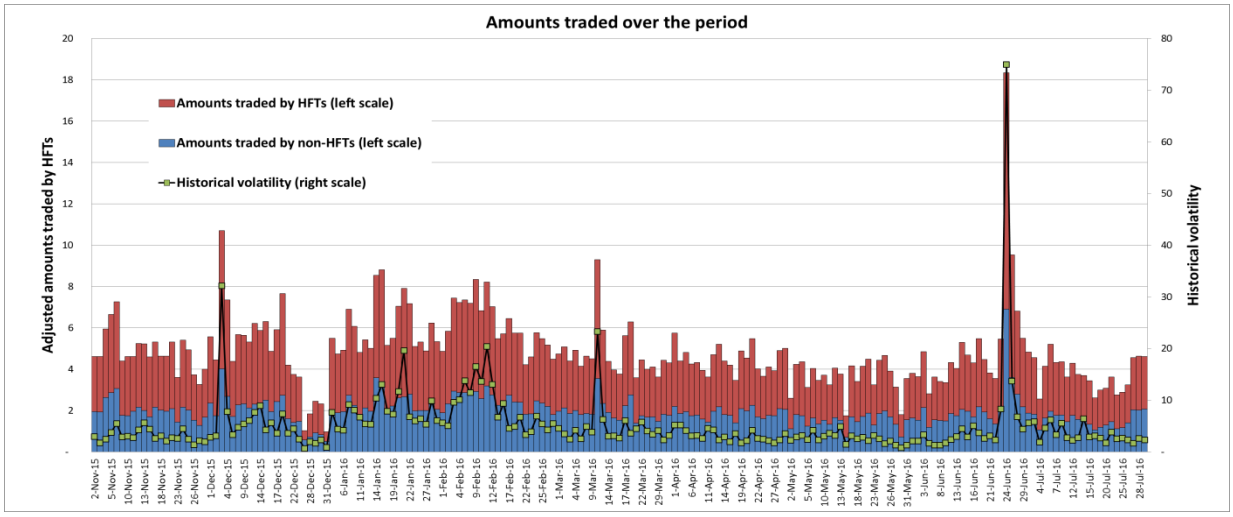

Figure 8: The chart depicts daily amounts traded[27] compared with historical volatility averaged per day. Periods of high historical volatility coincide with high volumes.

[25] Retail orders are generally considered "uninformed".

[26] The aggressive/passive ratio is calculated as amounts executed aggressively (the order initiating the trade) divided by all amounts traded. This ratio therefore ranges from 0% to 100%; a ratio of 100% corresponds to purely aggressive trades.

[27] Amounts traded are expressed as securities equivalent so as to disregard the significant price changes during the period under review.

HFTs displayed a relatively stable market share throughout the period; the amounts they traded were always close to 60% of total amounts traded (auctions excluded). For the period as a whole, their aggressive/passive ratio was fairly constant, around 53%. The chart below (Figure 9) also shows similar trends for aggressive market share and passive market share, although higher aggressive volumes were observed on days of exceptionally high volatility, such as June 24th 2016[28].

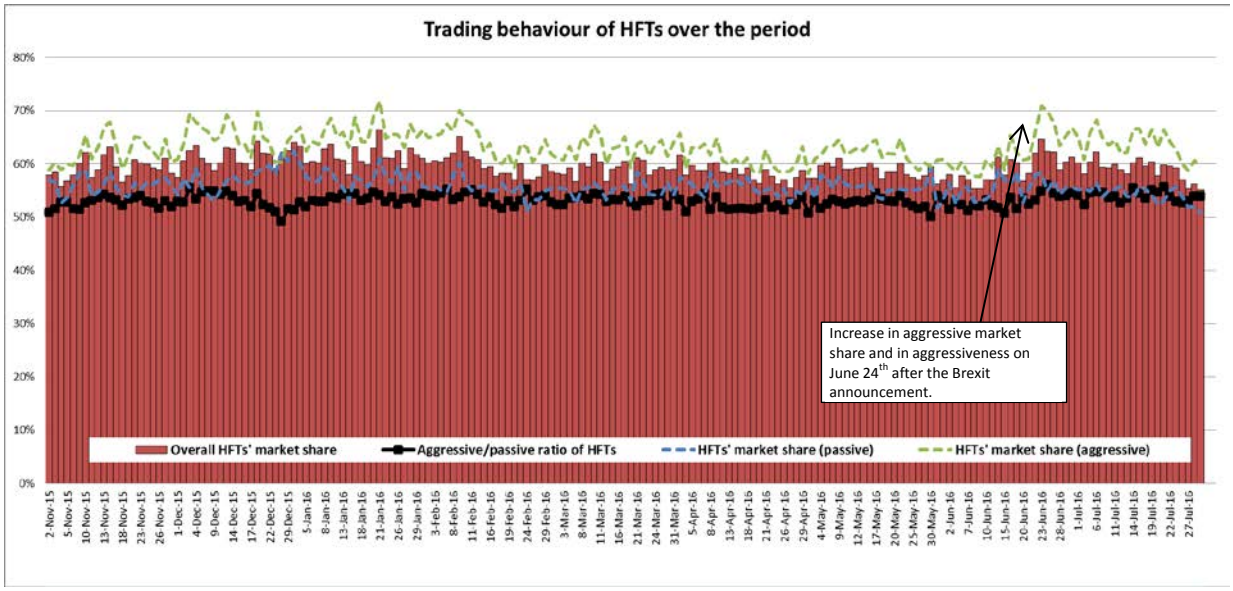

Figure 9: Market share is nearly constant at close to 60%. The aggressive/passive ratio is also stable at close to 53%.

It is clear that spikes in historical volatility coincided with sharp increases in amounts traded. Excluding exceptional trading sessions, the activity of HFTs did not, however, seem to be specifically affected by an increase in implied volatility over the period, as HFTs' market share (auctions excluded) remained close to 60% for the entire period under study.

On average, HFTs consumed more liquidity than they provided, with an aggressive/passive ratio above 50%. This ratio was relatively stable for the entire period and stood, on average, at 53%.

Comment on market-makers' expected behaviour

As HFTs position themselves mainly as market-makers that theoretically act only as intermediaries between buy-side flow and sell-side flow and that take advantage of price inefficiencies, one might expect their market share to be below 50%. Some of the flows could correspond to inventory moving from one HFT to another, before reaching a non-HFT, which would create volumes with no corresponding liquidity. However, in order to confirm this hypothesis a consolidated view of volumes across all trading platforms would be required.

Moreover, since the role of market-makers is to provide liquidity, one might expect the HFT aggressive/passive ratio for HFTs carrying out these strategies not to exceed 50%. As such, it should be noted that the increase in the aggressive/passive ratio following the U.S. market opening (see 3.2.2 below) indicates that some of the flow, most likely related to the increase in arbitrage opportunities, is purely aggressive and can hardly be treated as market-making.

[28] See analysis of June 24th below.

3.2.2. Intraday analysis

Intraday analysis shows the same relationship between volatility and amounts traded as noted above. The greater the price moves (high historical volatility), the larger the amounts traded. However, at the very end of the day, this relationship no longer applies: amounts traded increase sharply while historical volatility decreases. The increase in volumes with a broader range of participant types could lead to greater price stability. It is also possible that the passive strategy of one participant referred to in section 2.3 lies behind this drop in volatility.

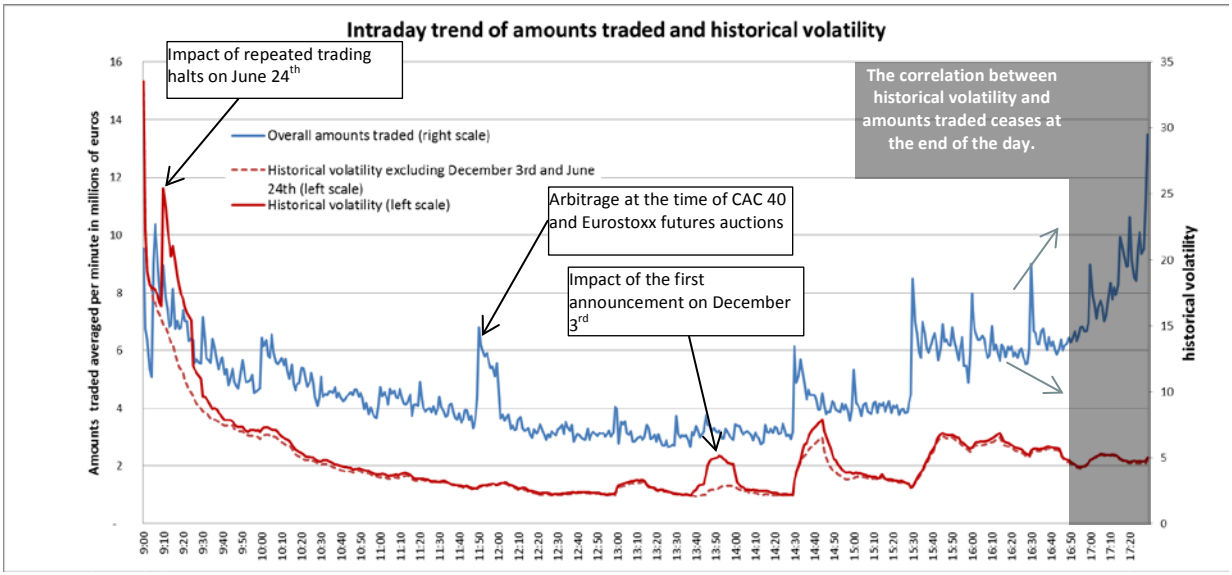

Figure 10: The metrics are averaged for all securities and for the entire period by minute. They are closely correlated, except at the very end of the day when volatility decreases as amounts traded increase.

During the trading day, amounts traded by the entire market decrease in the first part of the day[29], then increase on the first important announcements, at 2:30 p.m., and in particular after the U.S. market opening at 3:30 p.m. In the last hour, volumes swell until the close. A closer examination reveals four distinct phases:

- **At the beginning of the day**, HFTs' activity increases gradually, their aggressive/passive ratio decreases, and, at the same time, they increase their passive contribution (on a relative and absolute basis, see 2.4) in the order book. During this period, HFTs' market share increases from 50% to 58% and, at the same time, the aggressive/passive ratio falls from 65% to 55% on average. Not only do HFTs reduce their aggressive orders, but they also post more passive orders[30].
- **Before the U.S. market opening**, amounts traded by the market as a whole are relatively stable, as is HFTs' market share (60%) and the aggressive/passive ratio (52%). During this phase, HFTs provide as much liquidity as they consume.
- **The U.S. market opening** contributes to an increase in arbitrage opportunities. This leads to an increase in activity, which, in the case of HFTs, is particularly pronounced. Their market share rises from 58% to 65%. Their aggressive/passive ratio thus increases from 52% to 55%. This surge in aggressiveness is most likely due to the existence of arbitrage opportunities. HFTs therefore consume more liquidity than they provide, given that the market depth offered by HFTs during this second part of the day remains constant (see 2.4).

[29] Figure 11: purchase and sale amounts follow similar trends, so no distinction is made in the rest of the memo.
[30] A decrease in their aggressive/passive ratio results either from a decrease in aggressive trades or the addition of passive orders.

- **At the end of the day**, HFTs gradually withdraw and their market share decreases from 60% to 55%. Their aggressiveness increases from 52% to 55% due to the decrease in their market depth and their desire to unwind positions before the close, which tends to incite aggressive behaviour. It should be noted that, at the end of the day, the decrease in the HFTs' market share is compounded by a change in non-HFT behaviour, which dramatically increase their amounts traded.

It also appears that the behaviour of HFTs is particularly influenced by announcement periods and periods of high historical volatility (as seen above in the market depth analysis). A specific analysis of announcement periods shows a temporary change in the behaviour of HFTs. **Just before an announcement, the market share of HFTs decreases sharply, peaking just after the announcement**:

- **Before an announcement,** unlike other participants, HFTs sharply reduce their presence in the order book, and their passive trades decrease accordingly. This explains the sharp fall in their market share, which declines from 60% to 56%, as well as the increase in their relative aggressiveness: the aggressive/passive ratio rises from 52% to 57% before the 2:30 p.m. announcement[31].
- **After an announcement,** prices are often severely affected, which creates more arbitrage opportunities and leads to a sudden increase in aggressive flows from HFTs (as is the case after the U.S. market opening). The market share of HFTs therefore rises from 56% to 62% on average and they are temporarily more aggressive, even though their passive provision of liquidity in the order book quickly returns to its prior level. In contrast to what happens before announcements, HFTs do not reduce their passive orders after announcements but increase their aggressive orders.

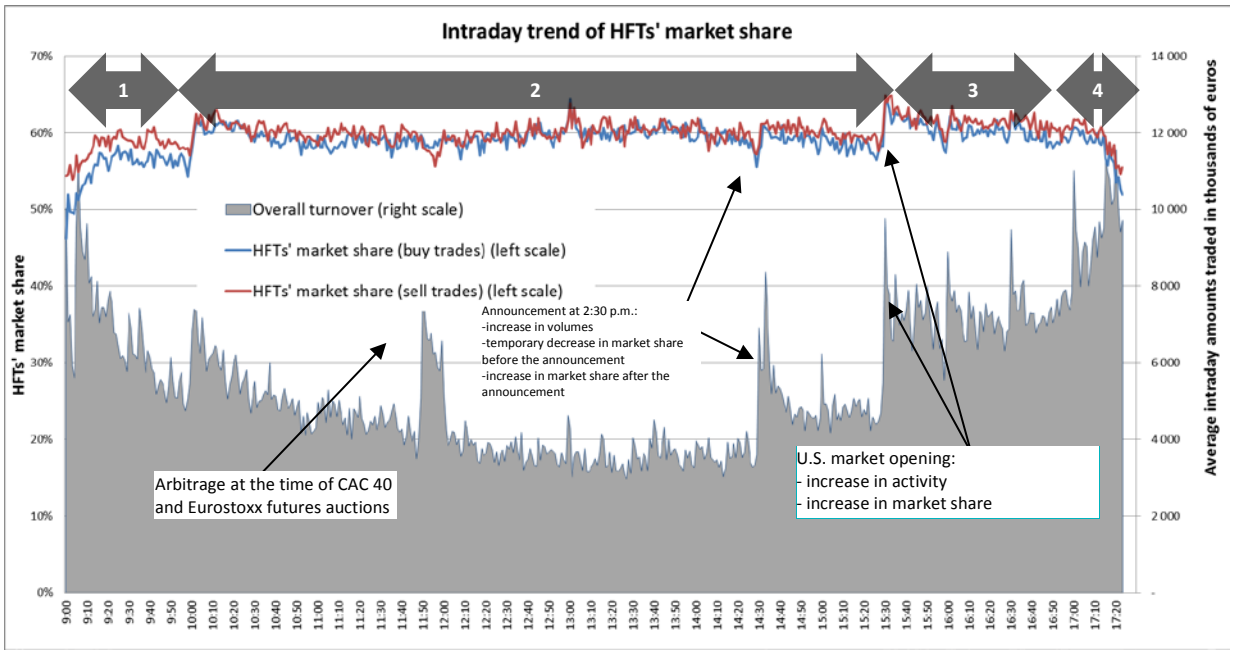

Figure 11: HFTs' market share increases at the beginning of the day and then stabilises at about 60% until the U.S. market opening, after which it rises to 65%. Amounts traded are much larger at the beginning and end of the day.

[31] The aggressive/passive ratio of HFTs increases not because they increase their aggressive flows but because they decrease their passive liquidity provision in the order book.

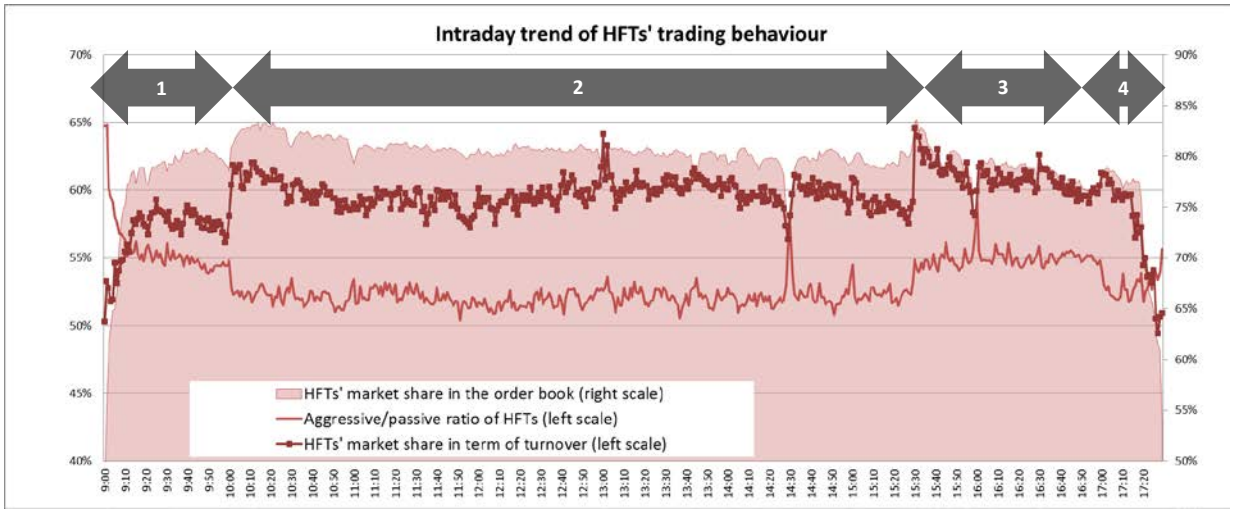

Figure 12: HFTs are much more aggressive after the U.S. market opening (55% versus 52% the rest of the time) while their market share increases at the same time. At the beginning and end of the day, their aggressive/passive ratio is higher, which is actually due to a decrease in their contribution to market depth. Their market shares in amounts traded and market depth terms are lower during these periods.

For the entire period under review, HFTs posted a relatively stable daily market share in terms of amounts traded, which did not seem to depend on the overall market stress.

The increase in HFTs' aggressiveness can be attributed primarily to:
- Their reduced presence in the order book (their provision of liquidity), particularly at the beginning of the day and before announcements.
- An influx of aggressive flows associated with arbitrage opportunities, as is the case at the U.S. market opening and when prices change sharply after an announcement.

At the beginning and end of the day and before an announcement, HFTs are less active through a reduction in their passive orders. Just after announcements that may be followed by periods of high historical volatility, they are more active through an increase in their aggressive orders.

Overall, HFTs consume more liquidity than they provide, and this behaviour stands out more during periods of high historical volatility (at the beginning of the day, during announcement phases and after the U.S. market opening).

Notes:

- The AMF analysed the change in the aggressive/passive ratio and in market share in amounts traded terms after the 10 announcements at 2:30 p.m. that had the greatest impact on prices during the period under review (expressed as historical volatility). The results are similar to the general case described above, but more striking. In particular during price changes that accompany significant moves, between 2:30 p.m. and 2:35 p.m., the market share of HFTs increases sharply to 71%, well above the average of 62% during the period.

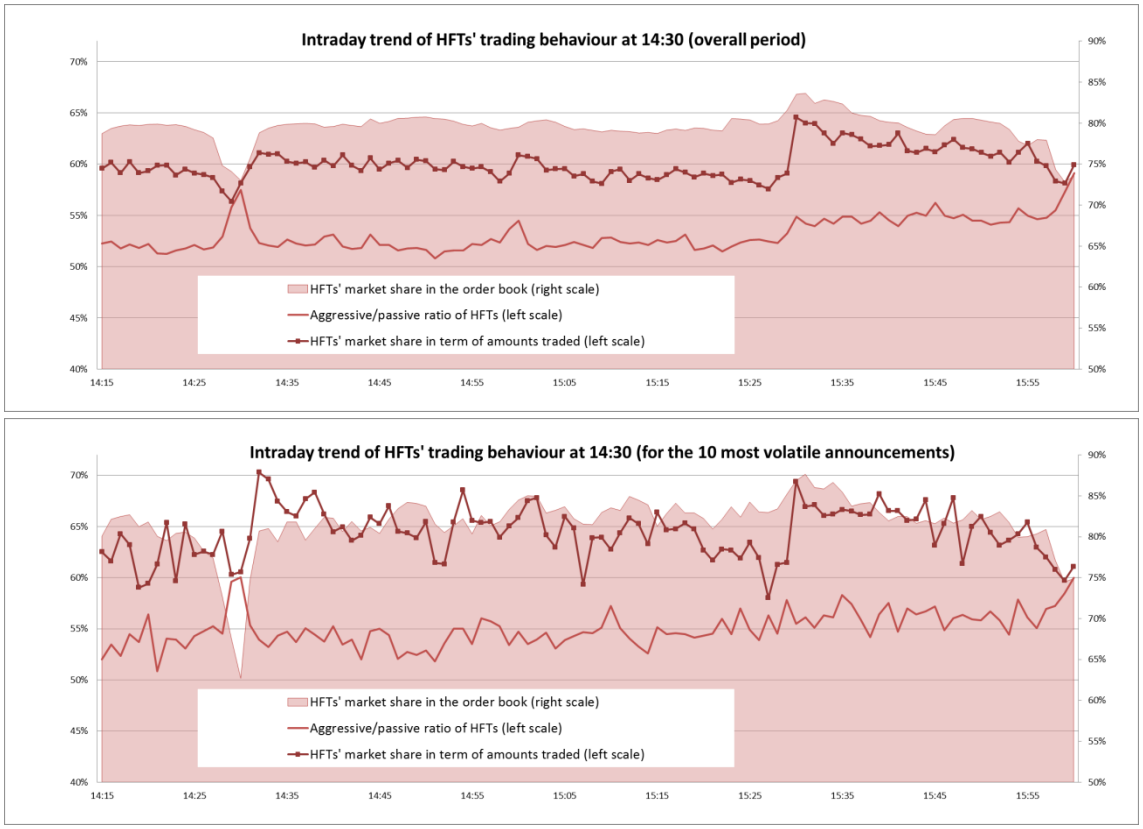

Figure 13: Announcements are accompanied by a reduction in passive orders in the order book which results in an increase of the aggressive/passive ratio. In periods of major announcements, it is primarily HFTs' market share that increases sharply, exceeding 71%, most likely due to multiple arbitrage opportunities.

- 60% of liquidity provided by HFTs is consumed by other HFTs and 40% by non-HFTs. Liquidity provided by non-HFTs is overwhelmingly consumed by HFTs (71%), which could indicate information asymmetry among participants, since aggressive trades are generally more informed trades than passive trades.

4. RELATIONSHIP BETWEEN HFTS' ACTIVITY AND VOLATILITY

The above analyses produce the outcomes presented in the following table: the coloured cells signify the behaviour of HFTs that differ from those of other market participants (non-HFTs). Red signals behaviours that have a negative impact on market quality, green those that have a positive impact, and grey those that have no impact.

<table>
<tr><th></th><th colspan="6">Behaviour of HFTs</th></tr>
<tr><th></th><th rowspan="2">Average value</th><th rowspan="2">Increase in implied volatility (significant risk)</th><th rowspan="2">Increase in historical volatility (price move)</th><th colspan="2">Announcement with price change</th><th rowspan="2">Beginning of day</th><th rowspan="2">End of day</th></tr>
<tr><th>Pre-announce-ment (2 minutes)</th><th>Post-announce-ment (0-5 minutes)</th></tr>
<tr><td rowspan="2">Depth at three best limits: provision of liquidity</td><td rowspan="2">80%</td><td>Constant market share. Behaviour identical to non-HFTs.</td><td>Little impact on market share.</td><td rowspan="2">Specific withdrawal of HFTs (up to -40% at 2:30 p.m. on average and -80% for announce-ments having the highest impact).</td><td>Slight rise in or constant market share (rapid response & arbitrage opportunities).</td><td rowspan="2">Gradual increase in the quantity offered during the first hour and increase in market share.</td><td rowspan="2">Gradual withdrawal during the last 30 minutes and fall in market share.</td></tr>
<tr><td>Decrease in amounts offered.</td><td>Decrease in amounts offered.</td><td>Fall in quantity offered (80% on December 3rd), but gradual return to the pre-announcement level</td></tr>
<tr><td>Spread</td><td>Sharp impact on spread</td><td>Slightly tighter spread.</td><td>Spreads widen.</td><td colspan="2">Sharp widening of the spread in anticipation of announcements and during major price changes.</td><td>HFTs are actively involved in spread tightening</td><td>No impact (one non-HFT tightens the spreads while all HFTs withdraw their orders).</td></tr>
<tr><td rowspan="2">Amounts traded (excluding auctions)</td><td rowspan="2">60%</td><td rowspan="2">No material impact.</td><td>Increase in amounts traded.</td><td rowspan="2">No impact.</td><td rowspan="2">Increase in amounts traded (in terms of market share, up to 82% on December 3rd, and amounts).</td><td rowspan="2">Increase in market share, simultaneous with the gradual entry of HFTs in the order book. Amounts traded decrease.</td><td>Increase following U.S. market opening (more arbitrage opportunities).</td></tr>
<tr><td>Increase in market share (except at the beginning and end of the day).</td><td>Less activity at the very end of the day.</td></tr>
<tr><td>Aggressiveness (aggressive/passive ratio)</td><td>53%</td><td>No material impact.</td><td>Increase in aggressive/ passive ratio</td><td>Increase in HFTs' ratio after withdrawal of passive orders.</td><td>High degree of aggressiveness (withdrawal of passive orders & arbitrage opportunities).</td><td>After the entry of passive orders, the ratio decreases gradually to 52% at 10:00 a.m.</td><td>More aggressive behaviour due to the U.S. market opening and the increased arbitrage opportunities (52% to 55%) and at the very end of the day after the withdrawal of passive orders.</td></tr>
</table>

- The increase in implied volatility has a **negative impact on the market depth offered by all participants**, however **HFTs maintain a constant market share in market depth terms**: in the first part of the period (until February 2016), implied volatility increased by 50% and market depth offered fell by 30% at the same time.
- Pre-announcement periods are marked by a sharp downturn in market quality: sharp reduction in market depth offered (-40% on average at 2:30 p.m.) and sharp increase in spread (+32% on average at 2:30 p.m.). During these periods, HFTs reduce their liquidity provision in the order book, their passive market share decreases and they appear to be more aggressive.
- There are more arbitrage opportunities during major price changes (after an announcement, for example) and after the opening of the U.S. market. **These generally result in a sharp increase in overall activity, which is more pronounced for HFTs, particularly in terms of market share and aggressiveness (market share rises from 58% to 65% and the aggressive/passive ratio from 52% to 55%).**
- Periods of high historical volatility are marked by a greater presence of HFTs. After announcements in particular, their passive presence in the order book rises sharply, as does both their market share in terms of amounts traded and their aggressiveness.
- HFTs consume more liquidity than they provide, in particular during periods of high (historical) volatility.
- At the beginning of the day, HFTs increase their weight in the order book, which gradually tightens spreads and increases their market share (spread is gradually halved while amounts offered by HFTs increase five-fold). The aggressive/passive ratio then gradually declines as HFTs consume less liquidity and provide more (the aggressive/passive ratio moves from 65% to 55%).
- At the end of the day, HFTs withdraw their orders from the order book (but one non-HFT maintains a lower spread). The aggressive/passive ratio increases gradually as HFTs consume more liquidity and provide less.

5. FOCUS ON DECEMBER 3RD 2015

5.1. THE DAY

December 3rd 2015 was one of the most volatile days of the entire period due to several ECB announcements. About two weeks before December 3rd and following the publication of the ECB's minutes, the markets were optimistic about the new monetary policy to be implemented by the ECB.

The ECB, which was seeking to fight low inflation (0.1% in November) and stimulate the European economy, had two levers at its disposal:

- lower its deposit rate, which was already in negative territory (-0.20%);
- bolster its purchase programme (quantitative easing, or QE) by extending the programme's duration and/or increasing the monthly amount of asset purchases (EUR 60 billion). The market was expecting not only an extension of the programme's duration but in particular an increase in its monthly amount.

The ECB generally publishes its announcements on Thursdays at 1:45 p.m. and holds a press conference the same day at 2:30 p.m. The analysis presented below is therefore structured around these two events during that day.

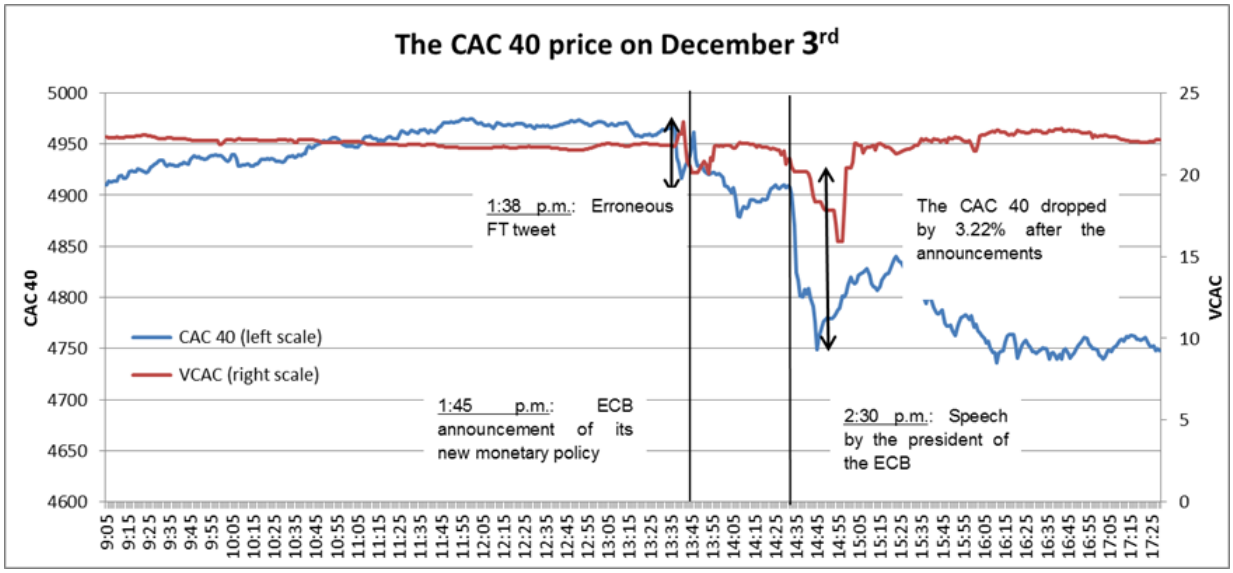

Figure 14: There were three major announcements during the day: an information leak from the *Financial Times* at 1:38 p.m., followed by two official ECB communiqués at 1:45 p.m. and 2:30 p.m.

The day was marked by three major announcements:

- A few minutes before the 1:45 p.m. announcement, the financial daily the *Financial Times* announced on Twitter that the European Central Bank would leave rates unchanged. This misinformation led to market distortions: at 1:38 p.m., the CAC 40 fell by a sharp 0.56% but regained its initial value several minutes later.
- At 1:45 p.m., the ECB announced that it was lowering its deposit rate by 10 basis points, from -0.2% to -0.3% from December 9th, and the CAC 40 then began to decline gradually.
- However, as the market was still optimistic about other monetary policy measures to be communicated during the press conference held by ECB President Mario Draghi, the fall was slight and share prices went back up, starting at 2:09 p.m.
- At 2:30 p.m., Draghi announced that the QE program launched in March 2015 would be extended until at least the end of March 2017, but with no increase in the amount of purchases. This came as a severe disappointment to the market. The CAC 40 dropped significantly from 2:33 p.m. to 2:45 p.m.: in just 12 minutes, it lost 3.22% amid very heavy trading.

For the period under review, December 3rd was the most volatile day in which there was a price jump during the trading session[32]. It therefore provides an example of HFTs' reactions in terms of liquidity consumption and provision on several major price shocks.

5.2. HFTS' BEHAVIOUR

The analysis focuses on the three events described above from two perspectives: first, the short-term impact of the three events and, second, the longer-term impact by isolating the period before the announcements (before 1:38 p.m.) and after the announcements (after 2:30 p.m.).

5.2.1. Local volatility impact on December 3rd announcements

At 1:38 p.m., the misleading announcement by the *Financial Times* was unexpected. The impact of this information leak on various market participants was therefore different from that described previously in the general case involving expected announcements, in particular:

- With expected announcements, there is generally a decrease in HFTs' market share in terms of market depth in the order book, as HFTs change their passive orders to a greater extent than non-HFTs.
- In this specific instance, reactions varied: after the misleading announcement at 1:38 p.m., the HFTs' market share in market depth terms increased from 81% to 91%. HFTs and non-HFTs both withdrew from the order book but, this time, HFTs' market depth fell by 42%, while for non-HFTs the decrease was 76%. **At 1:38 p.m., it is likely that non-HFTs could not track the price drop and hence were unable to update their orders, whereas HFTs were able to quickly move their orders and maintain their passive liquidity provision in the order book.**
- During the two announcements involving accurate information (1:45 p.m. and 2:30 p.m.), the market participants' behaviour was in line with that described in the general case (see 2.4 and 3.1.2).
- Before each of these two announcements, market depth decreased mainly because HFTs withdrew their orders[33]. The market share of HFTs in market depth terms decreased from 80% to 60% (Figure 16), which was reflected in a sharp widening in spread (Figure 15). The pre-announcement withdrawal of participants was particularly pronounced; the average spread on French securities reached its widest for the period under review at almost 19.9 ticks while, on average (in the hours before the announcement), it stood at 2.7 ticks.
- Just after each of these announcements, the amounts traded increased significantly. For example, three minutes after the 2:30 p.m. announcement, the amount increased nearly 40-fold and HFTs' market share in trade terms reached 82% for about two minutes (during this period, HFTs represented approximately 90% of aggressive trades). **The order book gradually recovered for approximately the 30 minutes after each announcement but never reached its pre-announcement levels. It is most likely that certain participants permanently reduced their presence in the order book after the two major shocks.**

[32] The day of June 24th 2016 was more volatile but the price jump/drop occurred pre-market.
[33] Or moved their orders.

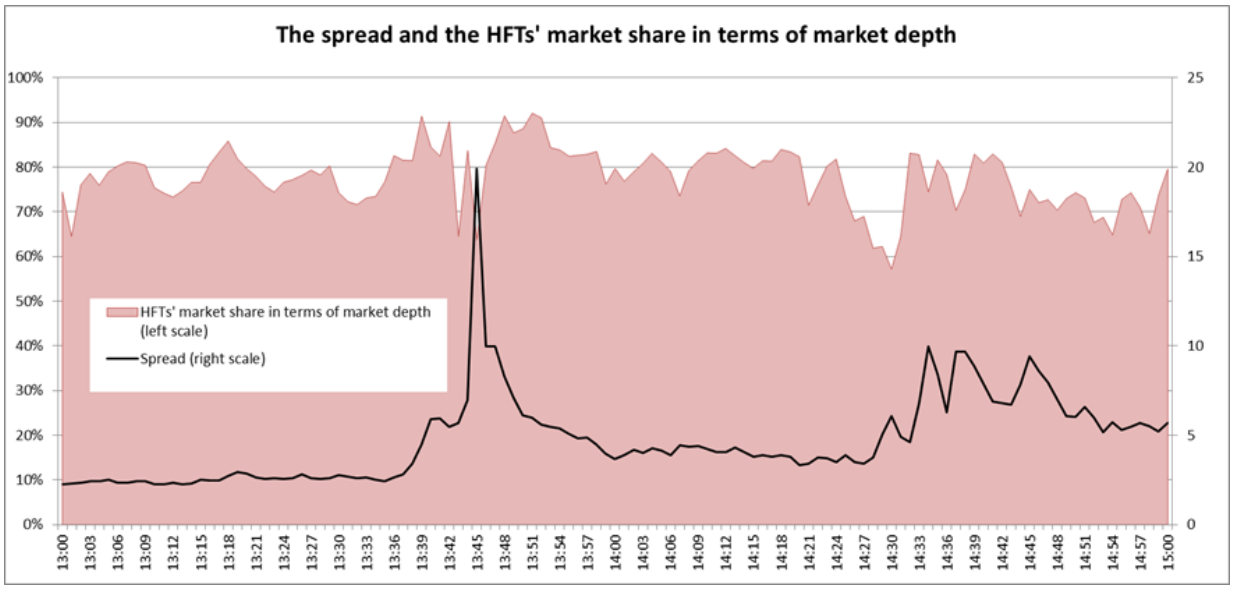

Figure 15: A few minutes before the announcements, spread widened after the withdrawal of passive orders by all participants and by HFTs in particular.

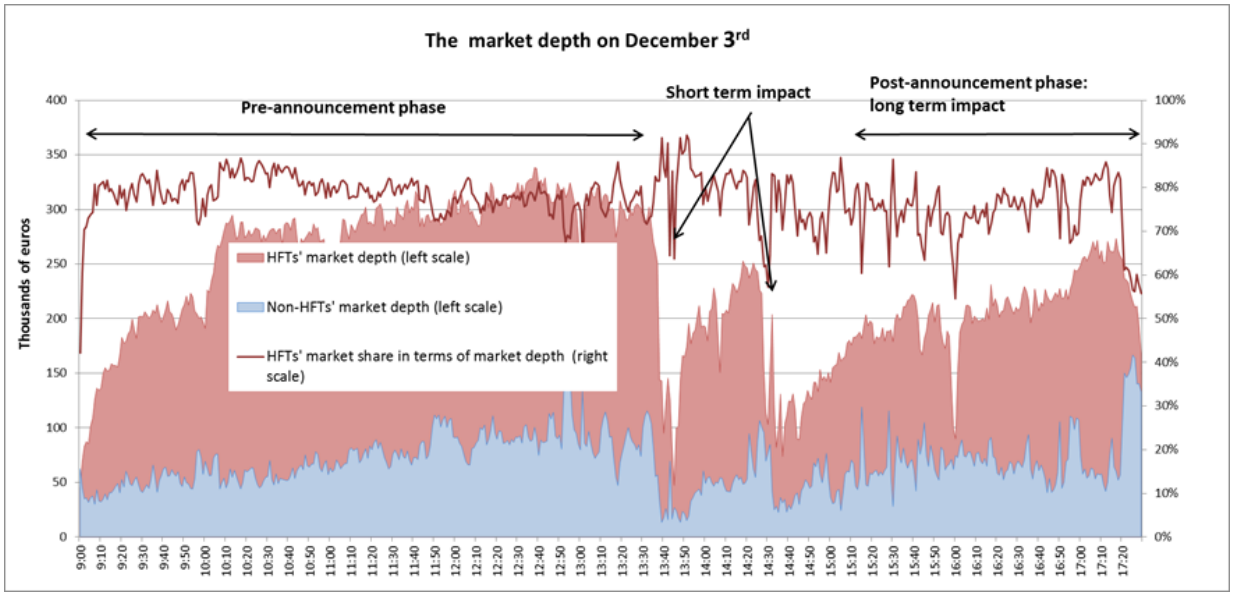

Figure 16: The December 3rd announcements had, first, a strong immediate impact: a very illiquid order book, with the share of HFTs in market depth terms falling from 82% to 57%. Second, they had a less significant long-term impact: a less liquid order book than in the pre-announcement phase, with the share of HFTs in market depth terms falling from 78% to 75%.

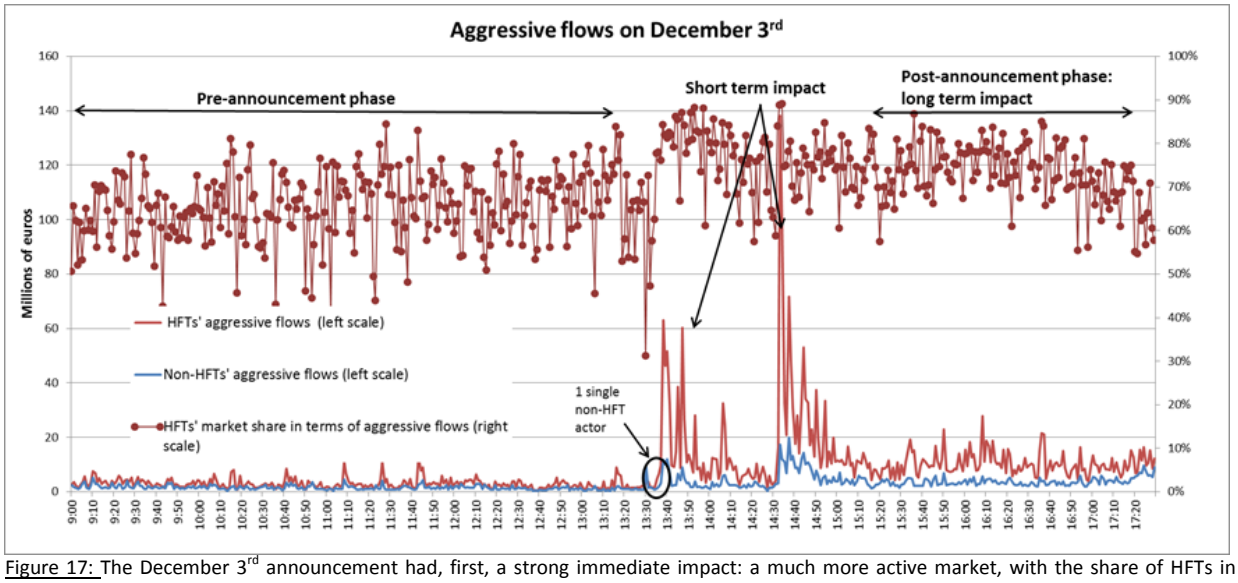

Figure 17: The December 3rd announcement had, first, a strong immediate impact: a much more active market, with the share of HFTs in aggressive trade terms increasing from 76% to 84%. Second, they had a less significant long-term impact: a more active market than in the pre-announcement phase, with HFTs share in aggressive trades terms increasing from 65% to 73%.

5.2.2. Long-term impact of the December 3rd announcements : pre-announcement phase versus post-announcement phase

The December 3rd announcements had a very strong impact on prices, which lasted throughout the day.

- After the announcements (after 2:30 p.m.), overall market depth offered at the three best price limits did not return to its initial level (it decreased from EUR 700,000 to EUR 450,000 on average) **and it was also the case for the HFTs' share of in market depth terms (from 77% to 75%, on average)** (Figure 18).
- Aggressive flows increased, leading to higher volumes despite a thinner order book: in the pre-announcement phase (before 1:38 p.m.), the amount traded on average per minute was EUR 4.6 million and HFTs represented 65% of aggressive flows; in the post-announcement phase, this amount tripled and HFTs represented 73% of aggressive orders, which led HFTs' market share to increase from 59% (pre-announcement phase) to 65% (post-announcement phase).
  It should be noted, however, that HFTs' aggressive/passive ratio was unaffected by these announcements because passive liquidity provision by HFTs increased simultaneously.

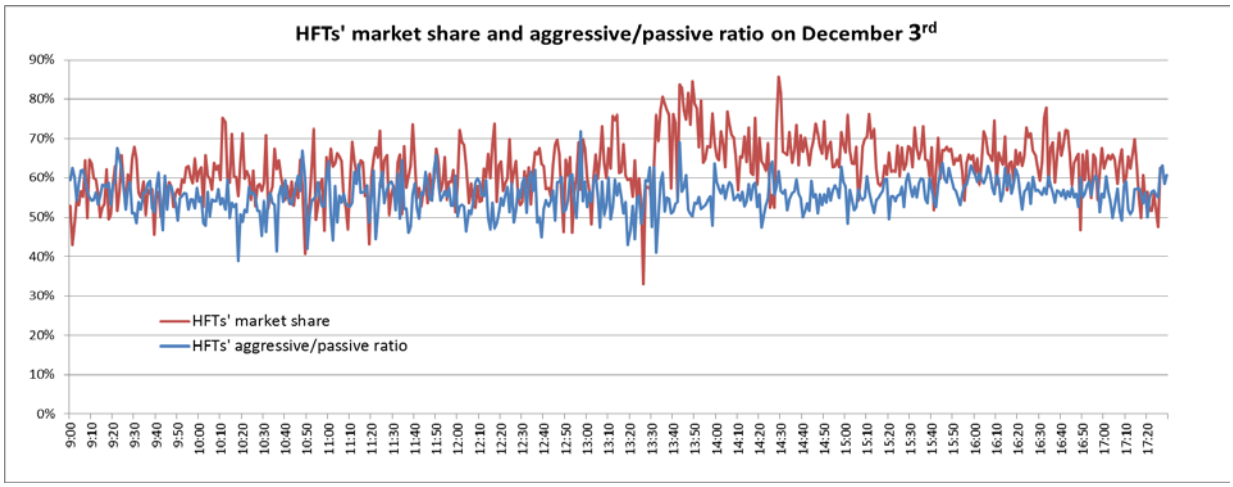

Figure 18: The December 3rd announcements had, first, a strong immediate impact on HFTs' market share, which rose significantly, and, second, a long-term impact, as HFTs market share remained high until the end of the day. In contrast, the aggressive/passive ratio was unaffected by these announcements.

December 3rd was marked by three announcements that had a strong impact on prices. The announcements were all accompanied by a significant withdrawal from the order book by all participants and by a sharp increase in volumes.

Contrary to the findings in the general case, the order book recovered slowly after each announcement, and it seems that certain participants (HFTs in particular) permanently withdrew their orders from the book in an overly volatile market environment.

Despite this sharp fall in HFTs' passive liquidity provision during this period of stress, these participants' market share in terms of amounts traded was particularly high during the announcement periods at close to 80% versus 60% on average.

6. FOCUS ON JUNE 24TH 2016 (BREXIT ANNOUNCEMENT)

6.1. THE DAY

On Friday, June 24th, the markets received word that the United Kingdom had decided to end 43 years of membership in the European Union (EU), causing the most volatile day over the period under study.

- Pre-Brexit: The Brexit referendum[34] was an eagerly awaited historic decision that had been expected by the market several days before the actual day of the vote (June 23rd). The days ahead of the vote results were characterised by high levels of market stress, starting in particular on June 7th. The markets saw wide price fluctuations and the indicator of implied volatility, the VCAC, began to increase from June 7th onwards (on that date, the VCAC stood at 21.73). It peaked at 36.41 on June 16th (a 71% increase in nine days). The day before the announcement, investors and analysts anticipated that the UK would vote to remain in the EU.
- June 24th, the day of the Brexit announcement: The official vote results were published in the early morning of June 24th, before the European markets opened. Contrary to expectations, UK citizens decided to leave the European Union (52% of the electorate voted for Brexit). This disappointment was immediately reflected in the market: in Paris, trading in 37 out of 40 stocks in the CAC 40 was halted at limit down at the open.

When the index finally opened, it was down 7.6%. It plunged by 8.04% to end the day at 4,106.73 points, after hitting a low of 4,007.97 points (-10.25%). In terms of amplitude and speed, this was one of the biggest market shocks since the 2008 crisis: it was the largest daily fall since October 2008.

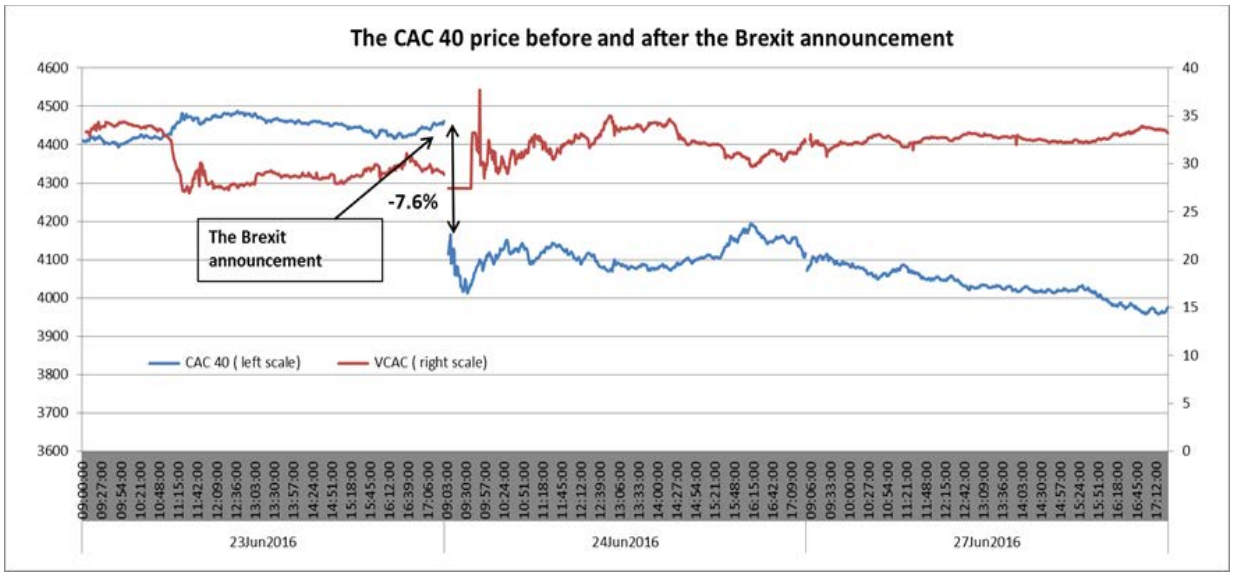

Figure 19: CAC 40 trend and in implied volatility for the three days surrounding the Brexit announcement.

- Post-Brexit: In the wake of the results announced on June 24th, the markets entered a period of uncertainty and instability that lasted until mid-summer.

[34] Citizens could vote either for Brexit, i.e. to leave the European Union, or against Brexit, i.e. to remain a member of the European Union.

6.2. BREXIT ANNOUNCEMENT IMPACT

As was the case on December 3rd, the market had not anticipated the Brexit announcement. However, it differs from the December 3rd in that the announcement occurred prior to the market opening. The Brexit announcement created a great deal of uncertainty before the markets opened, which moreover led to the trading halt of several CAC 40 stocks until 9:20 a.m.

The study is split into two main periods: the beginning of the day (until about 12:00 p.m.) cast uncertainty among market participants and saw very high levels of volatility – this marked a transitional period before the second phase of the day (after 12:00 p.m.), when the metrics measured stabilised.

6.2.1. Liquidity indicator analysis

June 24th was marked by significantly lower liquidity[35] (HFTs and non-HFTs alike) than in the two weeks prior to the announcement (reference period for which the stocks were adjusted relative to the day of June 24th[36]). At the beginning of the day, the uncertainty that followed the announcement led participants to sharply reduce their presence: total market depth offered was on average 45% lower than over the reference period. Liquidity then increased gradually during the day to stabilise 33% lower than over the reference period.

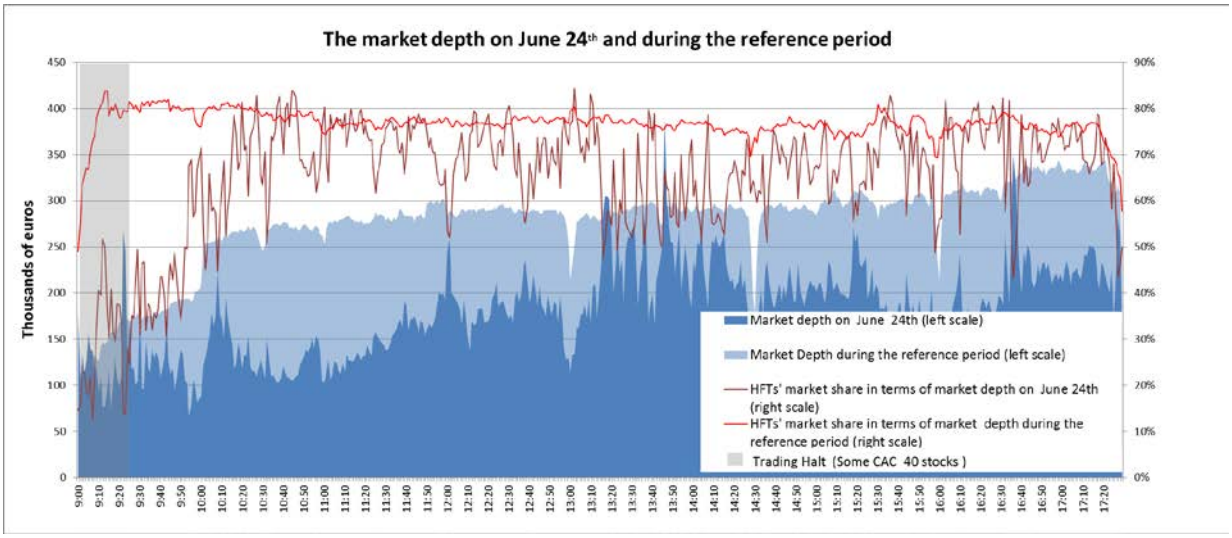

Figure 20: The order book was not as deep on June 24th and HFTs showed less of a presence than in the reference period, particularly at the beginning of the day.

[35] Measured as depth at the three best limits.

[36] The reference period selected runs from June 7th to June 23rd to allow for an unbiased comparison; the financial markets were stressed (rise in the VCAC) during this period, pending the outcome of the referendum: depth, spread, trading amounts and the aggressive/passive ratio are therefore comparable.
To be able to compare the metrics on June 24th with those in the reference period (depth and aggressive flows) without accounting for the impact of the price change, the metrics in the reference period were adjusted to that of June 24th taking into consideration the value of the CAC 40 on June 24th (i.e. *x0* a metric relative to the reference period: the adjusted value *x adjusted* = (*x0* * value of the CAC 40 on 24 June)/average value of the CAC 40 in the reference period).

On closer study, an analysis by participant category shows that, at the beginning of the day (transitional phase), HFTs and non-HFTs' behaviour contrasted markedly:

- HFTs reduced their presence significantly in the order book; market depth offered represented one-third of their usual market depth. This behaviour was predictable since such participants avoid placing passive orders during periods of uncertainty and when there is a high risk of price changes.
- Non-HFTs partially offset reduced liquidity by offering twice the size at best price limits. They thus supported liquidity without being able to fully offset the deficit caused by HFTs' withdrawal.

Over the course of the day, HFTs gradually re-entered the order book but it was only at 11:00 a.m. that their presence in the order book stabilised, albeit at a level far below their usual market share: they offered 40% less market depth than during normal periods and represented 67% of the order book compared with 76% during the reference period.

Non-HFTs withdrew to a lesser degree: they offered 22% less market depth than during normal periods and their market share increased to 33% of the order book compared with 24% over the reference period. **A detailed analysis of trades by non-HFTs shows that they in particular supported liquidity by fully executing very large size buy orders between 1:15 p.m. and 2:15 p.m.[37].**

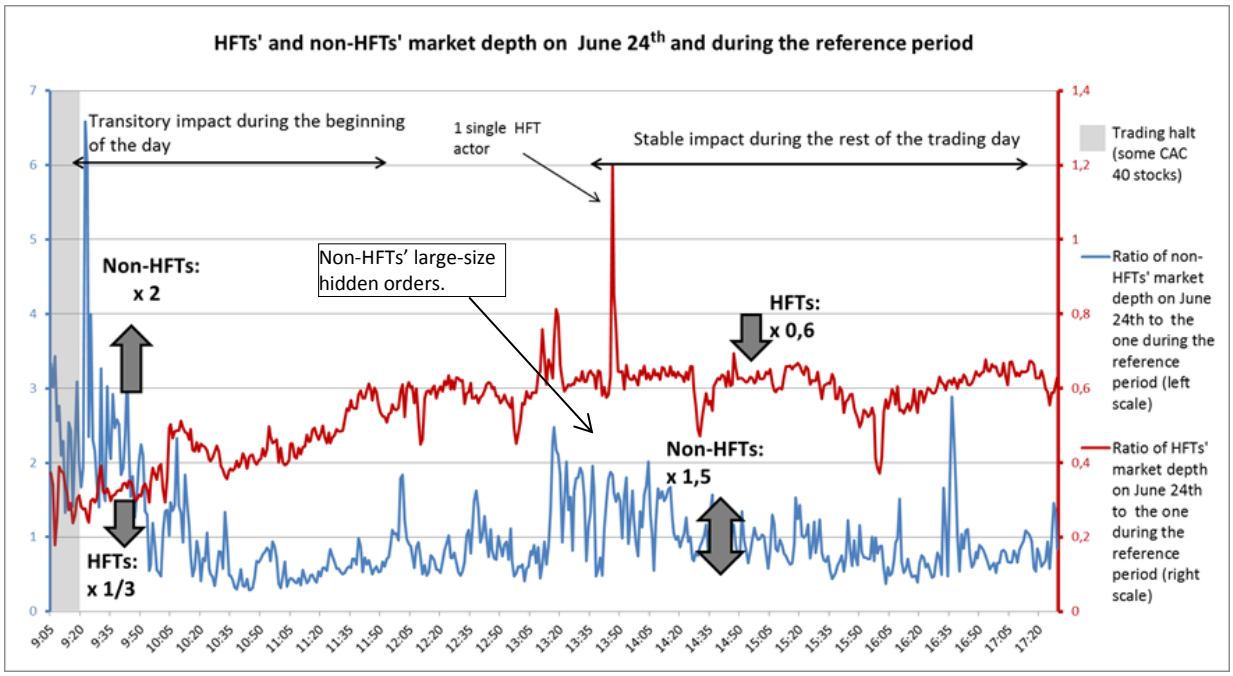

Figure 21: The metric used in this chart to compare the market depth of HFTs (or non-HFTs) on June 24th with their market depth during the reference period is the ratio[38] of the market depth of HFTs (or non-HFTs) on June 24th to the average market depth during the reference period.

[37] An analysis of the order book in periods when non-HFTs are very active shows the presence of very large sizes of best limit orders, whose quantities are often hidden, and are executed quickly. These orders show that non-HFTs' desire to trade supported the average liquidity on the securities during the session.

[38] Or the ratio x. If $x<1$, then depth on June 24th fell by $(1-x)$% relative to the reference period. And if $x>1$, then depth on June 24th increased by $(x-1)$% relative to the reference period.

Despite the very significant presence of non-HFTs at the beginning of the day, the spread was six times wider than in the weeks before the announcement. It gradually tightened, and stabilised at about 12:00 p.m. (in parallel with the stabilisation of the depth of HFTs in the order book) and remained 1.5 times wider than during the reference period.

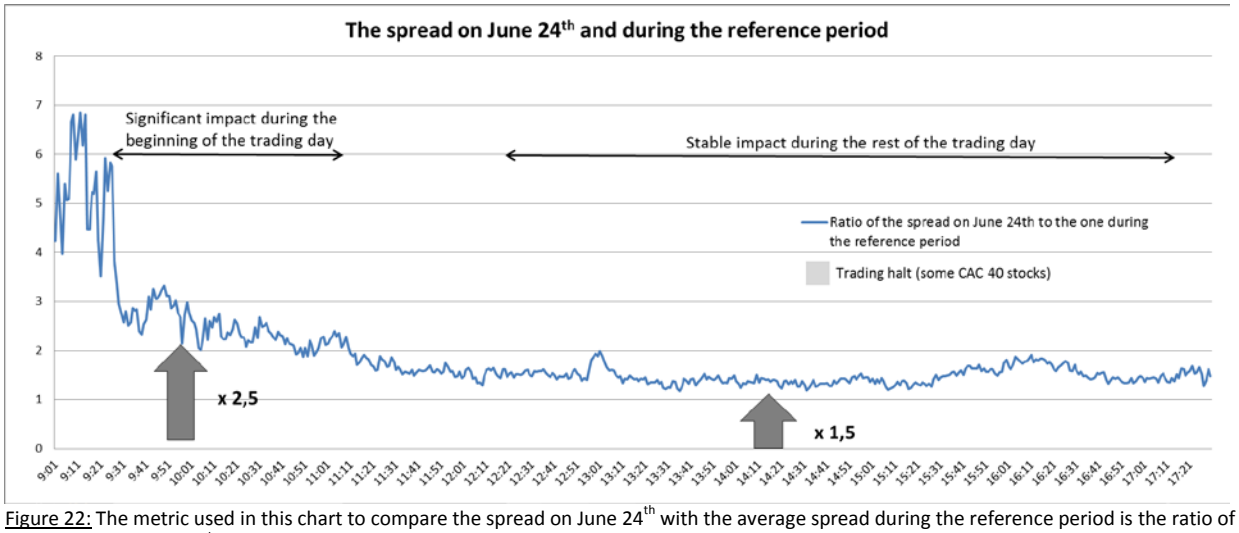

Figure 22: The metric used in this chart to compare the spread on June 24th with the average spread during the reference period is the ratio of the spread on June 24th to the spread during the reference period: the spread widened significantly at the beginning of the day, gradually decreased and then stabilised from 12:00 noon, while remaining wider than the spread during the reference period.

6.2.2. Amounts traded and aggressiveness

Throughout the day of June 24th, the market was much more active than during the reference period, despite low levels of order book liquidity.

At the very beginning of the day (until 9:40 a.m.), HFTs were less active on the market than during the reference period[39] (for example, at 9:22 a.m. their market share was 20% lower than during the reference period) and were more aggressive than during the reference period (for example, at 9:20 a.m. their aggressive/passive ratio was 30% higher than during the reference period). Overall, they consumed more liquidity than they provided.

After 9:40 a.m., the market share and aggressive/passive ratio of HFTs stabilised: HFTs were more active in the market (their average market share rose from 58% during the reference period to 63% on June 24th), and they were more aggressive than during the reference period (their aggressive/passive ratio rose from 52% during the reference period to 55% on June 24th).

Amounts traded fell gradually until midday: they were 5 times higher than during the reference period at the beginning of the day compared with 2.5 times for the rest of the day.

[39] Market share fell relative to the reference period because, first, non-HFTs increased their trades more sharply than HFTs and, second, fewer of the HFTs' limit orders were executed than for non-HFTs (the passive market share of HFTs decreased).

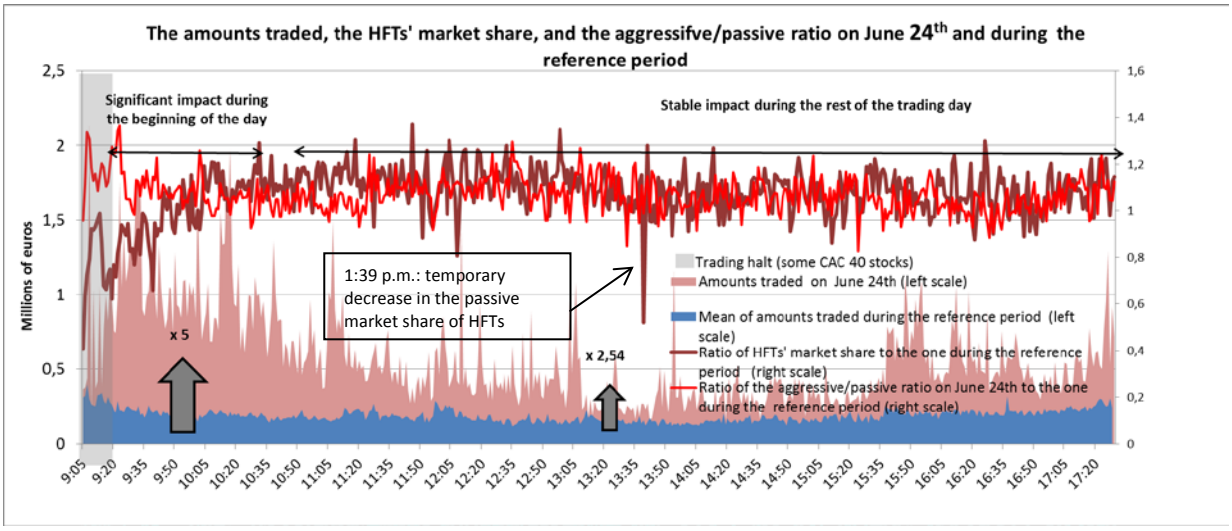

Figure 23: On June 24th, the market was more active, particularly at the beginning of the day. HFTs were somewhat more aggressive and their market share increased, except at the beginning of the day when they were particularly aggressive.

The day of June 24th was characterised by a particularly sharp downturn in the market quality: sharp widening of spreads and drop in the market depth at best limits in record-high amounts traded.

During this time of considerable uncertainty, HFTs sharply reduced their presence in the order book; their liquidity provision was 40% lower than usual. Large and fully executed orders offered by non-HFTs at best limits supported liquidity, in particular at the beginning and mid-session.

7. APPENDICES

7.1. APPENDIX 1 : EURONEXT'S SLP PROGRAM

Euronext's Supplemental Liquidity Provider (SLP) program aims at increasing liquidity on the most actively traded securities on Euronext Paris. Accordingly, Euronext imposes a market-making activity on program members, including order book presence time at competitive prices, in return for favourable pricing and rebates[40] in the form of a maker-taker model directly comparable to those of the major competing platforms.

To benefit from preferential prices, SLP program members use high-frequency market-making strategies to maintain a strong presence at best price limits. Their activity represents a large share of all estimated high-frequency activity on the securities involved in the program. Their activity is concentrated on the **continuous trading** phases for CAC 40 securities. SLPs' amounts traded at auction represent only 2.4% of their volumes, and only 4.7% of auction traded volumes. The analysis only considers continuous trading volumes. SLP members are pure HFTs or investment banks.

[40] https://euronext.com/info-flashes/revision-supplemental-liquidity-provider-programme.

7.2. APPENDIX : EXPECTED MARKET-MAKING ACTIVITY CHARACTERISTICS

Market-making activity consists mainly in providing liquidity to the market. For illiquid stocks, this activity can be vital as it provides a bid/ask price spread. For liquid stocks, market-makers help to tighten the bid/ask spread and to limit price spreads between different platforms.

Market-makers are therefore not meant to take directional positions on the market, they serve as intermediaries to help match supply and demand, and the length of time a position in a security is held is proportional to the size of the position and inversely proportional to the liquidity of the security. It could reasonably be expected that, as intermediaries, their market share would be **limited to 50% of amounts traded in the market**.

Inventory management is an important aspect of market-making. High-frequency market-makers are intermediaries that minimise inventory risk by holding positions for very short periods (only intraday):

- For a security whose price remains constant, in an evenly balanced market between buyers and sellers, a market-maker has no trouble managing its inventory, as its passive purchases are quickly offset by passive sales with an average gain equal to the spread.
- By contrast, for a security whose price remains constant in a market made up of buyers (or sellers) only, for a market-maker to manage its inventory, it passively sells (or buys) securities and must aggressively unwind them. Its average gain is therefore zero.

Market-makers' average gain is therefore estimated as equal to a half-spread for a security whose price is constant. It could therefore be expected that the **aggressive/passive ratio for these participants would not exceed 50%** (in a worst-case scenario in which the market consists only of buyers or sellers). The volatility risk occurs when the market-maker does not quickly unwind its position and the price suddenly changes. When the price fluctuates widely, the aggressive/passive ratio for these participants generally exceeds 50%, reflecting the transformation of their mean reversion strategies into directional (momentum) strategies.

In light of the above, a market-maker's gain is generally proportional to the spread, but inversely proportional to volatility (sharp price changes). **These participants could therefore be expected to suspend their market-making strategies in anticipation of large price moves (for example, at the time of expected announcements).**

Market-making activity is now conducted mainly by high-frequency traders on liquid stocks. These participants are in fact best able to offer effective inventory management in an increasingly fast-moving and fragmented market.

7.3. APPENDIX : HFT IDENTIFICATION CRITERIA

The AMF differentiates between three types of market participants in the order book: pure HFTs, mixed HFTs (investment banks with HFT activity) and non-HFTs. The classification is based on the lifetime of cancelled orders and is determined using two sets of criteria:

- **Through a comparison with other participants:** a participant is a pure HFT if the average lifetime of its cancelled orders is less than the average lifetime of all orders in the book and if it has cancelled at least 100,000 orders during the year.
- **With a set threshold:** the participant must have cancelled at least 500,000 orders with a lifetime of less than 0.1 second (i.e. the participant quickly updates the orders in the limit order book) and the top percentile of the lifetime of its cancelled orders must be less than 500 microseconds (i.e. the participant regularly uses fast access to the market).

A participant is a high-frequency trader if it meets one of these conditions; an investment bank meeting one of these conditions is described as mixed.

These two conditions reflect a balance between the method proposed by the CEMA HFT task force[41] in a report by ESMA in December 2014 on HFT activity and the method proposed for technical advice to the European Commission in December 2014 by the Task Force on Microstructural Issues (TFMSI).

The definition that will enter into force with MiFID II, i.e. 4 messages per second on average on Euronext or 2 messages per second on one stock, produces less accurate (generally false positive) results. Based on the AMF's estimates, it would currently classify at least the 25 most active members of Euronext as HFTs, representing more than 97% of Euronext's volume of orders (based on the rule of 4 messages per second on average on Euronext group).

[41] The CEMA HFT task force recently published the document *"Order duplication and liquidity measurement in EU equity markets"* in which a classification of HFTs is specified.

7.4. APPENDIX : IMPACT OF ANNOUNCEMENTS ON IMPLIED VOLATILITY

It should be noted that implied volatility also captures the expected risk of an announcement. After an expected announcement, the arrival of new information on the market automatically leads to a fall in implied (future) volatility. **The VCAC would therefore always tend to decrease after a planned announcement while historical volatility will increase if price is affected by the announcement.**

As an example, on December 3rd, the day on which the ECB was expected to make two announcements, the first at 1:45 p.m. and the second at 2:30 p.m., implied volatility fell after each announcement, and the sharp price change resulting from the ECB's announcement understandably led to a spike in historical volatility.

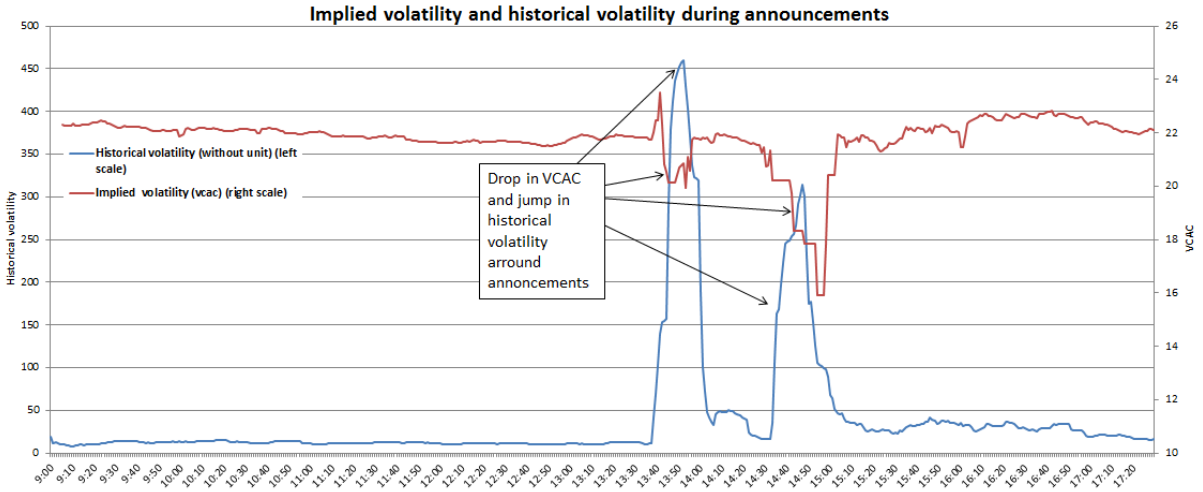

Figure 24: With an announcement that has a strong impact on price, historical volatility increases (significant price change) while implied volatility decreases (less uncertainty about the securities' future changes).

7.5. APPENDIX : COMPARING MARKET DEPTH METRICS

Market depth, as assessed by four different metrics, is illustrated below: three metrics associated with price limits and one associated with the spread relative to the mid-price (average price between best bid and best ask).

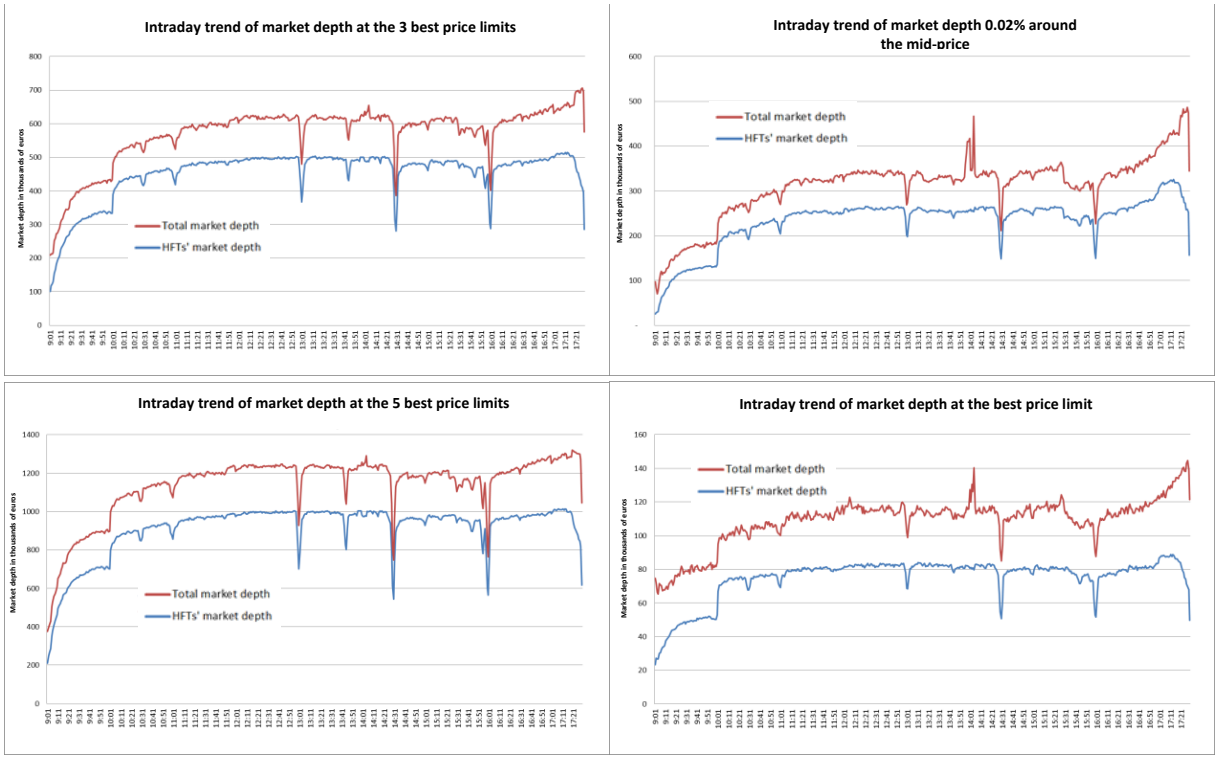

Figure 25: The four metrics are very similar. Market depth at best price limit is noisier (many small variations) while measures at the three and five best limits are more stable. The measure as a percent of the mid-price is fairly similar to the measures at the three and five best limits but accounts for the spread effects.

The metrics are very similar and therefore the choice of metric seems to have little impact on the paper's final conclusions. However, we have decided to focus on depth at the three best limits (as opposed to depth expressed as distance to the mid-price) as this measure does not account for spread. In particular, the measure of the order book's liquidity based on mid-price does not highlight the cause of the reduction in liquidity, notably whether it involves an increase in spread at constant depth or whether spread remains constant and the amounts at best limits decrease, or whether both metrics vary simultaneously.

However, this simultaneous change in both metrics is an important feature that should be highlighted. Moreover, in the analyses presented, spread and market depth are always emphasised to express a downturn or an upturn in market quality.

Lastly, we have decided to use the measure at the three best limits because it is less "noisy" (the curve is smoother) and its trend is representative of all the other curves.

7.6. APPENDIX : PRESENCE OF HFTS COMPARED WITH AMOUNTS TRADED

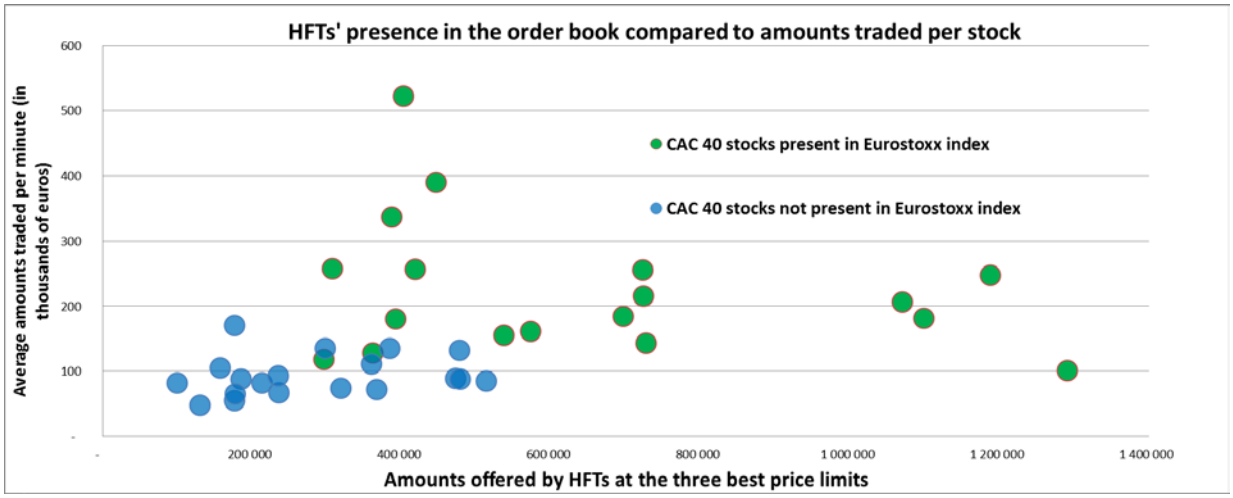

Figure 26: Scatter plot comparing depth offered by HFTs and average amounts traded in the securities. The depth offered is very closely correlated with activity on the securities (amounts traded).