On August 29th of this year, news broke of talks between some of the world's largest high-frequency trading (HFT) firms to build the infrastructure necessary for an ultra-fast communication between Chicago and Japan. Back in 2007, Daniel Spivey pitched his idea to several hedge funds: partner with him to create a fiber optic cable line, at the cost of only $300 million USD, to connect the Chicago Mercantile Exchange to the NASDAQ in New Jersey. Many funds jumped on the opportunity for the project would allow firms to trade with lower latency – the time it takes send and receive information – and hence operate with an advantage worth billions. Ever since, there has been an arms race to achieve the theoretical infimum latency time across HFTs. The new multi-billion dollar Chicago-Japan link is simply the next step. Now, quite expectantly academics and regulators have been baffled over the billions of dollars in which firms are pouring into propriety hardware. In addition, questions such as why the immense secrecy surrounding trading algorithms, why do we see price fluctuations happening by the millisecond, and is there actually a sort of hidden merit to HFTs with respect to market quality are of utmost importance. A proper inquiry into the operations and implications of HFTs should survey and analyze a large breadth of recent literature, and thus is the approach of this essay. However, to begin, one must decipher the important semantics of "high-frequency trading" for, even today, there does not exist a consensus with regard to one definition.

Algorithms are now ubiquitous in trading - beyond just HFTs. For example, an institutional investor will hide their intention to execute large orders with algorithms so as to insulate against an HFT beating the investor to the trade, or markets swings. A common denominator of HFTs, as derived from elements of the SEC's and CFTC's definitions, is that their algorithms autonomously trade continuously with low-latency technology and high speed market connections, with market positions being tremendously brief. However, beyond these characteristics, HFT's strategies are numerous. Some HFTs process world-wide information extraordinarily quickly to ride up or down imminent price ticks. Others employ arbitrage strategies between markets trading correlated assets. Others are considered "market-makers", by continuously quoting both buy and sell orders thereby providing liquidity and making profit from the bid-ask spread. As a result, our characteristic-based definition will not be sufficient for a discussion on the implications of HFTs in financial markets - rather, distinguishing between HFT strategies will serve instrumental for fruitful discourse.

Now a classic, in 1985 Glosten and Milgrom presented a model on how bid and ask quotes were generated by market-makers (back then, a person on the floor of an exchange). Due to the risk of asymmetric information – in that an investor may be better informed about the imminent future progression of a security – the bid-ask spread becomes non-zero to cover potential losses from this risk. The main finding applicable to our discussion on HFTs is that as asymmetric information increases, the profitability of an uninformed party's market participation decreases, and hence increasing the bid-ask spread.[1] Thus, we must look towards the recent theoretical literature to discover the nuances of HFT versus the classical non-computer-based system of trade execution.

[1] It should be noted that the bid-ask spread's inverse is the most common measure of market liquidity – and generally accepted economic theory regards high liquidity as socially beneficial.

Foucault, Hombert, and Rosu (2016) develop a model based on Kyle (1985) where a certain type of speculative firm is modelled dynamically interacting with a liquidity supplier – the market-maker. At the start, the firm has better long-run predictions over asset value than the market-maker. Furthermore, both agents receive a flow of signals regarding the asset's true value. In equilibrium, if the firm is faster at trading on information relative to the market-maker and focuses on trading in the extreme short-term (and therefore is analogous to a directional HFT), the firm (henceforth considered HFT) trades quickly to benefit off any discrepancies between the impact of information on short-term and long-term pricing. The paper expounds on how directional HFTs generate increases in price volatility and account for a larger proportion of trading volume. Moreover, in accordance to the Glosten-Milgrom model – one predicts given an HFT, asymmetric information increases, and therefore so does the bid-ask spread. However, the paper claims that the market-maker's overall risk in the presence of HFTs decreases for the market-maker may now partake in more valuable long-term speculation since HFTs become focused on the short-run. Unfortunately, given the two counter effects on liquidity when directional HFTs enter the market, the derivation of the claim that one effect is consistently larger in magnitude than the other is based solely off the authors' payoff scheme. As such, without any economic reasoning establishing a priori over one effect's dominance, or at least reasoning with probabilistic characteristics, such a claim is weak indeed. Regardless, this paper does provide well constructed and testable conclusions concerning how directional HFTs impact price volatility and trading volume.

Also based on Kyle (1985) is Rosu's 2016 paper. Rosu incorporates the presence of many speculative firms differentiated by speed, and inventory aversion - which transforms the strategy of those who trade fast from the long-term to the extreme short-term (these being the same result which allowed us to previously call liquidity demanding fast traders directional HFTs). The model result in directional HFTs generating the majority of price volatility and trading volume. Due to these characteristics, Rosu subsequently claims that increased volume and volatility are desirable since prices now reflect information as soon as it becomes available, and hence improves liquidity.[2] As such, and even with different approaches, theoretical literature on HFTs do indicate liquidity demanding HFTs as causing the beneficial (to all market participants) characteristic of greater market liquidity.[3]

Taking a different approach to the previous two is that of Biais', Foucault's and Moinas' 2015 paper. In lieu of a model of interaction between an HFT and market-maker, they approach HFTs through the lens of a (macroeconomic) welfare analysis. Their model considers a market with multiple venues for the trading of same or correlated assets. A firm in this market must determine if it would like to invest in low-latency technology. The critical assumption which differentiates the fast firm is assuming that he is able to search

[2] Rosu makes the connection between liquidity and informative prices though a different (although for all intensive purposes here, equivalent) definition of liquidity – the inverse price impact coefficient as defined in Kyle (1985).

[3] We do note the possible bias in findings as these two articles are authored (partially or fully) by Ioanid Rosu. However, through consultation of several other HFT literature surveys, one finds that HFTs causing greater liquidity is ubiquitous in the theoretical (and empirical) literature. Surveys provided in References.

for more attractive quotes and garner advanced information. One result is that more fast traders cause less gains from trading to all market participants due to the existence of costs from asymmetric information charged by market-makers (Glosten-Milgrom). Furthermore, when firms also base their low-latency investment decision on the fraction of fast firms in the market, one may find multiple equilibrium with the socially inefficient attribute of all firms wishing to invest. As such, the paper concludes that fast traders result in an outcome similar to an arms race - fast firms inherently create negative externalities for all market participants. It is imperative to note that if a firm invests in this technology – this does not necessarily classify the firm as an HFT.[4] However, it does suffice to say that any findings that result in social costs or benefits derived from being a fast trader does additionally hold for HFTs as they're a subset of fast traders; whereas in the micro-models before there would be non-homogenous decisions between HFTs and a general fast trader.[5] As such, it is valid to argue that the findings applicable to fast firms from this paper also apply to HFTs.

Hendershott's, Jones' and Menkveld's (2011) empirical paper establishes lower bid-ask spreads as being caused by algorithmic trading. They establish this claim by analyzing the 2003 implementation of an automatic price quoting system at the NYSE. During this transition, the new automatic system was implemented in waves, and therefore served nicely as an instrumental variable. Thus, at least for large-cap U.S. stocks, one can conclude an increase in algorithmic trading does increase liquidity. We now look further into the literature to see if such conclusions may also be drawn for HFTs.

Menkveld (2013), and Jovanovic and Menkveld (2016) bridge the gap in conclusions from general algorithmic to HFT in their papers. Both papers use data from the 2007 entry of an HFT market-maker into the Dutch stock market. The first paper makes the claim that the HFT made its profits by providing liquidity at the cost of resupplying its inventory, and that due to multiple trading venues for the same or correlated assets, it is only natural that an HFT comes along to synthesize these markets into one large market free of arbitrage (for any slow trader that is). As such, the notion that HFTs are the natural evolution of a classical market maker does have significant merit. In the second paper, the authors approach the same data now in curiosity of the impact of an HFT market-maker on market quality and liquidity. Through a differences-in-differences approach, Belgian stocks, un-impacted by the entrance of this HFT, were used for comparison. In regard to market quality, it was found that there was a 10% increase in trade frequency, an asymmetric information cost reduction of 23% – both statistically significant – and no statistically significant increase in volatility.[6] In terms of liquidity, the 15% reduction in bid-ask prices indicated a statistically significant increase in liquidity. Therefore, these results do indeed correspond to the theoretical literature implying increased liquidity and market quality over the entrance of HFTs, despite how the theory and empirical results are based on liquidity demanders and suppliers

[4] An example of efficient order execution by an institutional investor was provided near the introduction.

[5] In the interest of avoiding self-contradiction, our first two theoretical papers made the assumption that as a firm becomes faster in information processing, its (very-) short-term positions dominates as its trading strategy and therefore satisfy our HFT definition. If

[6] Details on how costs arising from asymmetric information were measured may be found in Black (1995).

respectively.

A final empirical paper by Gai, Yao, and Ye (2013) claims better HFT technology does not effect liquidity, and is divisive to other market participants. They study low-latency-enabling NASDAQ technological upgrades in 2010, which was rolled successively to portions of the market enabling clean econometric analysis. The data showed that only cancelled orders increased, while trading volume was stagnant, and only a subtle increase in bid-ask spreads and market depth occurred. The paper explains the surprising result over liquidity by how speed may only determine the provider of liquidity, and need not translate into price undercutting as was the case of an HFT versus a non-algorithmic market-maker. Furthermore, a concern articulated in this paper is that as HFTs continue along an arms race, it is not just trivially effecting the market, but also overloading trading venues with an incomprehensible number of non-imperative limit orders. Therefore, market supervision becomes increasingly difficult for regulators since methods for simply deciphering trades is expensive and time consuming. Where this paper makes its vital contribution to is its proposition that HFTs may be necessary and beneficial in their ability to link trading venues; but also that technological progression of HFTs impose strong negative externalities on the markets and all of society.

The biggest problem with trying to actually understand HFT's role in the market is a lack of adequate data. The data which is available to academics usually falls under the category of a market transition to HFTs, or public data from exchanges. Consequently, given the tumultuous evolution of HFTs, unequivocal results seem improbable in this field. As for the likely conclusions which can be drawn from data, and as is supported through theoretical models, evidence does positively favor the existence of HFTs in markets similar to those of Europe and North America. However, beyond the mere existence of HFTs, both models and evidence bring to light a cautioning message for regulators: be wary of an arms race.

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