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Coming Early to the Party

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Non-Technical Summary

In the past decade, High Frequency Traders (HFTs) have become dominant players in stock markets around the world and the object of robust debate as to whether they use their speed advantage to help or harm the fairness and efficiency of financial markets.

These issues have been investigated in the literature, mostly for the continuous trading phase, but have been ignored for the pre-opening phase and the opening auction. The common view is that HFTs usually do not participate to the pre-opening phase (i.e. do not “come early to the party”) given the absence of immediate execution and, hence, have a small chance of exploiting their speed advantage. In this paper, we provide empirical evidence on the strategic behaviour of HFTs in the context of the pre-opening phase of the NYSE-Euronext Paris Exchange, using data from the Base Européenne de Données Financières à HauteFréquence (BEDOFIH).

We find that HFTs come early to the party despite the absence of immediate execution. The majority of HFTs start to quote actively after 8.30 a.m. on each trading day, i.e., well before the 9.00 a.m. opening auction. We believe that this behaviour indicates their desire to observe and learn from the pre-opening order flow before making their order submission decisions, with the timing being dictated by different factors: right after the morning calls of the large brokerage firms, the opening time of equity derivatives markets (e.g. Eurex), the information flow from news providers, (e.g. Reuters or Bloomberg), and shortly after earnings announcements and French macroeconomic news announcements, which are usually released after 8:00 a.m.

Essentially, HFTs start posting orders to exploit the time priority option as soon as a large amount of information arrives in the market. Interestingly, HFTs post many orders in the pre-opening phase that are highly unlikely to be executed in the opening auction under NYSE-Euronext Paris regulations. We refer to these orders as “flash-crash orders” and the purpose of these orders is “fishing”, i.e., gaining time priority on orders that would be triggered only under extreme market movements, such as the “Flash Crash” in the US market on May 6, 2010.

Therefore, they come early to the party to (i) acquire information during the pre-opening phase, (ii) benefit from the priority option for “flash crash” orders, and (iii) benefit from the priority option in the opening auction.

Our results are likely to be of interest to stock exchanges, regulators and investment management professionals. Broadly speaking, levelling the playing field across market participants is a common objective for all these constituencies, being of utmost relevance for fair investment management practices. Further, the practice of posting a whole schedule of flash crash orders raises questions regarding potential adverse effects for stability of the market (even though it has not happen so far).

Market quality: As a group, HFTs neither improve nor harm liquidity provision in the opening auction and consistently lead the price discovery process throughout the pre-opening phase. Our findings are important for designing proper opening mechanisms in the presence of HFT

participation. For example, due to the rebate scheme provided by NYSE-Euronext only for activity carried out using the market-maker flag in the main trading phase, the presence of liquidity providers in the opening auction is marginal.

Market fairness: We document similar profit patterns for HFTs and NON-HFTs alike, suggesting that speed is not a necessary condition to make profits, at least in the context of the fixed time of the opening auction. In fact, both HFTs and NON-HFTs do have an information advantage that allows them to significantly contribute to price discovery and to make profits. The key difference is that HFTs extract information from the order flow, while NON-HFTs possess mostly fundamental information.

In summary, HFTs do behave strategically by posting and cancelling orders to extract information and make profits or by posting “flash crash orders” to benefit of the priority option, however, HFTs do not have special privileges by virtue of their speed advantage, relative to other market participants.

Coming Early to the Party

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ABSTRACT

We examine the strategic behavior of High Frequency Traders (HFTs) during the pre-opening phase and the opening auction of the NYSE-Euronext Paris exchange. HFTs actively participate, and profitably extract information from the order flow. They also post "flash crash" orders, to gain time priority. They make profits on their last-second orders; however, so do others, suggesting that there is no speed advantage. HFTs lead price discovery, and neither harm nor improve liquidity. They "come early to the party", and enjoy it (make profits); however, they also help others enjoy the party(improve market quality) and do not have privileges (their speed advantage is not crucial).

JEL classification: G12, G14.

Key-words: High-Frequency Traders (HFTs), Proprietary Trading, Opening Auction, Liquidity Provision, Price Discovery.

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"The U.S. stock market [is] now a class system, rooted in speed, of haves and have-nots. The haves paid for nanoseconds; the have-nots [have] no idea that a nanosecond [has] value. The haves enjoyed a perfect view of the market; the have-nots never saw the market at all. What had once been the world's most public, most democratic, financial market had become, in spirit, something more like a private viewing of a stolen work of art," – Lewis (2014)

High Frequency Traders (HFTs) have become dominant players in stock markets around the world and the object of robust debate, in recent years. Some popular writers like Lewis (2014) claim that HFTs disrupt the structure of global financial markets, affecting their fairness and efficiency. Others, especially in the academic literature, take a more nuanced view. It is shown in that literature that HFTs execute a variety of strategies and perform multiple roles in their order placement/cancellation and trading actions. In performing their multifarious roles, HFTs can, on occasion, potentially use their superior trading speed to consume liquidity and gain a trading advantage over other traders using their own account while, at other times, acting as endogenous liquidity providers, or even as designated market makers. In these various roles and strategy types, HFTs may also contribute to price discovery. Contrary to the suggestion of Lewis (2014), these findings suggest that HFT activity may, in principle, be beneficial for other agents in the market, since the latter gain immediacy of execution and, also, enjoy more informative prices. In other words, HFT activity may facilitate the efficient allocation of resources – an important function of financial markets. Hence, any overall assessment of the impact of HFTs on market quality, ameliorative or deleterious, and the design of regulatory actions to modulate their behavior has, of necessity, to rely on an analysis of the relative importance of these multiple roles. These issues have been investigated in the literature, mostly for the continuous trading phase, but have been overlooked in the pre-opening phase and the opening auction setup in major stock exchanges.

In this paper, we aim to fill this gap in the context of the pre-opening phase of the NYSE-Euronext Paris Exchange, and investigate the question of whether and why HFTs come "early to the party," rather than just start to post orders at the very beginning of the main trading phase. Further, we also aim to investigate whether, and to what extent, HFTs contribute to price discovery and liquidity provision during the période d'accumulation des ordres or the

phase de pré-ouverture (the pre-opening phase or order accumulation period), and the fixing d'ouverture (opening auction) versus the phase principale de négociation en continu (main trading phase), taking into account the different roles they play and the strategies they employ.

NYSE-Euronext is the fifth largest stock exchange group in the world in terms of listed market capitalization, as of April 2013, according to the World Federation of Exchanges, and the first among the stock exchanges in continental Europe. Besides, NYSE-Euronext Paris recognizes and facilitates the active participation of HFTs acting in various capacities: for their own account, as market makers, and on behalf of clients.[1] The major exchanges around the globe, have rules for the pre-opening phase and the opening auction, similar to those of NYSE-Euronext Paris. In particular, a striking feature of the pre-opening phase in most exchanges is the absence of immediate execution during the order accumulation phase.[2]

Our analysis is based on data from the Base Européenne de Données Financières à Haute Fréquence (BEDOFIH) for the NYSE-Euronext Paris exchange, which explicitly defines three trader categories: HFT, MIXED, and NON-HFT. HFTs are pure-play HFT firms, e.g., Citadel, and MIXED firms are investment banks with HFT activity, e.g., Goldman Sachs. The remaining traders are classified as NON-HFT. From now on, we refer to pure-play HFTs as PURE-HFTs and MIXED traders as MIXED-HFTs, to make this distinction explicit.

BEDOFIH also categorizes the different types of orders and trades placed by the various types of traders according to the type of account: some orders/trades are for the traders' own (proprietary) account (OWN), while others are on behalf of their clients (CLIENT), or for the purpose of liquidity provision by the traders as market makers (MM), using only their proprietary funds. Hence, in order to analyze the impact of a quote or trade, it is necessary to define *both* dimensions of a particular quote or trade: trader type and account type. Our analysis of the data from NYSE-Euronext Paris is explicitly based on this two-dimensional

[1] HFTs account for roughly 44% of quoting activity, and about 23% of trading activity, in our sample. Our numbers are roughly in line with those in a study by the European Securities and Markets Authority (ESMA), ESMA (2014), which estimates orders and trades with a HFT flag on NYSE-Euronext Paris at 50% and 21% respectively, of overall quoting and trading activity.

[2] Among other exchanges, Toronto Stock Exchange, Deutsche Bourse (Xetra), Tokyo Stock Exchange and London Stock Exchange all have similar rules for the pre-opening phase, when they do not allow the execution of the orders. Thus, our results may potentially also apply to other exchanges.

characterization of quoting and trading activity.

Our paper focuses on the resultant effects of the different roles played by HFTs during the pre-opening phase and the opening auction, in conjunction with the initial part of the main trading phase. Several questions arise relating to the broad issue we study in this paper: First, do HFTs "come early to the party," and if so, in what capacity, and why? Second, do HFTs benefit from such a presence by making a profit overall on these early orders, i.e., do they "enjoy the party?" Third, do they create any positive externality that benefits others (the rest of the market) by their coming early to the party, i.e., do they help other participants enjoy the party as well? Fourth, how do HFTs behave later on, when "everyone joins the party" during the main trading session? To answer these questions, we examine three distinct trading periods: the pre-opening phase, the opening auction and the first 30 minutes of the main trading phase.

Our main conclusions are fairly robust to a variety of empirical specifications and methodologies. We find that PURE-HFTs do indeed come early to the party, but not from the very beginning of the order accumulation period. Contrary to our expectation, given the absence of immediate execution, HFTs (both PURE and MIXED) are the main participants in the pre-opening phase and the opening auction. Interestingly, HFT participation in the pre-opening phase and the opening auction is carried out mainly via their OWN accounts, with their activity on their MM accounts being of marginal importance. One potential explanation for this behavior is that NYSE-Euronext Paris encourages liquidity provision by designated market makers only during the main trading phase, and so there is no reason for traders to mark orders with the market maker flag in the pre-opening phase.

The majority of HFTs start their quoting actively after 8.30 a.m. each trading day, i.e., well before the 9.00 a.m. opening auction We believe that this behavior indicates their desire to observe and learn from the pre-opening order flow before making their order submission decisions, with the timing being dictated by that of the "morning calls" of the large brokerage firms.[3] Interestingly, HFTs post many orders in the pre-opening phase that are unlikely to

[3]This conjecture is based on information we received from a few (anonymous) high-frequency traders. Other explanations include the fact that several equity derivatives markets open around 8.30 a.m. Furthermore, French companies usually disclose their earnings around 8.00 a.m. and news providers, like Reuters, release their broker analysis of such corporate announcements around 8.30 a.m.

be executed in the opening auction under NYSE-Euronext Paris regulations. The purpose of these orders is "fishing", i.e., gaining time priority on orders that would be triggered only under extreme market movements, such as the "Flash Crash" in the US market on May 6, 2010. Therefore, they come early to the party to (i) acquire information during the pre-opening phase, (ii) benefit from the priority option for "flash crash" orders in the main trading phase, and (iii) benefit from the priority option in the opening auction.

It is important to stress that the order flow and the theoretical opening price could be observed even without actively participating in the pre-opening phase by posting orders. However, submitting, modifying and cancelling orders during the pre-opening phase (beyond just observing the order flow) is crucial in order to learn about the marginal impact of an individual order on the theoretical opening price. The advantage of participating is twofold. First, traders can learn about the response of the aggregated market system to their orders, as reflected in the theoretical opening price (including "pinging" hidden quantities sitting in the limit order book). Second, traders can affect the theoretical opening price in response to new information that is constantly arriving in the market, either from news providers or from other market participants. Given the large number of order submissions and cancellations by HFTs during the pre-opening phase, it seems likely that HFTs are indeed exploiting these two advantages of participating in the pre-opening phase.

We next examine whether HFTs profit from their speed advantage in the pre-opening phase. We find that HFTs generally make profits on executed orders submitted in the very last minute of the pre-opening phase, and make losses on other orders (assuming that the position is liquidated at the market price one minute after the auction). Moreover, zooming into the last second of the pre-opening phase, we document that HFTs' cumulative profit increases consistently with time over this last second. Surprisingly, we also observe similar cumulative profit patterns for NON-HFT-OWN.

The similar potential profit patterns of HFTs and NON-HFTs might stem from two different sources. First, the superior fundamental information possessed by at least some NON-HFTs may outweigh the speed advantage and ability to extract information from the order flow

inherent to HFTs. The only way for HFTs to benefit from their speed advantage is if there is important information arriving in the market in the very last moment before the opening auction when NON-HFTs cannot take such a speedy action. However, the likelihood of such information arriving is very small, and in most cases, incremental information observed by HFTs in the very last moment before the opening auction may be of marginal importance. Second, the fixed timing of the opening auction (9.00 a.m. sharp) allows even slow traders to check the theoretical opening price a few seconds before the opening auction, even without the capacity for fast trading, and make their order submission decisions.

However, we acknowledge, that speed becomes important when traders liquidate positions taken in the opening auction, since during the main trading phase, only the fastest market participants can obtain the best execution terms, although this latter consideration is beyond of the scope of our analysis. We also acknowledge that some market participants might follow long-term strategies which may still be profitable over longer horizons, which we do not examine here, given our focus on short-term trading strategies.

To investigate whether HFTs perform any useful "social role," we analyze whether HFTs contribute to price discovery during the pre-opening phase, and to liquidity provision in the opening auction, as a side effect of their trading strategies. We find that HFTs, as a group, lead price discovery consistently throughout the pre-opening phase. We also document that proprietary traders, HFTs and NON-HFTs alike, are the main contributors to the price discovery process in the pre-opening phase. Moreover, a quarter of the residual price discovery in the last second is carried out by NON-HFTs. This evidence is consistent with our profit analysis and suggests that both HFTs and NON-HFTs that submit orders in the last second are informed traders. Further, we find that HFTs, as a group, do neither harm nor improve liquidity provision in the opening auction, assuming that traders provide liquidity, if they trade against the overnight market movement. All in all, our results suggest, that the presence of HFTs does not deteriorate market quality in the pre-opening phase in terms of liquidity provision, and substantially contributes to the price discovery process.

The outline of the paper is as follows. In Section 2, we review the academic literature on HFT

activity, mostly in the main trading phase, and price discovery and liquidity provision during the pre-opening phase and the opening auction, mostly from the pre-HFT era. In Section 3, we present our research issues in detail and also state the specific hypotheses we test in the paper. In Section 4, we describe the institutional structure of trading on NYSE-Euronext Paris, and the order and trade data we examine. We present our research methodology and our empirical results in Section 5. We conclude in Section 6.

I. Literature review

The literature on HFTs is relatively new and is well summarized in the following review papers: Chordia, Goyal, Lehmann, and Saar (2013), Jones (2013), Biais and Foucault (2014), O'Hara (2015), and Menkveld (2016). In our review, we will focus, therefore, only on the aspects of this broad literature, which are closely related to our research in this paper. Our study is related to two different strands of this literature: the effect of HFTs on market quality, broadly defined, and the role of HFTs in the pre-opening phase. We discuss each of these issues in detail below.

First, our study contributes to the literature on the impact of HFTs on market quality. The accumulated evidence provided by these various studies suggests that HFTs form a very heterogeneous group of traders and, as part of their strategies, they might contribute both positively or negatively to market quality, depending on the context.[4] This is in contrast to the popular, consistently negative view presented by Lewis (2014). There are two aspects to market quality: the speed and accuracy of price discovery and market liquidity. There is considerable research on both aspects of market quality in the context of HFT activity, which we review next.

The previous literature shows that HFTs aid price discovery, as they are typically better informed than other market participants. HFTs are able to collect information from multiple

[4]This literature is vast, including, among others, Hendershott, Jones, and Menkveld (2011), Easley, de Prado, and O'Hara (2012), Hagströmer and Norden (2013), Hendershott and Riordan (2013), Malinova, Park, and Riordan (2013), Menkveld (2013), Brogaard, Hendershott, and Riordan (2014), Brogaard, Hagströmer, Norden, and Riordan (2015), Baron, Brogaard, Hagströmer, and Kirilenko (2016), Biais, Declerck, and Moinas (2016), Korajczyk and Murphy (2016), and Kirilenko, Kyle, Samadi, and Tuzun (2017).

sources: directly from the order flow of multiple securities and multiple markets, but also from news feeds, social networks, historical data, etc., reacting fast when the market moves in a favorable way.[5] Given that these informational and speed advantages may seem unfair to other market participants, Budish, Cramton, and Shim (2015) suggest that a different market design, namely, frequent batch auctions, might attenuate these advantages. They argue that the speed advantage of the HFTs is marginal in the context of frequent batch auctions; however, it still pays off, if the new information arrives very close to the auction. Since we are looking at the behavior of HFTs, before and during the opening call auction, our paper sheds some light on this issue as well, even though it is not the main purpose of the paper, and our context is somewhat different, admittedly.

Liquidity is the other important aspect of market quality. Menkveld and Zoican (2016) provide a theoretical framework to characterize the duel between opportunistic and non-opportunistic HFTs, and conclude that the resulting effect on the liquidity provision depends on which group of HFTs dominates the market, while Hagströmer and Norden (2013) and Benos and Sagade (2016) provide empirical evidence on this issue. Besides, Brogaard, Hendershott, and Riordan (2014) and Brogaard, Riordan, Shkilko, and Sokolov (2014) show that in the main trading phase, HFTs trade against transitory (extreme) price movements, while Van Kervel and Menkveld (2016) and Korajczyk and Murphy (2016) show that HFTs also trade in the opposite direction of the large institutional orders, at the time of their initiation. In our paper, we investigate whether HFT trading activity in the opening auction amplifies or dampens overnight price movements, and find that HFTs as a group neither exacerbate nor moderate overnight price movements.

However, it is important to underscore that the existing literature focuses almost exclusively on the role of HFTs in the main trading phase only, thus excluding the pre-opening phase and the opening auction from the analysis. In our current paper, we shed light on this missing link, contributing to the literature by focusing on the pre-opening phase and the opening auction,

[5]For a theoretical justification, see Foucault, Hombert, and Roşu (2016), Cespa and Foucault (2011), and Gerig and Michayluk (2014); for empirical evidence, see Hendershott and Riordan (2013), Brogaard, Hendershott, and Riordan (2014), and Hu, Pan, and Wang (2016).

while contrasting the behavior of HFTs in these phases with the main trading phase. We also find that there is a considerable difference between the impact of HFTs on market quality in the pre-opening phase as opposed to the first 30 minutes of the main trading phase, conditional on the role they play.

Second, our work is also related to the earlier literature on the pre-opening phase and opening auction in the financial markets. Price discovery in the pre-opening phase has been extensively studied prior to the emergence of HFTs.[6] Cao, Ghysels, and Hatheway (2000), Ciccotello and Hatheway (2000), and Barclay and Hendershott (2003) investigate the price discovery mechanism in the pre-opening phase of NASDAQ. However, there are several important differences between the pre-opening phase in NASDAQ and NYSE-Euronext Paris. In particular, NASDAQ is a dealer market (not a limit order book market) on which dealers might enter non-binding, crossed or locked quotes to signal the direction of the price movement. Equally importantly, the NASDAQ interdealer market is open for order execution, whereas there is no order execution during the pre-opening phase in the case of NYSE-Euronext Paris. Biais, Hillion, and Spatt (1999) and Davies (2003) investigate the pre-opening phase in NYSE-Euronext Paris and Toronto Stock Exchange, respectively, with both these markets sharing similar pre-opening mechanisms. These papers, thus, find that the majority of quoting activity occurs as close as possible to the opening auction, which naturally leads to the fact that prices are typically noisy in the beginning of the pre-opening phase, and gradually reflect more information towards the end of the pre-opening phase. The important difference between the two papers is that Davies (2003) focuses on the behavior of designated market makers in the pre-opening phase, while Biais, Hillion, and Spatt (1999) do not distinguish between different types of market participants. In contrast, we differentiate our paper from these prior studies because (i) we analyze the behavior of HFTs in the pre-opening phase, and (ii) we find that the majority of quoting activity of HFTs does *not* occur close to the opening auction. Besides these empirical studies, Medrano and Vives (2001) develop a theoretical model of the strategic

[6] E.g., Amihud and Mendelson (1991), Biais, Hillion, and Spatt (1999), Cao, Ghysels, and Hatheway (2000), Ciccotello and Hatheway (2000), Madhavan and Panchapagesan (2000), Barclay and Hendershott (2003), and Davies (2003).

behavior of informed traders in the pre-opening phase, which suggests that in the presence of other informed traders, strategic traders intentionally manipulate prices (in order to keep them uninformative) by entering large orders in the beginning of the pre-opening phase and cancelling them right before the auction.

It is noteworthy that there are almost no existing studies that examine the actions of HFTs in the pre-opening phase and opening auction, except Bellia, Pelizzon, Subrahmanyam, Uno, and Yuferova (2016), Anagnostidis, Fontaine, and Varsakelis (2017), and Boussetta, Lescourret, and Moinas (2017). Bellia, Pelizzon, Subrahmanyam, Uno, and Yuferova (2016) analyze the role of HFTs in the pre-opening phase of the Tokyo Stock Exchange. However, this prior study does not have either the HFT identification provided and monitored by the regulators, or the role flag relating to whether they are acting as designated market makers, proprietary traders, or traders who act on behalf of their clients. Moreover, Bellia, Pelizzon, Subrahmanyam, Uno, and Yuferova (2016) do not investigate the reasons for HFTs to come early to the party. Two other papers using data from the same source, Anagnostidis, Fontaine, and Varsakelis (2017) and Boussetta, Lescourret, and Moinas (2017), have an entirely different objective relative to this current paper, as they focus solely on the role of price discovery by HFTs in the pre-opening phase. Anagnostidis, Fontaine, and Varsakelis (2017) develop a theoretical model for HFT and NON-HFT participation in the pre-opening phase and show that order placement activity by HFTs, who possess more precise information than NON-HFTs, increase price efficiency. However, when they act strategically (in order to conceal their information advantage), price efficiency might deteriorate, and improve only close to the opening auction. Empirical evidence in their paper is in line with our results in this study, and suggests that HFTs lead price discovery. Boussetta, Lescourret, and Moinas (2017) study price discovery in the context of fragmented markets, and find that the pre-opening activity of slow brokers is strongly related to the price discovery process across trading venues. Both these papers use the same dataset (BEDOFIH) as we employ in this paper and, thus, also have access to the exogenous HFT classification and the role flag.[7] The other more recent paper on the opening (and intraday)

[7]Our paper and the one of Boussetta, Lescourret, and Moinas (2017) are the outcomes of two of the three projects selected by EUROFIDAI, to whom EUROFIDAI provides free access to the BEDOFIH data, in addition

call auction is Theissen and Westheide (2016) who investigate the role of designated market makers during auctions on the Deutsche Bourse (Xetra), and find that they contribute to price stabilization. However, they do not investigate the strategic behavior of the traders during the pre-opening phase, and do not distinguish between PURE-HFT-MM and the other designated market makers.

We contribute to this stream of literature by focusing on the strategic behavior of HFTs wearing different "hats", and contrast their behavior with that of designated market makers (which has been examined earlier in the literature), with a focus on the pre-opening phase and the opening auction. We show that the previous results on the pre-opening phase are different from those we highlight in this paper, which is focused on HFT behavior. First, we confirm that the majority of trading activity (including HFT activity) does not occur at the end of pre-opening phase; in contrast, the most active period is around 8.30 a.m. on each trading day. Second, we show that HFTs participate in the pre-opening phase using their OWN accounts, and not with accounts used for designated market making. Third, we show that HFTs, as a group, lead the price discovery process; however, as a group, they do not moderate, nor do they exacerbate overnight market movements. Fourth, we document that executed orders entered at the end of the pre-opening phase are more profitable than those entered in the beginning of the pre-opening phase, no matter which trader/account category they belong to, i.e., these profits are not unique to HFT traders.

To summarize, our study contributes to the HFT literature by analyzing the behavior of the different types of HFTs in the pre-opening phase, the opening auction and the main trading phase, and comparing this behavior to that of other traders in these periods. We also study the impact of HFT activity during the pre-opening phase on trading profitability, as well as its consequences for price discovery and liquidity provision, and provide evidence that HFT behavior during NYSE-Euronext Paris pre-opening phase is different from what has been previously highlighted in the literature.

to financial support.

II. Research issues and hypotheses

Since the publication of "Flash Boys" by Michael Lewis (Lewis (2014)), there has been a discussion in the financial press and the popular literature about the role of HFT activity in global equity markets. Lewis suggests that HFTs use their speed advantage unfairly and profit from it with adverse consequences for other market participants, as indicated in the quote at the beginning of the paper. In addition, Lewis (2014) states, ""Liquidity" was one of those words Wall Street people threw around... A lot of people used it as a synonym for "activity" or "volume of trading," but it obviously needed to mean more than that, as activity could be manufactured in a market simply by adding more front-runners to it." Our analysis in this paper tests the veracity of these assertions with actual data and provides evidence-based conclusions on the complex issues surrounding HFTs activity during the pre-opening phase. (There are several other papers – see our review of the literature – that investigate similar issues in the main trading phase.)

The primary objective of our paper is to study whether HFTs come early to the party and actively participate in the pre-opening phase, even in the absence of immediate execution, and if so, what benefits they obtain from such participation. In particular, we aim to analyze the benefits, as measured by trading profits, which HFTs derive from their trading speed, in placing, modifying and cancelling their orders until the very last millisecond before the opening auction. In this connection, we also examine the incentives of other NON-HFT traders to participate in the pre-opening phase. Our secondary objective is to investigate how the presence of HFTs and, specifically, their superior trading speed, contributes to price discovery during the pre-opening phase, and liquidity provision in the auction that follows.[8] A related issue is price manipulation, as defined by the market regulator, Autorité des Marchés Financiers (AMF).[9]

[8] A previous paper has investigated a similar issue using data from the Tokyo Stock Exchange (Bellia, Pelizzon, Subrahmanyam, Uno, and Yuferova (2016)). However, TSE data do not provide details of the account type of quotes and trades. Therefore, in that case, the purpose of order submission cannot be analyzed explicitly, but can only be inferred, using statistical methods. Thanks to the detailed classifications provided by the BEDOFIH dataset for NYSE-Euronext Paris, we are able to investigate, at a granular level, which subgroups of HFTs participate and contribute to liquidity provision during the opening auction.

[9] In their document on "Joint Guidance on Auction Manipulation," (AMF (2010)), the AMF, the French security market regulator, together with the regulators of Belgium, Portugal and the Netherlands, defines market

However, our data are not granular enough to allow us to track *individual* traders, and therefore, we defer the question of whether HFTs manipulate auction prices to future research.

As previously mentioned, we consider three periods of the trading day in our analysis: the pre-opening phase, the opening auction and the first 30 minutes of the main trading phase. The third period helps us to disentangle differences across the various types of traders from those arising due to the different trading phases. During the pre-opening phase, HFTs (as do all the other traders) have the flexibility to (i) exploit time priority, (ii) time their order placement, as well as (iii) enter subsequent modifications and cancellations. This flexibility can be thought of as a compound American option, with multiple optionalities – to place the order, to modify it in terms of price and quantity, as well as to cancel it. Such an option is essentially a nested option, first to place the order, and then to modify or cancel the order, given that it was placed. In other words, it is an option on an option. In our first hypothesis, we investigate whether HFTs make use of this optionality, and use their speed advantage to do so. Hence, the null hypothesis that we test is that HFTs delay their order submission/cancellation decision as close as possible to the opening auction, in line with the usual intuition about the early exercise of American options. The previous literature provides evidence that this was the typical behavior for market participants before the emergence of HFTs.[10] However, we aim to test this hypothesis again because there could be several reasons, especially for HFTs, to exercise the American option before maturity due to (i) external flows of information, which induce the execution of the option in order to gain time priority, (ii) extraction of information from the order flow, for example, by investigating the presence of hidden orders and (iii) attempts to affect the theoretical opening price.[11]

manipulation as "Entering significant orders in the central order book of the trading system a few minutes before the price determination phase of the auction and cancelling these orders a few seconds before the order book is frozen for computing the auction price so that the theoretical opening price might look higher or lower than it otherwise would do."

[10] Biais, Hillion, and Spatt (1999) and Davies (2003) document that the majority of the order flow occurs as close as possible to the opening auction for NYSE-Euronext Paris and the Toronto Stock Exchange, respectively. More generally, so called "bid snipping" (submitting a bid as late as possible) is a common feature of the second-price, timed, internet auctions conducted by e.g., eBay (see Roth, Ockenfels, et al. (2002), Ockenfels and Roth (2006)), as a result of strategic bidders' behavior to conceal private information and/or to avoid bidding wars with incremental bidders.

[11] Medrano and Vives (2001) suggest that informed traders may manipulate the theoretical opening price by

HYPOTHESIS 1: *Independent of the account type for which they act, HFTs (PURE-HFTs and MIXED-HFTs) delay their order submission/cancellation decision during the pre-opening phase until the very last moment before the opening auction.*

The above hypothesis describes how HFTs behave by coming early to the party, but does not draw conclusions regarding whether they "enjoy the party" by coming earlier, i.e., benefit by doing so. Coming early to the party may generate several concomitant benefits: collecting information, building up inventories, etc. However, the litmus test for their participation is whether or not they make profits. We investigate this issue in the following hypothesis.

HYPOTHESIS 2: *Independent of the account type for which they act, HFTs (PURE-HFTs and MIXED-HFTs) do participate in the pre-opening phase and the opening auction, because they are able to use their speed advantage to make profits.*

By testing this hypothesis, we indirectly investigate whether HFTs who participate in the pre-opening phase are informed traders, and whether they monetize this advantage immediately after the market commences the main trading phase (i.e., whether they enjoy the party). We aim to verify through this hypothesis if the HFTs who participate in the opening auction are informed traders in the sense that they are systematically able to make profits on their transactions. We also aim to investigate through this hypothesis whether, because of their speed advantage they are the only ones enjoying the party, i.e., if they have special privileges relative to other market participants, or the market is a level playing field, i.e., even without the same speed capacity, others still make profits, or enjoy the party, as well.

With the next hypotheses, we aim to investigate whether HFTs allow the other participants to enjoy the party by improving market quality through price discovery and liquidity provision. In a market with continuous trading, price discovery is typically thought to occur only through *actual* trades. However, in the absence of trading, i.e., during the pre-opening phase, price discovery may occur through the posting of quotes and their modification or cancellation, which conveys information to other market participants. Similarly, even in the main trading phase, trading does not happen literally continuously, but in a discrete manner, with intermittent

strategically placing, modifying, and cancelling their orders.

periods of no trading. This raises the question of whether price discovery can happen even in the absence of actual trades, merely based on the posted quotes, modifications and cancellations.[12] Here, we study price discovery in the absence of execution, and examine how different types of traders contribute to it. In this manner, we overcome the restriction of the classical definition of price discovery, which happens only through market orders, as in the classical models by Kyle (1985) and Glosten and Milgrom (1985). We address this in our third hypothesis:

HYPOTHESIS 3: *Independent of the account type for which they act, HFTs (PURE-HFTs and MIXED-HFTs) contribute to the price discovery process, during different periods of the trading day (the pre-opening phase and the first 30-minutes of the main trading phase.)*

We next examine whether HFTs use their high-speed trading capability to provide (quasi) liquidity to the market rather than act as speculative traders and absorb liquidity. In this framework, liquidity provision is a different concept than the classical one during the main trading phase. In the main trading phase, liquidity provision can be investigated, for example, by using metrics defined in AMF (2017): market depth (number of shares at the inside levels of the limit order book) and spread (the actual round-trip transaction cost). In our framework, there is no such liquidity provision because the inside levels of the limit order book are not well-defined (given that the supply and demand schedules are crossed in the pre-opening phase); there are no transactions during pre-opening phase, and there is no bid-ask spread in the opening auction. Therefore, we define quasi-liquidity provision during the auction as the quantity of shares that are traded against the overnight market movement.[13] Based on this definition, we test whether HFTs do have a "social role," i.e., they are not merely opportunistic as Lewis (2014) claims and, even if they are seeking to profit from their own strategies, they may incidentally

[12]This investigation is not new in the context of the main trading phase, i.e., the continuous session. Kaniel and Liu (2006), Goettler, Parlour, and Rajan (2009), and Rosu (2016) model the choice of informed traders between market orders (transactions) and limit orders (quotes) in the main trading phase. Brogaard, Hendershott, and Riordan (2016) provide empirical evidence for price discovery in the main trading phase occurring largely via quote updates coming from HFTs.

[13]This definition is in line with one of Brogaard, Riordan, Shkilko, and Sokolov (2014), who measure liquidity provision in the main trading phase by the directional trade imbalances computed as the difference between trading activity in the direction of the returns and trading activity in the opposite direction. In particular, Brogaard, Riordan, Shkilko, and Sokolov (2014) look at the extreme price movements and find that, in these cases, on average, HFTs provide liquidity.

provide liquidity to the market. We contrast this evidence with the HFT liquidity provision in the main trading phase. Therefore, we test the following hypothesis:

HYPOTHESIS 4: *Independent of the account type for which they act, HFTs (PURE-HFTs and MIXED-HFTs) are the main liquidity providers during the opening auction and the first 30-minutes of the main trading phase.*

In the following sections, we describe the market architecture, the dataset and the methodology we use to investigate the above hypotheses.

III. Institutional structure and data description

A. Institutional structure

At the NYSE-Euronext Paris exchange, securities are traded both continuously, for most liquid stocks and, in an auction, for stocks that are not sufficiently liquid.[14] The traded securities are divided into trading groups, often with each one employing its own peculiar trading procedure. Therefore, for the purpose of this study, we ensure uniformity by considering only stocks that trade continuously, and with uniform rules in terms of opening and closing procedures.

The schedule of the trading day at NYSE-Euronext Paris is divided into six segments: the pre-opening phase, the opening auction, the main trading phase, the pre-closing phase, the closing auction and the trading-at-last phase. The pre-opening phase lasts from 7.15 AM until 9.00 AM, when the opening auction is carried out. After the opening auction at 9.00 AM, the main trading phase, i.e. the continuous trading period, takes place from 9.00 AM to 5.30 PM. A second order accumulation period known as the période d'accumulation des ordres - phase de pré-clôture (pre-closing phase - order accumulation period) starts at 5.30 PM and lasts only five minutes, followed by the fixing de clôture (closing auction). The phase de négociation au dernier cours (trading-at-last phase) goes from 5.35 PM to 5.40 PM, and aims to execute additional orders at the closing price. The pre-closing phase, the closing auction and the trading-at-last phases are excluded from the scope of this study, since we focus our attention on the beginning

[14]There are several small, illiquid stocks that are traded exclusively via auctions. We do not include these stocks in our sample, as there is usually no HFT activity in such securities.

of the day, when the information accumulated overnight is reflected in market prices. We focus only on the first 30 minutes of the main trading phase when this information is being reflected in market activity.[15]

B. Data

Our data are obtained from the BEDOFIH, which provides tick-by-tick order-level data from NYSE-Euronext Paris with microsecond time-stamps. The data cover the complete history of orders (new order entry, execution, revision of quantity or price, and cancellation, for both the visible and hidden segments of orders in the pre-opening and main trading phases).

The sample period we examine is the year 2013 for the 37 French stocks that belong to the CAC40 index.[16] These stocks all have the same trading rules and HFT activity is present in all of them. We exclude from our initial sample, composed of 9,435 stocks-days combinations, four trading days and 148 stock-days due to technical issues on NYSE-Euronext or half-day trading (31 January 2013, 6 June 2013, 24 December 2013 and 31 December 2013). Further, we exclude 135 stock-days because we are unable to match the opening price due to suspensions of the stock or erroneous orders submitted during the pre-opening phase. We end up with 9,152 stock-days, or 97% of the initial sample.[17] For the purpose of our analysis, we focus on the pre-opening phase, the opening auction, and the first 30-minutes of the main trading phase.

The BEDOFIH database also has an additional classification, established by the French stock market regulator, which allocates each trader to one of three groups: PURE-HFT, MIXED-HFT and NON-HFT. This classification, revised once a year, is the result of a set of quantitative requirements and knowledge of the traders' IDs. The identification algorithm is based on the median lifetime of an order (including both modifications and cancellations), plus a threshold based on the total number of cancellations. A further check is carried out taking

[15]Other details of the trading architecture and taxation are reported in the Internet Appendix, Section A.

[16]Three stocks of the CAC40 are not included in our database since their main trading venues are Amsterdam (Arcelor Mittal and Gemalto) and Brussels (Solvay).

[17]The French market is very fragmented: Euronext covers around 63% of the total daily volume traded, followed by Bats (20%) and Turquoise (9%), according to the Fidessa Fragmentation Index, as of 2014. Unfortunately, we do not have order-level data with trader/account identifiers for these other markets and we do not analyze them.

into account the identity of the trader.[18] The three trader groups are mutually exclusive and, during the year, their group classification cannot be changed (see EUROFIDAI (2014)). Recall that, dedicated HFT players, such as Citadel, fall into the PURE-HFT category, while slow traders are NON-HFTs. The MIXED-HFT category includes large investment banks and large brokers such as Goldman Sachs, and is the most active category in our sample.[19] All these traders can have their OWN (proprietary) trading desks that trade as quickly and frequently as PURE-HFTs, but they can also execute orders on behalf of their CLIENTS and, hence, take large positions in one or more stocks on their behalf. NYSE Euronext Paris also identifies each order with a flag that allows us to distinguish the actual account used to submit a particular order. Along this dimension, it is possible to distinguish between orders emanating from a trader's OWN account (proprietary trading) or OWN orders, those on behalf of the client or CLIENT orders, or those submitted due to their market making affiliation, MM orders. Alternatively, an order can also be flagged as a parent company order (PARENT) or related to retail market organization (RMO) and retail liquidity provision (RLP) activities.[20]

In this section, we describe HFT participation in these different roles, during the pre-opening phase and the first 30-minutes of the main trading phase. Table I presents the descriptive statistics of our sample, distinguishing between the pre-opening phase (Panel A), the first 30-minutes (Panel B) and the entire trading day including pre-opening and closing phases (Panel C). The median volume (in # of shares) at the opening auction is 1.2% (63,996 / 5,295,324) of the median total daily trading activity. The median number of messages submitted during the pre-opening phase is 3,578, out of which new orders are only 25.2% (903 / 3,578), and the rest comes from order modifications and cancellations of newly entered and "forgotten" orders, i.e., orders that are transferred from the previous days (the median number of such orders is 2,353 or 65.8% of the total # of messages).

[18]Conversations we had with AMF analysts confirm that they are confident that they are able to classify all HFT entities correctly, and that their classification is rather stable; a HFT in one year is likely also a HFT the year after.

[19]We note that this classification is based on the observed performance of the trader, and does not preclude the possibility that both HFTs and NON-HFTs have similar technological capacities, with the difference that the latter category does not utilize this capacity in full at all times.

[20]RLP orders can be executed only against RMO orders.

INSERT TABLE I HERE

To investigate the presence of the different group of traders in the pre-opening phase, and in the first 30-minutes of the main trading phase, we define the activity ratio based on the number of quotes, the Quote Activity Ratio (QAR) as:

$$QAR_{p,j,k,l} = \frac{\text{Number of quotes}_{p,j,k,l}}{\sum_{l} \text{Number of quotes}_{p,j,k,l}} \tag{1}$$

where p is one of the two periods considered, the pre-opening phase and first 30-minutes of the main trading phase, and the QAR relates to stock j, day k, and trader group l. In the QAR computation, we include only messages related to orders entered on day k and discard orders entered on the previous days.

For the opening auction, and for the first 30-minutes of main trading phase, we calculate the Trading Activity Ratio (TAR) in an analogous manner, by considering the number of shares actually traded:

$$TAR_{p,j,k,l} = \frac{\text{Number of shares traded}_{p,j,k,l}}{\sum_{l} \text{Number of shares traded}_{p,j,k,l}} \tag{2}$$

where p is one of the two periods considered for stock j, day k, and trader group l.

Table II shows average quoting activity (also split up by different message types), QAR, and average trading activity, TAR, for the pre-opening phase and the opening auction (Panel A) and for the first 30-minutes of the main trading phase (Panel B). PURE-HFTs are the most active market participants in terms of the QAR during the pre-opening phase (38.5% across all accounts), and the second most active group in the first 30-minutes of the main trading phase (44.3%). Notably, NON-HFTs contribute 30.4% to the message traffic in the pre-opening phase, and only 3.0% in the first 30-minutes of the main trading phase. Adding the account dimension reveals that most of the PURE-HFT activity in the pre-opening phase is carried out through their OWN accounts, while in the first 30-minutes of the main trading phase, the most active accounts for PURE-HFTs, in terms of the QAR, are those of MMs, with a similar pattern shared by MIXED-HFTs. The explanation for this differing behavior is related to the design of the SLP program, which provides benefits to liquidity providers only during the main trading

phase. During the first 30-minutes of this period, the quoting activity under the MM flag represents around 55% of the total quoting activity (28.9% for the PURE-HFTs, 26.3% for the MIXED-HFTs).

Zooming into quoting activity by the types of messages, we observe that all traders use *Limit Orders* most of the time, while *Market Orders* are used mainly during the pre-opening phase. (In the interest of clarity, we group together regular limit orders, stop limit orders and pegged orders as *Limit Orders* and regular market orders, stop market orders and market-to-limit orders as *Market Orders*.) We show that most of the message traffic in the pre-opening phase is generated by new limit order submissions (71.20%), while new market orders constitute only 8.28% of the total # of messages. The majority of new limit order submission arises from PURE-HFT-OWN traders (33.62%), followed by NON-HFT-CLIENT (13.04%) and MIXED-HFT-OWN (10.68%) traders. Notably, PURE-HFT-OWN cancel only 6.07% of their limit orders during the pre-opening phase, as compared to 81.44% during the first 30 minutes of the main trading phase, with similar cancellation patterns documented for MIXED-HFT-OWN/MM. In aggregate terms, only 6.90% of the message traffic in the pre-opening phase is generated by limit order cancellations, as compared to 44.06% of the message traffic in the first 30 minutes of the main trading phase.

INSERT TABLE II HERE

noindent We now turn to the trading activity of different trader categories in the opening auction and the first 30-minutes of the main trading phase. Interestingly, PURE-HFTs as a group are responsible for only 5.3% of the trading activity during the opening auction. The majority of trading activity, therefore, stems from MIXED-HFTs (59.4%) and NON-HFTs (35.3%). However, during the first 30-minutes of the main trading phase, the trading activity of PURE-HFTs rises to 22.9%, with almost 20.7% coming from transactions for which they wear their MM "hat." All in all, 28.4% of the total trading activity comes from transactions where at least one of the two counterparties is acting as an MM during the first 30-minutes of the main trading phase. To sum up, the trading activity of PURE-HFTs is very limited during the opening auction, while during the main trading phase, PURE-HFTs act mainly as

market makers: PURE-HFTs' TAR is four times higher during main trading phase than during pre-opening phase.[21]

HFTs are often referred to as the "fastest" market participants, which is by no means obvious. To establish this in our sample, we provide summary statistics on the quoting speed of different trader categories for different periods during the day. We define speed as the time elapsed between order entry/modification and modification/cancellation of the same order. Table III presents the summary statistics of the speed distribution of the different trader groups and account types. In line with our expectation, traders are faster during the main trading phase than in the pre-opening phase (due to the absence of immediate execution). During the main trading phase, both PURE-HFT-OWN and MIXED-HFT-OWN traders are very fast, with a 1st (5th) percentile of the speed distribution of 0.28 (0.50) and 0.02 (0.36) milliseconds respectively, as compared to NON-HFT-OWN traders with a speed of 0.48 (21.66) milliseconds. This finding suggests that both PURE-HFT-OWN and MIXED-HFT-OWN traders engage in strategies that require high speed. Remarkably, NON-HFT-OWN traders also might occasionally be very fast, e.g., we may observe extremely high speed if a smart router algorithm sends an order to multiple venues and, once an order is executed on one of them, the algorithm cancels the remaining orders. However, as can be seen from the 5th percentile of the speed distribution, NON-HFT traders do not have the capacity to be persistently fast. During the pre-opening phase, PURE-HFT-OWN are much faster than MIXED-HFT-OWN traders, with a 1st (5th) percentile of the speed distribution of 0.62 (0.99) and 34.96 (452.86) milliseconds, respectively. It is noteworthy that NON-HFT-OWN are more than twice as fast as MIXED-HFT-OWN traders during the pre-opening phase, as measured by the 5th percentile of the speed distribution.[22]

INSERT TABLE III HERE

[21] We observe substantial variation in HFT quoting and trading activity across stock-days. Nevertheless, HFTs are present in every stock, and on every day. The Internet Appendix, Sections B and C present more details on the cross-sectional and time-series distribution of HFTs activity in the pre-opening phase and the opening auction.

[22] The statistical speed comparison of different trader categories is available in Internet Appendix, Section D.

IV. Empirical results

A. *The order submission decision*

HYPOTHESIS 1: *Independent of the account type for which they act, HFTs (PURE-HFTs and MIXED-HFTs) delay their order submission/cancellation decision during pre-opening phase until the very last moment before the opening auction.*

When do HFTs join the party? As mentioned earlier, the decision to submit an order during the pre-opening phase may be viewed as an American option. From the intuition of option theory, we know that, in the absence of dividends or some other benefit, it is optimal to exercise an American option only at the expiry date. Hence, one would expect that traders who are able to act fast should postpone their decision until the very last moment. Biais, Hillion, and Spatt (1999) and Davies (2003) confirm this conjecture with their empirical analysis of aggregate trader behavior. However, it is not clear from these studies if *all* traders exhibit the same behavior. We investigate this issue with our sample by looking at the order submission decisions made by different trader categories. Figure 1 plots the daily number of new order submissions during the pre-opening phase for each stock-day. The figure shows that the behavior of the different trader types is quite different. On the one hand, NON-HFT-CLIENT traders actively submit orders at the very beginning of the pre-opening phase. On the other hand, only MIXED-HFT-MM traders delay their order submission decision until the very last moment. Other trader categories prefer to postpone their order submission decision at least until the middle of the pre-opening phase.

INSERT FIGURES 1 and 2 HERE.

The party starts to become interesting in the middle of the pre-opening phase. PURE-HFT-OWN traders are almost inactive before 8.30 a.m. After 8.30 a.m., however, PURE-HFT-OWN submit a large number of orders in almost all stock-days in our sample. The exact timing of the order submission changes from one stock-day to another between 8.30 a.m. to approximately 8.55 a.m., but the number of orders submitted is similar across stock-days. We conjecture that the timing of order submission changes slightly across stock-days, in order to avoid predictable

patterns in submission strategies, and thus, avoid free-riding by other market participants on the information conveyed by these order submissions (see Figure 2 for a breakdown of new order submissions and modifications by stock and by day). After the relevant number of new orders entered after 8.30 a.m., PURE-HFT-OWN traders remain active with a decreased intensity of order submissions, suggesting completely different behavior from the one documented in the previous literature, i.e., they do *not* exercise the American option at maturity, but instead start to exercise it well before maturity. The other main players, MIXED-HFT-OWN and NON-HFT-OWN traders, exhibit similar behavior. In particular, MIXED-HFT-OWN enter a considerable number of orders immediately after 8.10 a.m. and NON-HFT-OWN enter a considerable number of orders between 8.30 a.m. and 8.32 a.m. After that time the activity for both categories declines sharply, and rises again close to the opening auction at 9.00 a.m.

What are the factors that determine the placement of orders in the first place? Since there is no cost of placing or canceling an order, it makes sense to place an order as early as there is sufficient information about order flow from other market participants. The orders placed can always be modified or canceled, without incurring any additional cost. For both PURE-HFT-OWN and NON-HFT-OWN traders, it seems that the first flow of information arrives around 8.30 a.m., as evident in Figure 1. We investigate, in depth, what is driving this flow of information. Conversations with practitioners indicate to us, that the exact timing is dictated by several factors: the morning calls of the large brokerage firms, the opening time of equity derivatives markets (e.g., Eurex), order flow from the futures markets (CAC40 and STOXX50 futures contracts are open for trading from 8.00 a.m.), the information flow from news providers, (e.g. Reuters or Bloomberg). Besides, earnings announcements usually occur before 8.30 a.m. and some of the French macroeconomic news announcements are usually released around 8.00 a.m. Therefore, as soon as a large amount of information arrives in the market, both PURE-HFT-OWN and NON-HFT-OWN traders start to post orders to exploit the time priority option.

The other reason for the active participation of traders during the pre-opening phase is information extraction from the order flow. This information might come from two sources. The

first is the marginal response of the aggregate system (i.e. all the other traders) to the specific strategy of the trader. The second is fundamental (private) information that comes from other market participants. Both sources of information are then reflected in the theoretical opening price, and later in the auction price. On top of the external flow of information, submitting, modifying and cancelling orders during the pre-opening phase is crucial in order to learn the marginal impact of an individual order on the theoretical opening price as well as to "ping" hidden orders.

Having documented that there are good reasons to post orders before the end of the pre-opening phase, we next consider the patterns of order cancellations. During the pre-opening phase, traders have the flexibility to time their order placement as well as subsequent modifications and cancellations, in line with exercising a compound American option to place the order, and then to modify or cancel it. What are the factors that affect cancellation decisions, and when should orders be optimally canceled? There might be several reasons to cancel an order. First, a trader might want to cancel an order in response to new information with an intent to move the theoretical opening price closer to fundamental value. Second, traders might use combinations of order submissions/cancellations to "ping" down hidden quantities. In both cases, order cancellations may occur well before the opening auction. Third, a fast trader has the option to cancel his orders at the very last moment before the opening auction, if the theoretical opening price is not in line with expectations (with or without considering the effect on the theoretical opening price).

This problem is similar to the classic case of determining the optimal stopping time of an American option. What are the costs and benefits of stopping, i.e., canceling the order? The cost is clearly the loss of the time priority, achieved from the early placement of the order, or losing one's place in the queue of all orders placed at the same price. Essentially, this amounts to the loss of the optionality or the insurance value of the option to obtain execution of the order at the initial price. There is no corresponding benefit since the agent can always place a new order at a different limit price. Hence, in the absence of a "dividend," i.e., new information, the option should be exercised in the very last moment; however, in case of a "dividend payment,"

i.e., information arrival, the option may be exercised earlier.

INSERT FIGURES 3 and 4 HERE.

Figure 3 shows the pattern of cancellations for the pre-opening phase for the different trading categories, across stocks and days. With the exception of NON-HFT-CLIENT traders, whose cancellation activity starts well before 8.00 a.m., all other trader categories tend to cancel part of their orders closer to the opening auction. For PURE-HFT-OWN traders, Figure 3 shows that they cancel orders in a significant fashion around 8.45 a.m, as well as mostly closer to the opening auction. A reasonably large number of cancellations comes from MIXED-HFT-OWN and NON-HFT-OWN traders. However, there is a remarkable cross-sectional and time-series difference between these two categories. On the one hand, Figure 4 shows that the PURE-HFT-OWN traders are more selective in their cancellation activity, across stocks. On the other hand, the other two relevant traders' categories systematically cancel a consistent number of orders on all the stock in our sample. Across days, Figure 4 again confirms that the cancellation activity by PURE-HFT-OWN is selective, and mostly concentrated in the very last minute of the pre-opening phase.[23,24]

New order submission and cancellation activity taken together suggests that there is no evidence that HFT activity is a result of a strategy to "ping" hidden quantities sitting in the limit order book. If the latter were true, we would observe a spike in cancellations similar to the pattern of new order submissions in Figures 1 – 2.[25] Finally, a fast trader has the option to cancel at the very last moment before the opening auction, if these orders were entered without any intention to be executed, but rather to confuse other market participants (likely, with an effect on the theoretical opening price). The latter activity is monitored by AMF, as it is considered

[23]There is a spike in cancellation activity by PURE-HFT-OWN traders on 25 September 2013, with the number of cancellations being almost 10 times higher than for any other day. Hence, for the sake of better visibility, the graphs exclude this day.

[24]A graphical representation of the order submissions for the last second of the pre-opening phase can be found in the Internet Appendix, Section E, where we show that both PURE-HFT-OWN and MIXED-HFT-OWN traders are able to submit and cancel orders even 10 milliseconds before the opening auction.

[25]Besides that, Section F of the Internet Appendix shows that "iceberg orders" have only a marginal effect on the theoretical opening price. Section G of Internet Appendix shows that the proportion of the hidden quantity relative to the total quantity is less than 10%, except for the last minute of the pre-opening phase.

to be price manipulation. The evidence is consistent with this view, since cancellations move the theoretical opening price in the middle of the pre-opening phase; however, cancellations have a negligible effect at the very end of the pre-opening phase. In other words, we do not find any evidence consistent with price manipulation in the spirit of the model in Medrano and Vives (2001) or the regulations in AMF (2010).[26]

We now move to a more formal test of Hypothesis 1: the order submission/cancellation hypothesis. In particular, we estimate the following probit model separately for new order entries/modifications and cancellations:

$$Pr(Y_{t,j,k,l} = 1) = \alpha_l + \sum_{t=1}^{T} \beta_{t,l} \times TD_t + \epsilon_{t,j,k,l} \tag{3}$$

where the $Y_{t,j,k,l}$ is equal to one, if the median number of new order submissions/modifications or cancellation per each 100 milliseconds in the time interval t is greater than the *median* of the order submissions/modifications or cancellations across day k, stock j, and time interval t, for a trader group l; TD_t is a dummy for the time interval t: 8.10-8.30, 8.30-8.59, last minute, last second, and last 100 milliseconds (all time intervals are mutually exclusive). We use the 7.15-8.10 time interval as a base case, when available; otherwise, we use the closest interval available.

We investigate first whether order submissions/modifications are different in the various intervals for the different groups of traders. The results of the probit analysis are reported in Table IV.

INSERT TABLE IV HERE

Panel A of Table IV summarizes the results previously presented in Figure 1, and shows the total number of new orders submitted, and the number of existing orders modified, for different time intervals during the pre-opening phase. The pattern of order submission strategies across traders is very clear: PURE-HFT-OWN traders submit orders immediately after 8.30 a.m.,

[26]In Section IV.C we apply the Weighted Price Discovery Contribution (WPDC) metric to measure which trader contributes to price discovery. A detailed breakdown of this measure, order by order, is also presented in Internet Appendix, Section F.

but also during the entire last 30 minutes of the pre-opening phase. MIXED-HFT-OWN and NON-HFT-OWN orders are more concentrated around 8.10 and 8.30 a.m., but also closer to the auction.

The number of orders submitted by PURE-HFT-OWN traders (1,346) in the last 100 milliseconds prior to the opening auction is lower than those posted by NON-HFT-OWN traders (3,417), and lower than those submitted by MIXED-OWN traders (8,164). Even for the orders submitted in the last second or even in the last minute, PURE-HFT-OWN traders are not the first, but MIXED-HFT-OWN traders are. Instead, in the time bucket 8.30 – 8.59 a.m. the number of orders submitted by PURE-HFT-OWN traders is three times higher than those of the NON-HFT-OWN traders (the second group of traders for order submissions), and five times higher than the number of orders submitted by MIXED-HFT-OWN traders. Panel B of Table IV reports the total number of orders submitted/modified, divided by the number of 100 milliseconds intervals for each bucket. We document that the proportion of new orders submitted for PURE-HFT-OWN traders is comparable in the last second and the last 100 ms, while for MIXED-HFT-OWN and NON-HFT-OWN traders, the number of new orders submitted in the last 100 milliseconds is two to three times higher than the orders submitted in the last second.

Panel C of Table IV provides the estimation results of the probit regression for the likelihood of submitting/modifying an order per 100 milliseconds in a particular time interval, i.e., if the trader-group submits orders systematically above the median order submissions across day-stock-intervals, applying Equation (3). The probability of observing a number of new order submissions or modifications of existing orders greater than the median, for the PURE-HFT-OWN group between 8.30 and 8.59, is 35.5% higher than between 8.10 and 8.30. The respective probability is 13.7% higher for order submissions in the last second, and 11% higher for the last 100 milliseconds. The pattern for MIXED-HFT-OWN and NON-HFT-OWN traders is quite different compared to the one for PURE-HFTs. Compared to the base case (from 7.15 a.m. to 8.10 a.m.), the probability of observing a larger number of new orders for the former is higher in the time buckets 8.10-8.30, and also in the last second. For the latter, the higher probability buckets are those for 8.30-8.59, and again in the last second. It is noteworthy

that the probability of order submissions/modifications for NON-HFT-OWN traders is not statistically significant in the last minute, and in the last 100 milliseconds, potentially indicating that their technology is reliable enough for them to wait until the last second, but not until the last 100 milliseconds.

We also conduct an F-test to compare the marginal effects of the 8.30-8.59 time interval, the last minute, and the last second intervals, and confirm that the majority of the new order submissions/existing order modifications occur between 8.30 and 8.59. Therefore, we reject our Hypothesis 1, which states that HFTs delay their order submissions decision until the very last moment of the opening auction. This behavior indicates their desire to observe and learn from the pre-opening order flow before making their order submission decisions.

We perform a similar analysis for order cancellations. In this case, the probit analysis is performed with the dependent variable $Y_{t,j,k,l}$ equal to one, if the number of cancellations in the time interval t is greater than the *median* of the cancellations across day k, time intervals t and stock j for the trader group l.

INSERT TABLE V HERE

Panel A (Panel B) of Table V shows the total number (the average) of cancellations for different time intervals during the pre-opening phase. First, we observe that the number of cancellations is reasonably small as compared to the number of new order submissions/modifications. Second, the importance of speed in the pre-opening phase may be manifested through the ability to cancel the order at the very last moment to avoid an undesirable execution. Zooming into the last second/100 milliseconds, we document that PURE-HFT-OWN and MIXED-HFT-OWN traders cancel four and seven times more orders, respectively, than NON-HFT-OWN traders, in total. This finding highlights the fact that the ability to act fast permits traders to use the option to cancel more frequently.

Panel C of Table V provides the estimation results of the probit regression for the likelihood of order cancellations in a particular time interval. We document that both PURE-HFT-OWN and MIXED-HFT-OWN traders cancel their orders actively in the last minute; however, they

do not defer their cancellation decisions until the very last moment. In particular, PURE-HFT-OWN traders are 9.3% (13.7%) more likely to cancel their orders between 8.30 and 8.59 (the last minute) than between 7.15 and 8.10. The cancellation probability in the last 100 milliseconds (16.8%) is remarkably higher than the probability in the entire time period between 8.30 and 8.59. For MIXED-HFT-OWN traders, only the cancellation probability between 8.30 and 8.59, and during the last minute, are statistically larger than between 7.15 and 8.10; all other marginal effects are not statistically significant. Therefore, we reject the hypothesis that HFTs delay all their order cancellation decisions until the very last moment of the opening auction, but a non-trivial quantity of orders have a higher probability (16.8%) of being canceled by PURE-HFT-OWN traders in the last 100 milliseconds.

Having tested and documented that HFTs do not delay their order submissions/modifications or cancellations until the very last moment of the opening auction, we next investigate the strategic behavior of HFTs regarding whether to prevent their orders from execution or not. In Table II, we observe the relatively moderate number of cancellations relative to the number of new order submissions. These low cancellation ratios may be indicative of traders' desire to execute an order at the opening auction. An alternative explanation is that certain orders are not at all meant to be executed at the opening auction. In particular, traders can exploit a particular feature of NYSE-Euronext Paris market: according to Euronext (2016), there is a collar of 6% for CAC40 stocks on a maximum opening price deviation from the previous day's close. Hence, limit buy (sell) orders with a price lower (higher) than 6% compared to the previous day closing price cannot be executed at the auction (and clearly can be hit during the main trading phase only in case of large market swings). We refer to these orders as "flash crash" orders. In Figure 5, we investigate whether and how many PURE-HFTs and MIXED-HFTs orders belong to this category.

INSERT FIGURE 5 HERE

Figure 5, Panels A and B, show the number and timing of new flash crash orders submissions by PURE-HFT-OWN and MIXED-HFT-OWN traders, respectively. We observe that the usage of flash crash orders is mainly a feature of PURE-HFTs rather than MIXED-HFTs, and that the

number and timing of flash crash order submissions is comparable to the regular orders, which is evident by comparing Figure 1 and Figure 5. A more detailed analysis reveals that the order duration (life) of an order submitted during the pre-opening phase by PURE-HFTs is strongly bimodal: an order is either cancelled or executed within one minute, or it remains until the end of the trading day (see Figure 5, Panel C). On the contrary, MIXED-HFTs mainly submit orders with a short lifetime (see Figure 5, Panel D). The orders that are cancelled or executed within one minute are perfectly in line with our expectations of HFT behavior, i.e., HFTs react fast to changes in market conditions by cancelling and resubmitting their orders. However, most PURE-HFTs post orders that can almost never be executed at the auction, and even have very moderate chances of being executed during the main trading phase. Panels E and F of Figure 5 show the deviation of the limit order prices from the previous day's closing price for PURE-HFT-OWN and MIXED-HFT-OWN traders. The blue bars represent orders that can be executed at the auction, while the red bars represent orders that cannot be executed.

In summary, there is a significant number of orders that are flash crash orders, i.e., those that have prices far below or above 6% relative to the previous day's closing price. We argue that PURE-HFTs submit flash crash orders to gain time priority in case of extreme market movements, or to exploit erroneously entered orders. Given that possibility, flash crash orders should play a role only in the main trading phase, and hence, it is not surprising that other market participants do not make use of such orders, as they are not able to monitor the market continuously and react fast to changing market conditions.

Biais, Hillion, and Spatt (1999) document for the Paris Bourse that "... in fact, the last 10 minutes before the opening are the most active of the day. Further, the majority of the orders placed during the preopening period obtain execution." (Biais, Hillion, and Spatt (1999), p.1220) Contrary to these findings, we show that for PURE-HFT-OWN traders the most active period is around 8.30 am (roughly in the middle of the pre-opening phase). Moreover, most of the orders submitted by them are "flash crash" orders that cannot be executed at the opening auction, and are submitted in order to gain time priority in the main trading phase, in case of extreme market movements.

Davies (2003) focuses on the role of designated market makers in the pre-opening phase on the Toronto Stock Exchange, and documents that "high levels of pre-trade market transparency and poor incentives for early order submission cause most traders to wait until just before the TSE market opening to submit their orders." (Davies (2003), p. 492) Contrary to his findings, we document that the usage of MM accounts by HFTs (PURE and MIXED) is marginal as compared to the usage of their OWN accounts in the pre-opening phase. However, when HFTs do use their MM accounts, they indeed tend to defer their activity to the end of the pre-opening phase.

In the next section, we turn to a discussion of whether there is any pecuniary benefit for HFTs to execute their orders in the opening auction.

B. Profits

HYPOTHESIS 2: *Independent of the account type for which they act, HFTs (PURE-HFTs and MIXED-HFTs) do participate in the pre-opening phase and the opening auction because they are able to use their speed advantage to make profits.*

INSERT FIGURE 6 HERE

In order to test this hypothesis, we start our analysis by investigating, whether the quantity executed at the opening auction depends on the time of order entry/modification. Figure 6 plots the log-quantity executed in the auction aggregated by the time of order entry, excluding market and aggressive orders, for which execution is guaranteed. We show that for all categories, there is a positive relation between the time of the order entry/modification (closeness to the opening auction) and the log-quantity executed. This suggests that the ability to post an order closer to the opening auction increases the probability of being executed. However, Figure 6 does not allow us to answer the question of whether market participants can make larger profits on orders entered closer to the opening auction. We, therefore, investigate the ability of the different traders to potentially make profits. Figure 7 plots the cumulative potential profits aggregated across stock-days made on orders submitted during the pre-opening phase (Panel

A), and the last second of the pre-opening phase (Panel B), assuming that the position taken in the auction is reversed one-minute after the auction at the market price, i.e., it is evaluated at the mark-to-market price one minute after the opening auction.

INSERT FIGURES 7 HERE

Panel A of Figure 7 shows that almost all the different groups of traders lose money on orders entered at the beginning of the pre-opening phase, and potentially make money (or reduce their losses) on orders entered at the very end of the pre-opening phase. More specifically, PURE/MIXED-HFT orders show positive cumulative returns on orders executed at the opening auction, if evaluated at the mark-to-market price one minute after the auction (the only exception being the MIXED-HFT-CLIENT group). Given that the auction price evaluated one minute after is a zero-sum game, the traders that show negative cumulative returns in this case are NON-HFTs, especially the NON-HFT-CLIENT category. However, NON-HFT-OWN traders show a profit pattern similar to that of PURE/MIXED-HFT-OWN traders.

We next investigate how relevant speed is to realize these profits. In order to determine whether speed matters in generating profits, we zoom into the very last second of the pre-opening phase (see Panel B of Figure 7). In this manner, we are able to highlight whether fast traders can potentially make profits on late order submissions, and whether speed is a necessary condition for making profits on these orders. Surprisingly, we observe that not only is the PURE/MIXED-HFTs group able to make profits on the orders entered in the last second, but pretty much all the different groups of traders do, with the NON-HFT-OWN traders showing a capacity to generate profits similar to those of PURE-HFT-OWN traders. However, the cumulative profits of NON-HFT-OWN traders increase uniformly through the last second; in contrast, those of PURE-HFT-OWN traders are more concentrated in the last 500 milliseconds. In any case, the orders submitted by NON-HFT-OWN traders in the last few milliseconds do result in a significant increase in their cumulative profits. The explanation for this persistent pattern is twofold. First, the most likely informed traders in our groups are the NON-HFT-OWN traders, who can potentially make profits based on their informational advantage. However, the HFTs have the speed advantage to react milliseconds before the opening of

the market, and potentially exercise the option to cancel. The final result is that the fundamental information available to NON-HFT traders can sometimes outweigh the speed advantage of the HFTs. Second, even slow traders often do use algorithms for order submissions and, given that the opening time is fixed, it is relatively easy to time the order submissions until the last few milliseconds before the auction.[27]

In order to formally answer the question of whether speed allows traders to engage in more profitable transactions, we estimate the following regression:

$$Profit_{t,j,k,l} = \sum_{t=1}^{T} \beta_{t,l} \times TD_t + \epsilon_{t,j,k,l} \tag{4}$$

where the $Profit_{t,j,k,l}$ is the profit that is made on the executed orders submitted/modified in the time interval t, for a trader group l, on day k, for stock j, assuming that the position is reversed one-minute after the auction; and TD_t is a dummy for the time interval t: 7.15-8.10, 8.10-8.30, 8.30-8.59, last minute, last second, and last 100 milliseconds (all time intervals are mutually exclusive).

INSERT TABLE VI HERE

Panel A of Table VI shows the total profit made on the orders executed at the auction depending on the time of order entry/modification aggregated across orders, stocks, and days. We observe that virtually all traders lose money on orders entered in the beginning of pre-opening phase, and make money on orders entered at least as late as the last minute before the auction, as already highlighted in Figure 7.[28]

Panel B of Table VI provides the results from the profit regression estimation. We observe that PURE-HFT-OWN traders as a group earn, on average, across stock-days, 45.14 euros on orders entered in the last 100 milliseconds, with the highest amount earned on last second

[27] We also look, in detail, at the distribution of the returns across the individual orders executed. Internet Appendix, Section H zooms into the picture of profits made by each order that was submitted in the last second.

[28] We also document the standard deviation of the stock-day profits for each trader/account category and show that PURE-HFT-OWN traders have the least volatile profits among proprietary traders. Besides these, profit volatility steadily decreases from one minute until 100 milliseconds before the opening auction. Results are available from the authors upon request.

orders: 47.87 euros. However, an F-test suggests that we cannot reject the equality of the total profits made during these two intervals. We would like to emphasize that this is an average number and, therefore, does not exclude the possibility that some HFTs might make larger profits or larger losses. MIXED-HFT-OWN traders make the largest profits on the orders entered in the last minute before the auction (160.8 euros), while NON-HFT-OWN traders make the largest profits in the last second (15.81 euros), and the last 100 milliseconds before the auction (25.87 euros).

Panel B of Table VI also provides the results of the F-test for whether cumulative profits in the last second are statistically different from those in the last minute, or in the interval 8.30 – 8.59 a.m. In most cases, the null hypothesis cannot be rejected due to the fact that profits are very volatile. The only exceptions are PURE-HFT-OWN and MIXED-HFT-OWN traders, for whom we reject the equality of profits during the last minute of the pre-opening phase and profits during the 8.30 –8.59 a.m. period. The cases where the null hypothesis that the cumulative profits of the last second are statistically equal to the cumulative profits in the last minute, are rejected: the cumulative profits in the last second are lower than those in the last minute.

Essentially, we observe that not only are HFT traders able to submit orders close to the opening auction, but they are able to earn positive profits on them. We argue that NON-HFTs traders may enjoy the same speed advantage as PURE/MIXED-HFT traders because the exact timing of the auction (9.00 a.m.) is known, and hence even slow traders may have a simple algorithm to check the theoretical opening price in a fraction of a millisecond before the opening auction, and make their order submission decisions. Our finding is in line with the theoretical predictions of Budish, Cramton, and Shim (2015), who argue that frequent batch auctions might reduce the speed advantage of HFTs and thus, make markets more "fair."

In summary, we document that speed is important for making profits on the orders executed during the opening auction; however, we fail to document that HFTs have a pronounced speed advantage relative to NON-HFTs in the pre-opening phase, perhaps due to the known fixed-timing of the auction. In the next two subsections, we discuss whether the presence of HFTs in

the pre-opening phase has any positive externalities for other market participants, by looking at their effect on price discovery and liquidity provision.

C. Price discovery

HYPOTHESIS 3: *Independent of the account type for which they act, HFTs contribute to the price discovery process, during different periods of the trading day (the pre-opening phase and the first 30-minutes of the main trading phase.*

We measure the contribution of different trader groups to price discovery, using a modified version of the weighted price discovery (WPC), a concept proposed and used by Barclay and Warner (1993), Cao, Ghysels, and Hatheway (2000), and Barclay and Hendershott (2003). Specifically, we first define the price discovery contribution, order by order (PDC), as follows:

$$PDC_{i,j,k} = Deviation_{i,j,k} - Deviation_{i-1,j,k} \tag{5}$$

where the $Deviation_{i,j,k}$ is a measure of the deviation of the i-th order price, for stock j, on day k, relative to the reference price, being the opening price for the call auction, or to the price observed at 9.30 a.m., 30-minutes into the main trading phase of the trading day. The deviation is calculated in two different ways for the pre-opening and main trading phases. For both versions of the calculation, a reduction in the deviation is viewed as a contribution to price discovery (the total deviation sums up to -100%).

For the main trading phase, we focus on trades, and the deviation of the traded price is calculated as follows:

$$Deviation_{i,j,k} = \left| \frac{P_{i,j,k}}{P930_{j,k}} - 1 \right| \times 100 \tag{6}$$

where $P_{i,j,k}$ is the trading price at the time of the i-th transaction, for stock j, on day k, and $P930_{j,k}$ is the price at 9.30 a.m. for stock j on day k. The return in the first 30-minutes is calculated using, as the end point, the average traded price between 9.30 a.m. and 9.35 a.m., in order to minimize the effect of the bid-ask bounce. The contribution to price discovery is, therefore, the amount by which the $Deviation_{i,j,k}$ is reduced from the $Deviation_{i-1,j,k}$. A

unique feature of our dataset is that the orders that initiated the trade, i.e., the "aggressive orders," are directly identified by NYSE-Euronext Paris, thus simplifying our identification, and allowing us to determine the direction of the trade.

For the pre-opening phase, $Deviation_{i,j,k}$ is defined as

$$Deviation_{i,j,k} = \left| \frac{T_{i,j,k}}{O_{j,k}} - 1 \right| \times 100 \tag{7}$$

where $T_{i,j,k}$ is the theoretical opening price at the time of arrival of order i, for stock j, on day k, and $O_{j,k}$ is the actual opening price for stock j on day k. A negative $PDC_{i,j,k}$ (see Equation (5)) reduces the deviation, and moves the price closer to the reference price. Finally, the $WPDC$ for stock j, day k, and order i, is defined as follows:

$$WPDC_{i,j,k} = \frac{PDC_{j,k}}{\sum_{j} |PDC_{j,k}|} \times \frac{PDC_{i,j,k}}{PDC_{j,k}} \tag{8}$$

where $PDC_{i,j,k}$ is the price discovery contribution of order i, for stock j, on day k and $PDC_{j,k}$ is the accumulated price discovery contribution for stock j, on day k. The first term of WPC is the weighting factor for the stock on day k. The second term is the percentage contribution of price discovery made by order i to the total price discovery, during either the pre-opening or the main trading phase, for stock j on day k.

$$WPC_{j,k,l} = \sum \beta_l * I_l + e_{j,k,l} \tag{9}$$

where $WPC_{j,k,l}$ is our measure of price discovery for stock k, on day j, for trader/account l. I_l is a dummy variable that equals 1 for trader/account l.

INSERT TABLE VII HERE

Panel A of Table VII reports the average $WPDC$ for each trader/account category, for the pre-opening and the main trading phases. Remarkably, orders entered in the beginning of the pre-opening phase deteriorate price discovery. Most of these orders come from the NON-HFT-CLIENT group and move the theoretical opening price away from the actual auction price. From 8.30 to 8.59, when all other trader/account types join the party, around 50% of the price

discovery occurs, which translates into the fact that half of the total price discovery occurs in the last minute of the pre-opening phase. One second before the opening auction, the absolute deviation of the theoretical opening price from the actual auction price is around 10.60%. This deviation reduces to 1.71%, 100 milliseconds before the auction takes place.

The MIXED-HFT-OWN traders consistently lead to price discovery during the pre-opening phase in all sub-periods, with a $WPDC$ of 47.47% for the entire pre-opening phase. The price discovery contribution of MIXED-HFT-OWN increases, the closer the order time is to the opening auction and reaches 81.81% in the last 100 milliseconds. The contribution of PURE-HFT-OWN trades to price discovery during the entire pre-opening phase is 11.75%. In the last second (100 milliseconds), PURE-HFT-OWN trades contribute 13.61% (8.75%) to price discovery. Interestingly, NON-HFT-OWN trades contribute 24.39% (4.27%) in the last second (100 milliseconds) to $WPDC$. Most of the price discovery occurs via newly entered limit orders. Notably, in the last second and 100 milliseconds, this pattern does not change. In other words, cancellations only marginally move the price at the very last moment before the opening auction.[29]

Regression results are reported in Panel B of Table VII, and the F-tests for the equality of coefficients are available from the authors upon request. Regression results confirm the evidence provided by the summary statistics. Traders trading on their OWN account lead the price discovery. MIXED-HFT-OWN, NON-HFT-OWN, and PURE-HFT-OWN trades are the first, second, and third largest contributors to price discovery for the entire pre-opening phase, respectively. Notably, the same pattern is observed in the last second of the pre-opening phase. These results are consistent with our profit analysis, where we document that slow traders also profit more from the orders executed in the auction that were entered as close as possible to the auction and, therefore, these orders are likely to have greater informational content. In the first 30 minutes of the main trading phase, PURE-HFT-MM traders start actively participating in the market. They are the largest contributors to price discovery (38.31%), followed by MIXED-

[29]The Internet Appendix Section F provides a detailed breakdown of $WPDC$ for each order type: only 0.18% (2.77%) of the total price discovery is due to cancellations of limit orders, and 1.3% (0.45%) is due to cancellation of market orders in the last second (100 milliseconds).

HFT-OWN trades with a $WPDC$ of 31.03%. The contribution of PURE-HFT-OWN trades to $WPDC$ falls to 2.47% in the main trading phase, as compared to 11.75% in the pre-opening phase.

In summary, HFTs as a group lead to price discovery during the pre-opening phase (in all sub-periods, and not only in the very last moment), and during the main trading phase, although the breakdown per trader/account shows that this contribution is provided by different HFT trader groups between the two different phases.

D. Liquidity provision

HYPOTHESIS 4: *Independent of the account type for which they act, HFTs are the main liquidity providers during the opening auction and the first 30-minutes of the main trading phase.*

In this subsection, we investigate whether HFTs provide quasi-liquidity in the opening auction. Recall that we refer to quasi-liquidity provision because the classical definition of liquidity provision cannot be applied to the trades in the opening call auction. More specifically, in the literature, there are different definitions of liquidity provision; for example, AMF (2017) use two common metrics of the liquidity provision in the main trading phase: market depth (number of shares at the inside levels of the limit order book) and the bid-ask spread (the actual round-trip transaction cost). However, due to the absence of the immediate execution, the bid and ask schedules in the pre-opening phase are crossed and, hence, it is not clear how to define the inside levels of the limit order book. Besides, all orders are executed at a single price during the auction and, hence, there is no bid-ask spread in the auction, either. Therefore, we propose the concept of quasi-liquidity in the opening auction, where liquidity provision is defined as the number of shares traded against the overnight market movement, and liquidity consumption as the number of shares traded in the direction of the overnight market movement. Conceptually, this is in line with the liquidity definition of Brogaard, Riordan, Shkilko, and Sokolov (2014) who measure liquidity provision in the main trading phase as the directional trade imbalance computed as the difference between trading activity in the opposite direction of extreme price

movements, and trading activity in the direction of the extreme price movement.

In order to make the measure comparable between the opening auction and the main trading phase, and in line with Brogaard, Hendershott, and Riordan (2014), who define marketable orders as liquidity demanding orders and nonmarketable orders as liquidity supplying orders for each trade, we calculate liquidity consumption in the main trading phase as the number of shares traded, if the trader initiates the trade, and liquidity provision as the number of shares traded, if the trader does not initiate the trade.

During the main trading phase, we determine who initiates a trade by looking at the time stamp of order entry/modification of the orders culminating in transactions or looking at a particular flag, called the "aggressivity indicator," provided by NYSE-Euronext Paris on a trade-by-trade basis.[30] Based on this information, we calculate whether traders are providing or consuming liquidity in a particular transaction. Therefore, during the main trading phase, we consider the trader/account category as a liquidity provider, if it posts orders that do not initiate trades, i.e., orders that are not market orders or marketable limit orders.

For each trader/account, l, for each stock j, on each day, k, during the main trading phase, we calculate the net liquidity provision, NLP, as the difference between liquidity provision and liquidity consumption for the main trading phase:

$$NLP_{j,k,l} = \frac{\text{Number of shares traded}_{j,k,l} \mid \text{Trader/Account}_l \text{ does not initiate trade}}{\text{Total traded volume of first 30 minutes of main trading phase}_{j,k}} - \frac{\text{Number of shares traded}_{j,k,l} \mid \text{Trader/Account}_l \text{ initiates trade}}{\text{Total traded volume of first 30 minutes of main trading phase}_{j,k}} \tag{10}$$

However, in the case of the opening auction, we cannot distinguish between whether a particular trader/account type initiated the trade or not. Therefore, we use information about the overnight return since the close of the prior trading day to determine whether a trader/account trades in the direction of the market movement or against it. We consider a trader/account as a quasi-liquidity provider, if it trades against the market movement, i.e., if it sells (buys)

[30] We verify the consistency of the flag by mapping all the trades with the original submitted orders. The most recent order (the aggressive order) identifies the same trade initiator as the NYSE-Euronext "aggressivity indicator."

when the overnight return is positive (negative). Conversely, we consider a trader/account as a liquidity consumer, if it trades in the direction of the market: it buys (sells) when the overnight return is positive (negative). We measure NLP during the opening auction as the difference between the liquidity providing volume and the liquidity consuming volume:

$$NLP_{j,k,l} = \frac{\text{Number of shares}_{j,k,l} \text{ traded against the direction of the market}}{\text{Total traded volume of the auction}_{j,k}} - \frac{\text{Number of shares}_{j,k,l} \text{ traded in the same direction as the market}}{\text{Total traded volume of the auction}_{j,k}} \tag{11}$$

Thereafter, we estimate the following regression to test whether a particular trader/account category provides or consumes liquidity in the net terms:

$$NLP_{j,k,l} = \sum \beta_l * I_l + e_{j,k,l} \tag{12}$$

where $NLP_{j,k,l}$ is our measure of price discovery for stock k, day j, trader/account l. I_l is a dummy variable that equals 1 for trader/account l.

INSERT TABLE VIII HERE

Table VIII Panel A reports the net liquidity provision, NLP, which we define in Equation (10) for the first 30-minutes of the main trading phase, and in Equation (11) for the opening auction. Table VIII Panel A shows that, in general, the HFTs are weak quasi-liquidity providers, consuming quasi-liquidity using the CLIENT account (NLP of -0.09%) and providing quasi-liquidity with OWN accounts (NLP of 1.11%) and with their MM accounts (0.01%) at the opening auction. They are one of the largest quasi-liquidity providers in the opening auction after NON-HFT-OWN (NLP of 2.19%) and MIXED-HFT-MM (NLP of 1.68%) accounts. MIXED-HFT-CLIENT and MIXED-HFT-OWN accounts are the largest net quasi-liquidity consumers with a NLP of -3.82% and -2.29%, respectively.

We next run the regression using the specification in Equation (12). The results are reported in Table VIII Panel B, and the F-tests for the equality of coefficients are available from the authors upon request. We confirm that NON-HFT-OWN and MIXED-HFT-MM trades share

first place, while PURE-HFT-OWN and NON-HFT-CLIENT trades share second place, in terms of net quasi-liquidity provision. MIXED-HFT-OWN accounts are the second largest quasi-liquidity consumers in the opening auction. In the opening auction, HFTs trading on their OWN account jointly consume quasi-liquidity, and adding activity stemming from MIXED-HFT-MM traders shows that HFTs neither provide nor consume quasi-liquidity. The latter is consistent with Davies (2003), who shows that designated market makers moderate overnight price changes.[31]

Analyzing the first 30-minutes of the main trading phase reveals that the PURE-HFT-MMs are the largest liquidity consumers with an NLP of -10.84%. The two largest liquidity providers are again the NON-HFT-OWN and MIXED-HFT-MM categories with NLP of 3.79% and 3.50% respectively, while PURE-HFT-OWN traders have a NLP of 1.49% during main trading phase. Regression analysis confirms that in the first 30 minutes of the main trading phase, NON-HFT-OWN, NON-HFT-CLIENT, and MIXED-HFT-MM traders are the main liquidity providers, while PURE-HFT-MM traders are the largest liquidity consumers. The F-test of the joint effect of the HFTs on liquidity reveals that HFTs as a group consume liquidity during the main trading phase with this effect solely driven by PURE-HFT-MM trades.

In sum, we show that HFTs, as a group, neither harm nor help quasi-liquidity in the opening auction, with those acting as designated market makers strongly moderating the overnight price movements.

V. Conclusion

There is an ongoing debate regarding whether HFTs use their speed advantage to help or harm the fairness and efficiency of financial markets. We examine, in detail, HFT behavior, the profitability of their trades, and the externalities of their actions, with the aim of verifying whether their quoting and trading activity during the pre-opening phase simply amplify the

[31]In the Internet Appendix, Section I, we also perform the analysis on the presence of HFTs in the limit order book close to the theoretical opening price, which is similar to the usual analysis for liquidity provision during the main trading phase, although we note that the interpretation of such an analysis differs substantially in the pre-opening phase as compared to the main trading phase.

trading noise or lead to an improvement in price formation. The pre-opening phase, together with the opening auction, is a unique period of the trading day for many reasons: the overnight accumulation of information, the release of new information before the opening of the market, and a market setup, at least for the NYSE-Euronext Paris and some other major exchanges, which does not allow immediate execution. Therefore, this calls for a set of specific strategies that differ substantially from those during the main trading phase. The previous literature on the pre-opening phase of the trading day is focused on traditional market makers, in an earlier era when automatic high-speed trading was not predominant. In the case of NYSE-Euronext Paris, where the presence of HFTs is substantial, we find that HFTs do not delay their order submission/cancellation decision until the very last moment before the pre-opening phase. They are neither the first nor the last to enter the market; they join the party in the middle of the pre-opening phase, after observing the initial order flow, and learn from it.

Taking a broader perspective, leveling the playing field across market participants is a common objective for both the regulators and the exchange. On the one hand, our results show that the presence of HFTs does not disrupt the market during the pre-opening phase, and the speed differences between the market players does not create substantial inequalities of market access. The comparison of the profits of the different players provides an additional indication regarding the fairness of the market: if one trader is systematically able to make profits at the expense of other trading members, then a correction mechanism has to be added by the regulators and the exchange. Our analysis of the returns shows that HFTs are able to profit from their executions in the opening auction, especially from the orders that are submitted or modified in the very last second of the pre-opening phase. However, we document similar effects for NON-HFTs as well, suggesting that speed is not a necessary condition to make profits, at least in the context of the fixed time of the opening auction. In other words, HFTs do not have special privileges by virtue of their speed advantage, relative to the other market participants. This result is in line with the theoretical prediction of Budish, Cramton, and Shim (2015), who argue that auctions lead to more "fair game" between market participants.

In terms of positive externalities, the early participation of HFTs also generates benefits

for other market participants in terms of price discovery. We show that HFTs consistently lead the price discovery process through the pre-opening phase, helping the information to be incorporated promptly in prices. Nevertheless, the results for liquidity provision in the opening auction are mixed, and depend on the account type used. However, the practice of posting "flash crash" orders, with the aim of gaining time and price priority under extreme market conditions, raises the question of whether this practice could lead to instabilities, in view of the strong interconnections across venues and across markets. Even though there have been no significant episodes of market disruption in our sample period, posting an entire schedule of orders inflates the available liquidity and, in case of a "fat finger" event, may trigger trading halts, resulting in contagion effects across venues in a very short time, given the speed of trading across markets.

As a group, HFTs neither improve nor harm liquidity provision in the opening auction. The details of our findings are important for designing proper opening mechanisms in the presence of HFT participation. In particular, our results highlight the heterogeneity of the roles played by HFTs in different periods of the trading day, especially during the initial part of the day. Due to the rebate scheme provided by NYSE-Euronext only for the activity carried out using the MM flag in the main trading phase, the presence of liquidity providers in the opening auction is marginal. The rules of the exchange, in this case, strongly encourage the provision of liquidity by electronic traders only in the main part of the trading day, but not in the opening auction. This deserves further scrutiny. Our findings are also likely to be of interest to stock exchange managers, policy makers and stock market regulators to better define the market quality, and design the rules to be adopted for the pre-opening phase and the opening auction.

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Table I
Orders' Characteristics

This table presents the summary statistics across stock-days for order submission, quoting activity and trading activity in our sample. We split the data according to the period of the day when the orders were submitted, modified, canceled, or executed. In particular, Panel A presents summary statistics for the pre-opening period and opening auction, Panel B presents summary statistics for the first 30 minutes of the main trading phase, and Panel C presents summary statistics for the entire trading day including pre-opening and closing phases. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Pre-opening period and Opening Auction

	Median	SD	P5	P95
Total # of messages	3'578	2'702	946	9'644
# of new orders	903	762	300	2'604
# of orders from the previous days	2'353	1'971	456	6'850
# of modified orders	94	141	19	418
# of cancelled orders	85	187	23	432
Total volume (# of shares) traded	63'996	712'192	10'556	593'696
Number of trades	324	336	132	1'000
Total value (euro) traded	2'513'097	5'558'760	436'146	13'757'064

Panel B: First 30 minutes of the main trading phase

	Median	SD	P5	P95
Total # of messages	17'969	12'275	7'215	44'249
# of new orders	8'630	5'821	3'546	21'047
# of modified orders	1'260	1'279	414	4'144
# of cancelled orders	7'963	5'418	3'132	19'297
Total volume (# of shares) traded	296'348	4'255'484	53'568	3'053'344
Number of trades	1'640	2'208	560	6'280
Total value (euro) traded	11'078'753	22'515'901	2'778'637	56'429'965

Panel C: Entire day (including Pre-Opening and Closing)

	Median	SD	P5	P95
Total # of messages	291'873	197'106	123'398	723'125
# of new orders	141'797	94'993	60'449	348'691
# of modified orders	15'077	13'882	5'025	46'272
# of cancelled orders	133'698	91'248	55'491	332'714
Total volume (# of shares) traded	5'295'324	28'012'086	1'355'736	38'461'680
Number of trades	23'816	17'908	10'780	65'148
Total value (euro) traded	200'118'166	235'785'046	69'697'864	745'175'744

Table II
Quoting and Trading Activity

This table shows the proportion of quoting activity stemming from new orders, revisions, and cancellations, the average quoting activity (see Equation (1), and the average trading activity (see Equation (2)) by trader/account type, for the pre-opening phase and the opening auction (Panel A) and the first 30-minutes of the main trading phase (Panel B). *Limit orders* include limit orders, stop limit orders and pegged orders. *Market orders* include market orders, stop market orders and market to limit orders. All the numbers in each panel, for limit and market orders, sum to 100%. Quoting and trading activity sum to 100% across trader/account type, for each panel. Data are presented for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT) and six account types (OWN, CLIENT, MM, parent company orders, or PARENT, related to retail market organization or RMO, and retail liquidity provision, or RLP activities). The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Pre-opening period and Opening Auction

		Limit orders			**Market orders**			**Average Quoting Activity**	**Average Trading Activity**
		New orders	Modification	Cancellation	New orders	Modification	Cancellation		
PURE HFT	Client	0.18%		0.00%	0.02%		0.00%	0.2%	0.3%
	Own	33.62%	2.40%	2.04%	0.14%		0.00%	38.2%	4.9%
	RLP								
	MM	0.08%		0.04%	0.00%			0.1%	0.1%
MIXED HFT	Client	3.95%	2.88%	0.42%	0.44%	0.33%	0.07%	8.1%	14.9%
	Own	10.68%	2.48%	1.84%	2.51%	0.30%	1.09%	18.9%	35.2%
	RLP								
	MM	0.61%	1.45%	0.13%				2.2%	2.8%
	Parent	0.96%	0.00%	0.12%	0.53%	0.00%	0.33%	1.9%	6.5%
NON-HFT	Client	13.04%	0.25%	2.06%	4.40%	0.44%	0.56%	20.7%	27.1%
	Own	8.06%	0.89%	0.25%	0.23%	0.09%	0.04%	9.6%	8.1%
	RMO	0.02%	0.00%	0.00%	0.01%	0.00%	0.00%		0.1%
	Parent	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0%	0.1%

Panel B: First 30 minutes of the Main Trading Phase

		Limit orders			**Market orders**			**Average Quoting Activity**	**Average Trading Activity**
		New orders	Modification	Cancellation	New orders	Modification	Cancellation		
PURE HFT	Client	0.03%		0.02%	0.00%	0.00%	0.00%	0.1%	0.3%
	Own	2.09%	1.31%	1.70%				5.1%	1.9%
	RLP	4.31%	1.67%	4.27%				10.3%	0.0%
	MM	14.82%	0.43%	13.68%				28.9%	20.7%
MIXED HFT	Client	1.65%	0.85%	1.33%	0.00%	0.00%	0.00%	3.8%	8.8%
	Own	6.83%	0.96%	6.04%	0.01%	0.00%	0.00%	13.8%	35.0%
	RLP	2.39%		2.36%				4.7%	0.0%
	MM	13.26%	0.36%	12.67%				26.3%	7.7%
	Parent	1.69%	0.77%	1.51%	0.00%	0.00%	0.00%	4.0%	6.9%
NON-HFT	Client	0.60%	0.26%	0.23%	0.16%	0.00%	0.07%	1.3%	13.1%
	Own	0.42%	1.01%	0.25%	0.00%	0.00%	0.00%	1.7%	5.5%
	RMO	0.00%			0.00%	0.00%	0.00%	0.0%	0.0%
	Parent	0.00%						0.0%	0.0%

Table III
Speed of the Traders

This table shows the distribution of speed capacity for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT) and six account types (CLIENT, OWN, RLP, RMO, MM, PARENT) for the pre-opening phase and the first 30-minutes of main trading phase. We refer to speed as the time elapsed between order entry/modification and modification/cancellation of the same order. We report the number of observations for which the speed can be measured, the median and the 5th percentile of the speed distribution. Speed is expressed in milliseconds. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belongs to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Distribution of speed by stock-date

		Pre-opening Phase				First 30 minutes of the Main Trading Phase			
		Obs	Median	p5	p1	Obs	Median	p5	p1
PURE-HFT	Client	509	218'572.151	411.781	286.672	38'825	6'260.222	0.025	0.015
	Own	612'926	40.757	0.998	0.619	5'979'210	557.768	0.499	0.276
	MM	2'463	3.871	1.226	0.730	27'582'237	1'401.864	0.382	0.020
	RLP					12'468'990	415.033	2.107	0.938
MIXED-HFT	Client	270'723	10'559.414	252.372	77.849	3'785'219	8'570.877	6.016	0.026
	Own	481'779	7'777.581	452.859	34.957	12'042'621	3'265.591	0.360	0.017
	MM	115'776	4'000.250	152.875	50.503	25'462'584	4'191.120	2.315	0.219
	RLP	4	73'947.496	3'113.455	3'113.455	4'561'523	4'398.939	11.962	1.638
	Parent	32'749	146'145.375	3'094.530	1'035.097	3'938'282	10'990.470	1'000.906	998.590
NON-HFT	Client	176'896	2'011.020	470.504	57.052	965'473	16'935.029	36.383	0.018
	Own	136'782	4'155.566	186.675	38.503	2'388'079	5'732.241	21.666	0.480
	RMO	29	336'525.469	26'500.360	18'046.421	85	453'160.594	16'377.998	9'126.977
	Parent	290	437.349	18.275	12.879	186	35'925.279	3'104.647	1'722.902

Table IV
Order Submission

This table shows the total number of orders submitted/modified during the particular interval of the pre-opening phase (Panel A), the total number across stock-days divided by the number of 100 millisecond intervals (Panel B), and the results of the probit regressions estimation (Panel C), where each column represents an individual probit regression for each trader/account where the dependent variable is equal to one, if the median number of orders submitted/modified in a given stock-day-interval, for each 100 milliseconds bucket, is greater than the median across stock-day-intervals of the respective trader-account group (see Equation (3)). ***, **, * correspond to 1%, 5%, and 10% significance levels. Standard errors are clustered at the stock level. All intervals are mutually exclusive. The base case is indicated in the table. We exclude from the regression orders submitted in the previous days that are still in the limit order book. Data and regressions are presented for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT) and two account types (OWN and MM). The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Total number of new and modified order submitted per account and time interval

	PURE-HFT MM	PURE-HFT OWN	MIXED-HFT MM	MIXED-HFT OWN	NONHFT OWN
Previous days		44		909	46'463
From 7:15 to 8:10		3'145		22'194	7'759
From 8:10 to 8:30	884	1'579		213'492	2'483
From 8:30 to 8:59	1'403	3'206'245	46'710	667'999	970'950
Last minute	1'397	302'359	94'332	339'933	82'905
Last second	968	16'907	7'485	24'612	13'252
Last 100 milliseconds	4	1'346	526	8'164	3'417

Panel B: Number of new and modified order submitted per account for 100ms time interval

	PURE-HFT MM	PURE-HFT OWN	MIXED-HFT MM	MIXED-HFT OWN	NONHFT OWN
From 7:15 to 8:10		0.095		0.673	0.235
From 8:10 to 8:30	0.074	0.132		17.791	0.207
From 8:30 to 8:59	0.081	184.267	2.684	38.391	55.802
Last minute	2.328	503.932	157.220	566.555	138.175
Last second	96.800	1690.700	748.500	2461.200	1325.200
Last 100 milliseconds	4.000	1346.000	526.000	8164.000	3417.000

Panel C: Probit Regression on median order submission (100 ms buckets)

	PURE-HFT MM	PURE-HFT OWN	MIXED-HFT MM	MIXED-HFT OWN	NONHFT OWN
From 7:15 to 8:10				Base	Base
From 8:10 to 8:30	Base	Base		0.473***	-0.0211
From 8:30 to 8:59	-0.0498	0.355***	Base	0.0101	0.225***
Last minute	0.721***	0.0368***	-0.0665***	0.0264***	0.0113
Last second		0.137***	0.0862***	0.351***	0.0755***
Last 100 milliseconds		0.110***	0.0961***	0.0536***	-0.0139
# obs	456	25,872	13,619	47,772	31,764
T-test on equality of coefficients Fstat (Pvalue)					
$\beta_{830-859}=\beta_{Lastminute}$	198.9 (0.000)	82.8 (0.000)		8.7 (0.003)	30.4 (0.000)
$\beta_{830-859}=\beta_{Lastsecond}$		23.2 (0.000)		690.9 (0.000)	13.3 (0.000)
$\beta_{Lastminute}=\beta_{Lastsecond}$		45.9 (0.000)	140.0 (0.000)	758.1 (0.000)	6.3 (0.012)

Table V
Order Cancellation

This table shows the total number of order cancellations during the particular interval of the pre-opening phase (Panel A), the total number across stock-days divided by the number of 100 millisecond buckets (Panel B) and the results of probit regressions estimation (Panel C), for which each column represents an individual probit regression for each trader/account where the dependent variable is equal to one if the median number of orders cancelled in a given stock-day-interval, for each 100 milliseconds bucket, is greater than the median across stock-day-intervals of respective trader-account group (see Equation (3)). ***, **, * correspond to 1%, 5%, and 10% significance level. Standard errors are clustered at stock level. All intervals are mutually exclusive. The base case is indicated in the table. We exclude from the regression orders submitted in the previous days that are still in the limit order book. Data and regressions are presented for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT) and two account types (OWN and MM). The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Total number of cancelled order per account and time interval

	PURE-HFT MM	PURE-HFT OWN	MIXED-HFT MM	MIXED-HFT OWN	NON-HFT OWN
From 7:15 to 8:10		29		16'601	848
From 8:10 to 8:30	884	235		19'509	506
From 8:30 to 8:59	1'403	147'400	3'033	114'517	15'985
Last minute	203	133'554	4'906	116'507	9'787
Last second		3'977	756	7'046	1'040
Last 100 milliseconds		446		590	80

Panel B: Average number of cancelled order per account and time interval

	PURE-HFT MM	PURE-HFT OWN	MIXED-HFT MM	MIXED-HFT OWN	NON-HFT OWN
From 7:15 to 8:10		0.001		0.503	0.026
From 8:10 to 8:30	0.027	0.007		0.591	0.015
From 8:30 to 8:59	0.043	4.467	0.092	0.591	0.484
Last minute	0.006	4.047	0.149	3.531	0.297
Last second		0.121	0.023	0.214	0.032
Last 100 milliseconds		0.014		0.018	0.002

Panel C: Probit Regression on average order cancelation (100ms buckets)

	PURE-HFT MM	PURE-HFT OWN	MIXED-HFT MM	MIXED-HFT OWN	NON-HFT OWN
From 7:15 to 8:10		Base		Base	Base
From 8:10 to 8:30		0.411***		0.0823	0.0955***
From 8:30 to 8:59		0.0935	Base	0.0709***	0.0184
Last minute		0.137*	0.0876***	0.00741	-0.0472
Last second		0.322***	-0.212***	0.116***	-0.0415
Last 100 milliseconds		0.168**		0.0120	-0.0387
# obs		10,553	3,284	28,405	9,038
T-test on equality of coefficients Fstat (Pvalue)					
$\beta_{830-859}=\beta_{Lastminute}$		4.4 (0.037)		19.5 (0.000)	21.7 (0.000)
$\beta_{830-859}=\beta_{Lastsecond}$		82.7 (0.000)		6.0 (0.014)	16.3 (0.000)
$\beta_{Lastminute}=\beta_{Lastsecond}$		68.5 (0.000)	141.1 (0.000)	125.7 (0.000)	1.3 (0.250)

Table VI
Cumulative Profits

This table shows the cumulative profits, in euros, during the particular interval of the pre-opening phase (Panel A) and linear regressions estimation separately for each trader/account (Panel B). In panel B, each column represents an individual regression for each trader/account category where dependent variable is the total return for each interval-stock-day (see Equation (4)). ***, **, * correspond to 1%, 5%, and 10% significance levels. All intervals are mutually exclusive. The regressions are estimated without a constant. Data and regressions are presented for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT) and two account types (OWN and MM). The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Total Profits for each time interval per account and time interval of order submission

	PURE-HFT MM	**PURE-HFT OWN**	**MIXED-HFT MM**	**MIXED-HFT OWN**	**NON-HFT OWN**
Previous days				-9'884.02	-33'738.52
From 7:15 to 8:10		8'488.83		-7'107.70	-5'020.14
From 8:10 to 8:30		-2'293.02		-141'723.12	-7'655.94
From 8:30 to 8:59		-115'667.13	103.98	540'266.45	933'642.52
Last minute	81.82	194'036.68	49'224.66	1'185'957.42	137'699.88
Last second	8'100.02	148'265.81	21'702.22	126'087.88	68'944.08
Last 100 milliseconds	40.64	20'717.75	50'028.00	-18'247.89	55'721.31

Panel B: Regression on cumulative returns

	PURE-HFT MM	**PURE-HFT OWN**	**MIXED-HFT MM**	**MIXED-HFT OWN**	**NON-HFT OWN**
Forgotten Orders				-898.5	-267.8*
From 7:15 to 8:10		8.258		-25.66	-13.49
From 8:10 to 8:30		-4.343		-65.64***	-18.14
From 8:30 to 8:59		-21.36*	20.80***	73.07**	171.1
Last minute	16.36***	31.51*	11.25*	160.8***	35.17
Last second	10.83***	47.87***	15.28**	26.04***	15.81***
Last 100 milliseconds	13.55*	45.14***	335.8**	-3.612	25.87***
# obs	756	16,685	5,948	27,112	16,806
Adj R^2	0.034	0.003	0.012	0.002	0.000
T-test on equality of coefficients Fstat (Pvalue)					
$\beta_{830-859}=\beta_{Lastminute}$		4.2 (0.048)	2.5 (0.120)	3.5 (0.071)	0.8 (0.373)
$\beta_{830-859}=\beta_{Lastsecond}$		28.7 (0.000)	0.7 (0.399)	1.6 (0.213)	0.9 (0.360)
$\beta_{Lastminute}=\beta_{Lastsecond}$	4.7 (0.036)	0.7 (0.400)	0.3 (0.620)	6.0 (0.019)	0.3 (0.617)
$\beta_{Lastsecond}=\beta_{Last100ms}$	0.1 (0.727)	0.1 (0.791)	5.1 (0.030)	9.2 (0.005)	1.7 (0.198)

Table VII
Weighted Price Discovery Contribution (WPDC)

This table shows the average $WPDC$ (Panel A) and the linear regressions estimation (Panel B). Price discovery metrics are defined in Section IV.C. In Panel A, each column represents $WPDC$ for different intervals in the pre-opening phase, and the first 30 minutes of the main trading phase. The last line in Panel A, represents the proportion of price discovery left for a particular interval. In Panel B, each column presents thr estimation results of the linear regression (see Equation (9)) for different intervals. The regressions are estimated without a constant. For the purpose of $WPDC$ computation, intervals are not mutually exclusive. ***, **, * correspond to 1%, 5%, and 10% significance levels. The $WPDC$ is presented for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT), six account types (CLIENT, OWN, RLP, RMO, MM, PARENT) during the pre-opening phase and the first 30-minutes of the main trading phase. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Weighted Price Discovery Contribution (WPDC)

		Entire pre-opening	**From 8:10**	**From 8:30**	**Last minute**	**Last second**	**Last 100 milliseconds**	**First 30 min. of Main Phase**
PURE HFT	Client	0.32%	-0.09%	-0.12%	-0.14%	-0.03%		-0.31%
	MM	-0.03%	-0.02%	-0.02%	-0.06%	-0.49%		-38.31%
	OWN	-11.75%	-9.07%	-8.86%	-1.97%	-13.61%	-8.75%	-2.47%
MIXED HFT	Client	-8.75%	-7.86%	-8.90%	-2.89%	-2.30%	-1.66%	-6.88%
	MM	-6.03%	-5.07%	-5.06%	-10.54%	-2.79%	-0.75%	-6.03%
	OWN	-47.47%	-37.35%	-40.74%	-51.92%	-54.61%	-81.83%	-31.03%
	Parent	-12.71%	-10.47%	-10.03%	-14.49%	-0.91%	-0.52%	-10.00%
NON HFT	Client	3.09%	-16.48%	-13.27%	-4.31%	-0.82%	-1.42%	-1.03%
	OWN	-16.96%	-13.74%	-13.16%	-13.78%	-24.39%	-4.27%	-3.85%
	Parent	0.24%	0.24%	0.25%	0.11%	-0.04%	0.01%	0.02%
	RMO	0.05%	-0.08%	-0.07%	0.00%	0.00%		-
	WPDC left		-122.83%	-121.78%	-48.77%	-10.60%	-1.71%	

Panel B: WPDC Regression

		Entire pre-opening	**From 8:10**	**From 8:30**	**Last minute**	**Last second**	**Last 100 milliseconds**	**First 30 min. of Main Phase**
PURE HFT	Client	0.00324	-0.000950	-0.00123	-0.00142**	-0.000273		-0.00314
	MM	-0.000259	-0.000195	-0.000223	-0.000608*	-0.00493**		-0.383***
	OWN	-0.118***	-0.0907***	-0.0886***	-0.0197***	-0.136***	-0.0875***	-0.0246***
MIXED HFT	Client	-0.0875***	-0.0786***	-0.0890***	-0.0289***	-0.0230***	-0.0166**	-0.0688***
	MM	-0.0603***	-0.0507***	-0.0506***	-0.105***	-0.0279***	-0.00749**	-0.0603***
	OWN	-0.475***	-0.374***	-0.407***	-0.519***	-0.546***	-0.818***	-0.310***
	Parent	-0.127***	-0.105***	-0.100***	-0.145***	-0.00909***	-0.00520*	-0.100***
NON HFT	Client	0.0309	-0.165***	-0.133***	-0.0431***	-0.00817***	-0.0142***	-0.0103
	OWN	-0.170***	-0.137***	-0.132***	-0.138***	-0.244***	-0.0427***	-0.0384***
	Parent	0.00239**	0.00237***	0.00252***	0.00107	-0.000434	8.03e-05	0.000171
	RMO	0.000452	-0.000763	-0.000739	-3.27e-05	-1.18e-05		-0.00001
Adj R^2		0.340	0.318	0.597	0.865	0.837	0.858	0.469
# obs		3,012	3,012	3,012	2,761	2,761	1,976	4,518

Table VIII
Net Liquidity Provision

This table shows the average net liquidity provision, i.e., liquidity provision minus liquidity consumption relative to the total trading volume (Panel A) and the linear regressions estimation (Panel B). Liquidity provision metrics are defined in Section IV.D. In Panel B, each column presents estimation results of the linear regression (see Equation (12)) for different intervals. The regressions are estimated without a constant. ***, **, * correspond to 1%, 5%, and 10% significance levels. The NLP is presented for three trader groups (PURE-HFT, MIXED-HFT, NON-HFT), and six account types (CLIENT, OWN, RLP, RMO, MM, PARENT) during the pre-opening phase and the first 30-minutes of the main trading phase. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

Panel A: Average net liquidity provision

		Opening auction	First 30 minutes
PURE-HFT	Client	-0.09%	-0.03%
	OWN	1.11%	1.49%
	MM	0.01%	-10.84%
	RLP		0.01%
MIXED-HFT	Client	-3.82%	1.46%
	OWN	-2.29%	2.26%
	MM	1.68%	3.50%
	Parent	0.28%	0.01%
	RLP		-5.10%
NON-HFT	Client	0.96%	3.42%
	OWN	2.19%	3.79%
	RMO	0.04%	-0.01%
	Parent	-0.08%	0.03%

Panel B: Net liquidity provision regression by stock-date

		Opening auction	First 30 minutes
PURE-HFT	Client	-0.000902***	-0.000312*
	OWN	0.0111***	0.0149***
	MM	0.00007	-0.108***
	RLP		0.000109***
MIXED-HFT	Client	-0.0382***	0.0146***
	OWN	-0.0229***	0.0226***
	MM	0.0168***	0.0350***
	Parent	0.00283	-0.0510***
	RLP		0.000126***
NON-HFT	Client	0.00961*	0.0342***
	OWN	0.0219***	0.0379***
	RMO	0.000396***	-0.000115***
	Parent	-0.000785***	0.000288***
# obs		100,672	118,976
Adj R^2		0.0117	0.226
Clustered St. Err: By Stock			

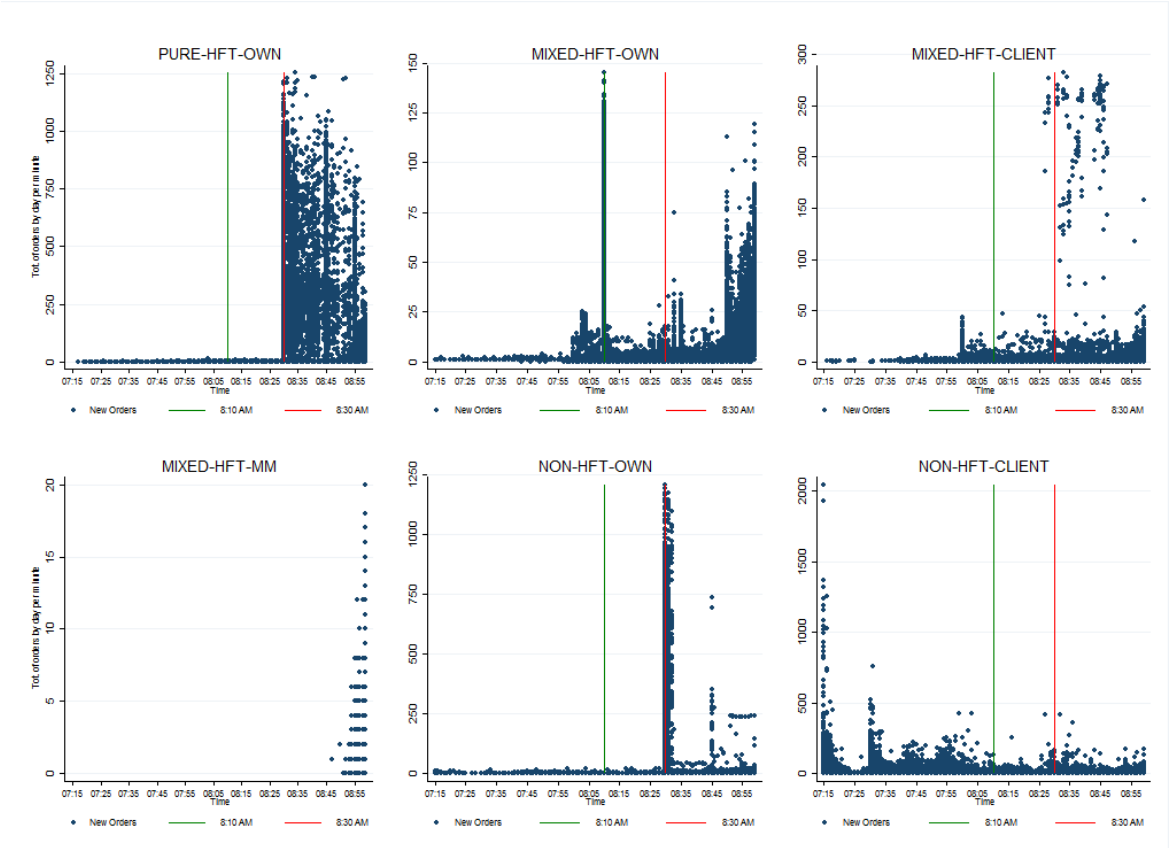

Figure 1. New Order Submissions during the Pre-Opening Phase

This figure shows the total number of new order submissions for the most relevant trader/account categories. Each dot represents the total number of new order submitted during the one-minute window interval, for each stock-day. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

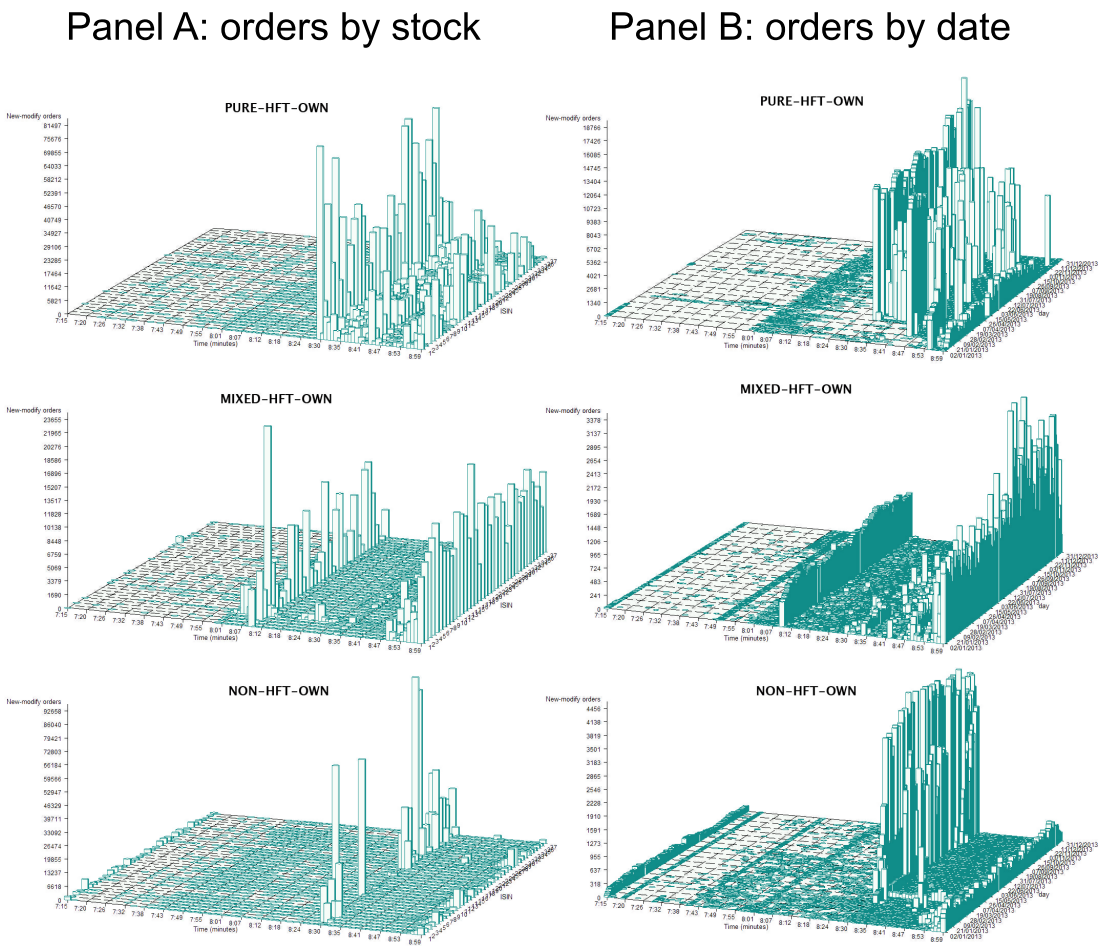

Figure 2. New Order Submissions and Modifications across Stocks and Days during the Pre-Opening Phase

This figure shows the total number of new order submissions for the most relevant trader/account categories. Each bar represents the total number of new order submitted during the one-minute window interval, for each stock, summed across days (Panel A) and for each day, summed across stocks (Panel B). The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belongs to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

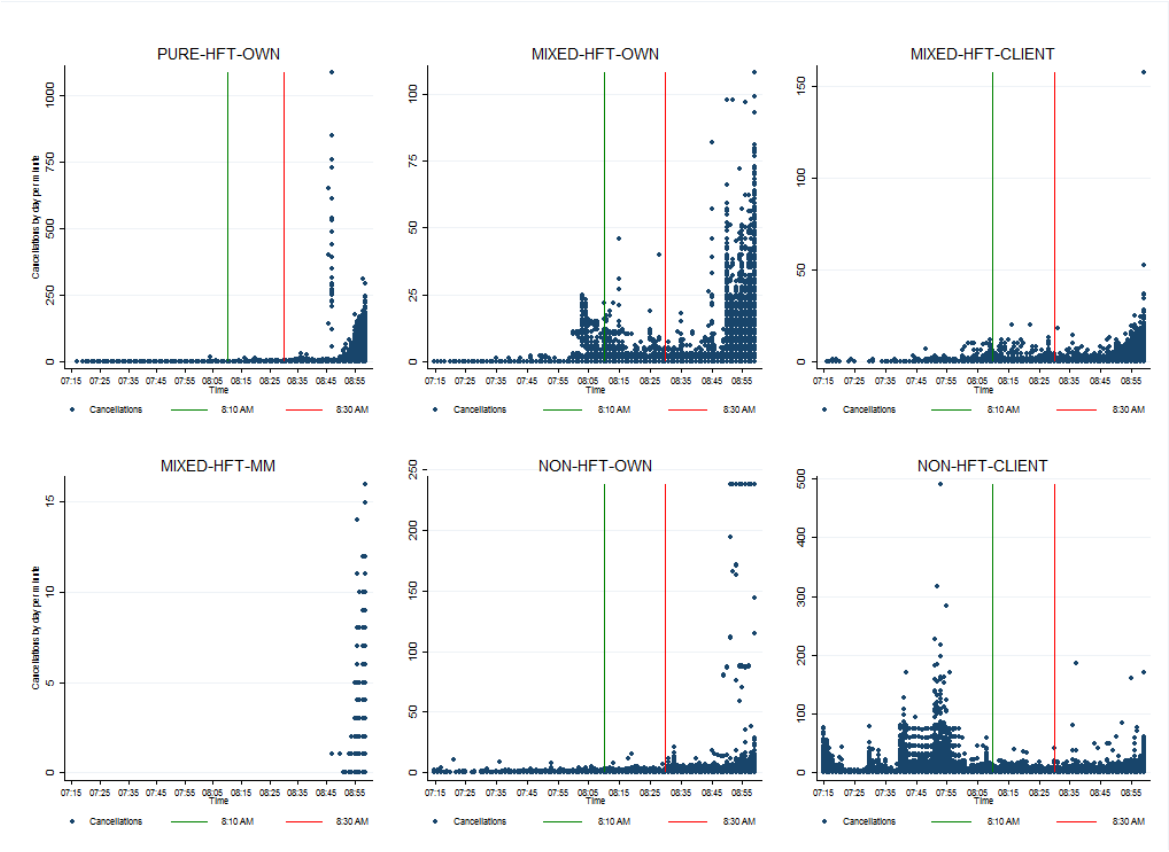

Figure 3. Cancellations during the Pre-Opening Phase

This figure shows the total number of order cancellations for the most relevant trader / account categories. Each dot represents the total number of cancellations during the one-minute window interval, for each stock-day. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

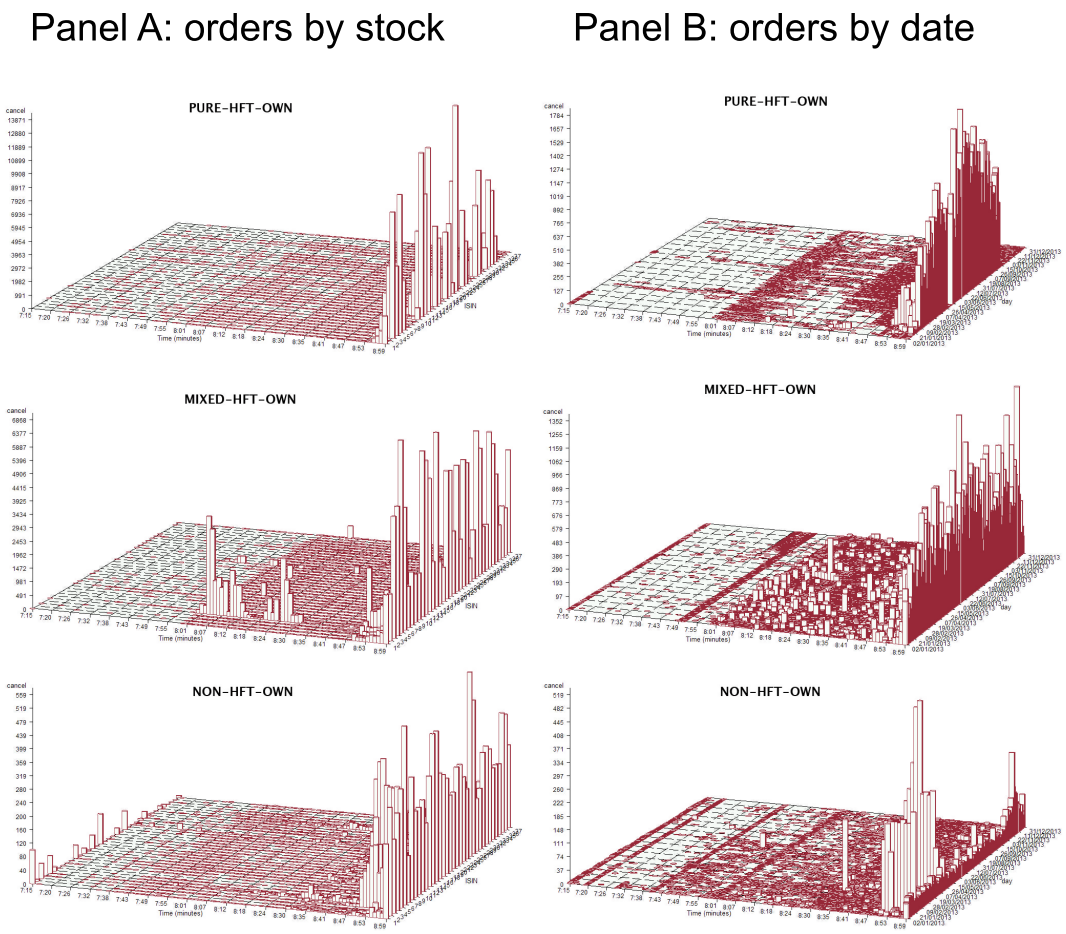

Figure 4. Cancellations across Stocks and Days during the Pre-Opening Phase

This figure shows the total number of cancellations for the most relevant trader/account categories. Each bar represents the total number of cancellations submitted during the one-minute window interval, for each stock, summed across days (Panel A) and for each day, summed across stocks (Panel B). The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

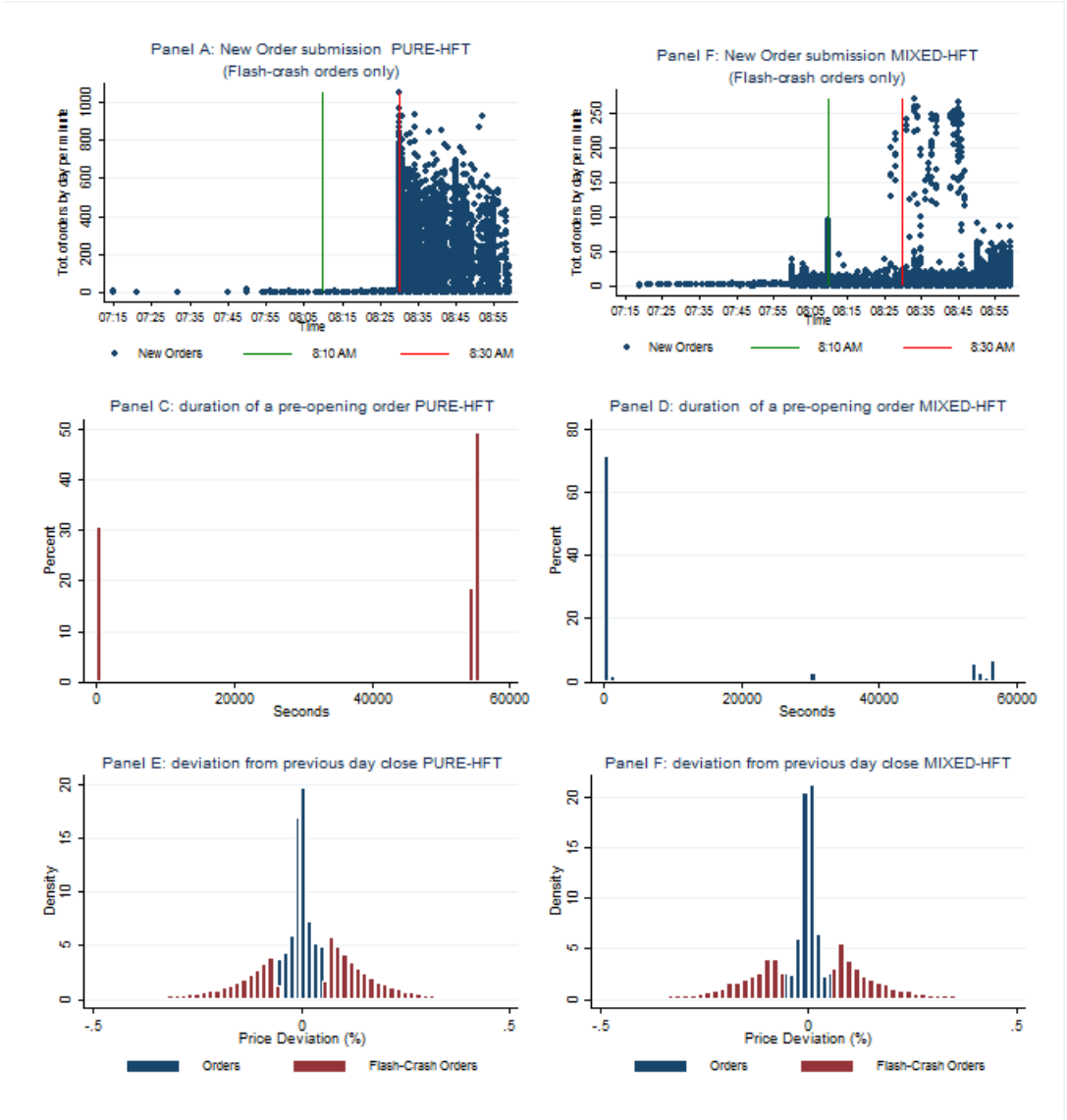

Figure 5. Flash Crash Orders during the Pre-Opening Phase

This figure, Panels A and B, show the total number of new flash crash order submissions, where each dot represents the total number of new order submitted during the one-minute window interval, for each stock-day; Panels C and D show the order lifetime in seconds; Panels E and F display the distribution of the (log) price difference of the previous day's closing price from the limit prices of the orders submitted during the pre-opening phase by PURE-HFTs and MIXED-HFTs, respectively. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

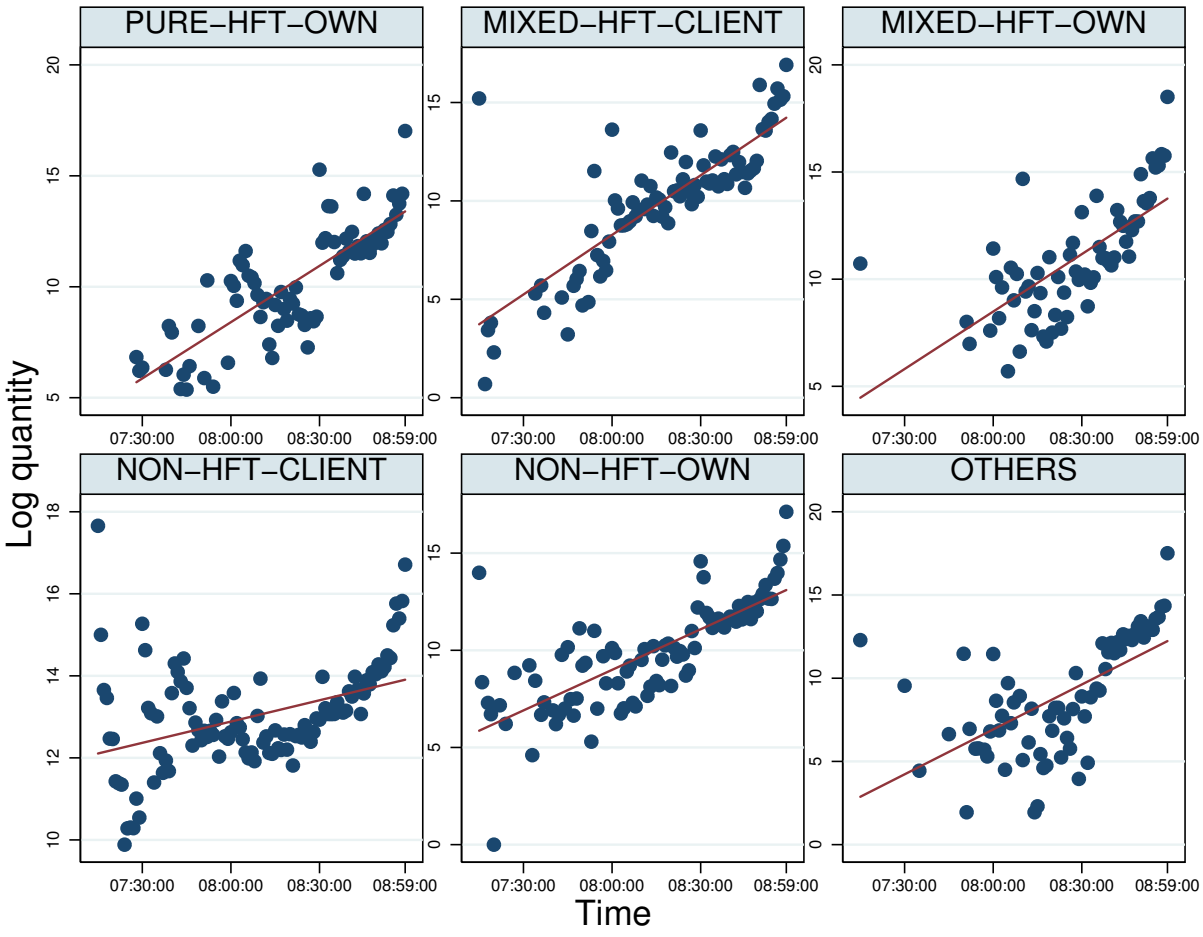

Figure 6. Time of submission and quantity executed at the auction

The scatter plots shows, for each trader/account, the (log) of the total quantity executed at the auction and the time where the executed orders have been submitted. We exclude from the representation all market orders and the aggressive orders submitted during the pre-opening phase. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

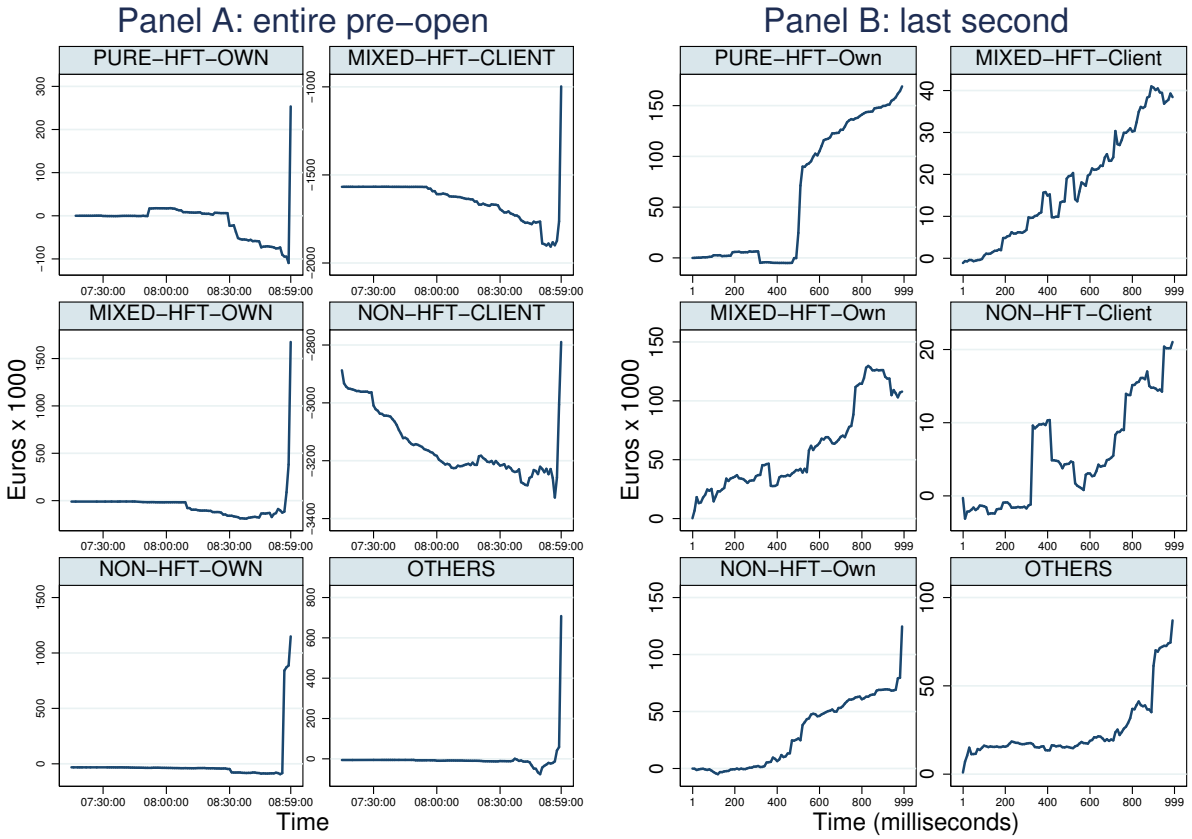

Figure 7. Time of submission and cumulative profits

The figure shows, for each trader/account, the cumulative profits (aggregated across executed order-stock-days) on the position taken at the auction and the time where the executed order has been submitted during the entire pre-opening phase (Panel A) and during last second of hte pre-opening phase (Panel B). We assume that position taken in the auction is liquidated one minute after the auction at the market price. The sample is composed of 37 stocks traded on NYSE-Euronext Paris that belong to the CAC40 index, for the year 2013. Order flow data, with trader group and account flags are from BEDOFIH.

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