Review

Order Routing Decisions for a Fragmented Market: A Review

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Abstract: This paper reviews the up-to-date theoretical, empirical, and experimental literature related to the trading venue choice in the context of the fragmented equity markets. We provide a brief background on the history of trading fragmentation in the equity market and its determinants. We discuss the direct and indirect impacts of the market fragmentation on market quality in various dimensions, including liquidity, volatility, and price efficiency. Next, we identify possible determinants and channels from theoretical and empirical studies that could explain order routing decisions and present the possible directions for future research. Finally, we discuss the major regulatory reforms in the U.S. equity market on routing venue decisions. This topic is relevant in current times when phenomena such as "GameStop Frenzy" have drawn significant attention to commission-free trading venues.

Keywords: market structure; fragmentation; market quality; trading volume; order routing decision

1. Introduction

The evolution of the United States stock exchange started in 1790 with the birth of the Philadelphia stock exchange. After more than 200 years of the evolutionary process, equity trading in the U.S. is currently dispersed across 16 national exchanges, more than thirty alternative trading systems, and numerous broker-dealers and wholesalers (SEC 2021). The market has never had such fragmentation before, and traders nowadays have many options in choosing venue to execute their orders. Each trading venue competes against the other in terms of fee structure and trading protocols. Moreover, strong trading volume growth, technology innovation, and policy initiatives intensify the competition among exchanges. An exchange must adopt ever more advanced trading technology or update pricing models and trading rules to attract more market share. Ultimately, market fragmentation[1] has increased. By merging with and acquiring regional exchanges, three groups, namely the New York Stock Exchange (NYSE) group, Nasdaq group, and the CBOE Global market, together dominate the trading volume in the U.S. equity market. Meanwhile, the competition is explicitly enforced by the US Regulation National Market System (Reg-NMS) regulatory policy that allows new trading venues. Newly launched exchanges, such as the Investor Exchange in 2016, Members Exchange (MEMX), Miami International Securities Pearl Exchange (MIAX), and Long-Term Stock Exchange (LTSE) in 2020, foster diversity through innovation in pricing features.

Market fragmentation impacts the investor and market as well. On the one hand, intensified competition lowers transaction fees and ultimately benefits market participants. On the other hand, varying levels of venue transparency and the heterogeneity in transaction speeds change information asymmetry among investors, thus raising adverse selection concerns. Especially, the recent increase in retail trading gamification phenomena such as "Game Stop" has drawn significant attention to commission-free trading brokers and the payment for order flow (PFOF) practice by market makers in off-exchanges. Therefore, examining the routing order decision is extremely relevant in the current time and is worth exploring.

In this paper, we concentrate on the portion of the microstructure literature that addresses order flow fragmentation, specifically, order routing decisions[2]. We provide an up-to-date survey of the main theoretical developments and empirical studies of the determinants of venue routing choice. We also identify several promising directions for future research.

The routing decision is directly affected by the market design, which decides the venue's pricing structure, levels of transparency, and execution quality. We document the changes in the studies from examining features of call vs. continuous markets to limit order vs. hybrid market. Remarkably, studies such as Venkataraman (2001) and Brogaard et al. (2021) highlight the role of human intermediates and show that floor trading service by humans is irreplaceable because of their expertise. The experience that floor-traders have allows them to deal with highly complex issues related to liquidity provision situations more efficiently than an algorithm. Therefore, human floor trading service ultimately improves market quality by narrowing the spreads and decreasing pricing errors. Moreover, the routing venue decision involves the trade-offs among transaction cost, execution risk, and adverse selection risk. In fact, types of traders matter as well in terms of the trade-off. Informed traders are concerned more with the trade-off between cost and execution risk as they already have the profitable private information, while uninformed traders focus more on the trade-off between the cost and adverse selection risk. Meanwhile, the routing venue decision is also influenced by technology. The nano-second response speed allows high-frequency traders to quickly react to new information and send orders across venues to harvest the information arbitrage profit. At the same time, exchanges must continually invest in low-latency technology, including co-location, to attract order flow.

In the end, we discuss the major regulatory reforms in the U.S. equity market that impact the market trading environment and the routing venue decision. Overall, the routing venue decision shapes the direction of the exchanges' evolution and the policy attention, and the changes in the exchanges' design and policy reforms again alter the routing venue decision.

The rest of the survey is organized as follows. Section 2 discusses the development of U.S. trading venues and the consequences of increased fragmentation and venue competition. Section 3 describes the possible determinants and channels that could explain the order routing choice. Section 4 reviews the impact of policy reforms on the routing decision, and Section 5 concludes.

2. Market Fragmentation

This section briefly shows the evolution of U.S. equity exchanges and discusses the related theoretical and empirical literature that focus on the impact of market fragmentation and venue competition. First, we show that the development of the U.S. trading venues results in a highly fragmented market. Next, we review related studies on market fragmentation and show that fragmented market changes venue competition and market quality such as liquidity and volatility.

2.1. The Evolution of U.S. Equity Trading Venues

The modern U.S. equity market has been evolving from floor trading by brokers who read the ticker tape and bid on offer to purely electric trading coded into computer algorithms. Table 1 presents the timeline in the evolution of U.S. equity national exchanges. Notably, the electronic communications network (ECN) was developed in the 1990s to allow direct-matched trading between buyer and seller without an intermediary. The big ECNs, such as Archipelago and Instinet, started gaining popularity as alternative trading systems.

Table 1. Timeline of the evolution for U.S. equity national exchanges.

Year	Timeline
1790	Philadelphia Stock Exchange founded (PHLX)
1817	New York Stock and Exchange Board (NYSE) was officially founded
1835	Boston Stock Exchange (BEX) founded
1882	San Francisco Stock Exchange founded Chicago Stock Exchange (CHX) founded
1885	Cincinnati Stock Exchange founded (renamed as National Stock Exchange in 2003)
1899	Los Angeles Oil Exchange founded
1924	The New York Curb Market created (renamed as New York Cub Exchange in 1929, and renamed as American Stock Exchange in 1953)
1956	Pacific Coast Stock Exchange was created by the merge of San Francisco Stock Exchange and Los Angeles Oil Exchange (rename as Pacific Stock Exchange in 1973)
1971	Nasdaq founded
1996	Archipelago created
2005	Bats Global Markets (BATS) founded Archipelago purchased Pacific Stock Exchange (PCX)
2006	Archipelago was acquired by NYSE and the exchange renamed as NYSE Arca
2007	Boston Stock Exchange (BSE) was acquired by Nasdaq and renamed as Nasdaq OMX BX Philadelphia Stock Exchange (PHLX) was acquired by Nasdaq and renamed as Nasdaq PHLX
2008	American Stock Exchange (AMEX) was acquired by NYSE and renamed as NYSE American BATS launched BZX exchange
2010	Direct Edge launched EDGA and EDGX exchanges BATS launched BYX Exchange
2014	BATS merged with Direct Edge
2016	Cboe acquired Bats Global Markets Investors Exchange launched
2017	National Stock Exchange (NSX) was acquired by NYSE and renamed as NYSE National
2018	Chicago Stock Exchange (CHX) was acquired by NYSE and renamed as NYSE Chicago
2020	Members Exchange (MEMX) launched MIAX Peral's Exchange (MIAX) launched Long-term Stock Exchange (LTSE) launched

Market participants benefit from the evolution of the technology. First, the stock trading process became much easier with the proliferation of the internet and personal computer. Second, the reduction in the brokerage commission due to enhanced competition also incentivized traders to participate in the equities market. Figure 1 shows the changes in total equities trading volume (in a million shares) in the U.S. market from 2011 to 2021. The average trading volume in the U.S. equities market increased by half, from 160 billion shares per month in 2011 to 250 billion shares per month in 2021.

Figure 1. Change in trading volume in 2011 vs. 2021. This figure plots the average number of shares executed in the overall market per month in 2011 and 2021. The data was taken from the CBOE's U.S. Equities Market Volume Summary (https://www.cboe.com/us/equities/market_share, accessed date: 20 August 2021).

Moreover, equity trading volume steadily increased by greater participation from retail investors induced by zero brokerage commissions and the widely adopted "working from home" policy under the Coronavirus disease (COVID-19) pandemic. In consequence, the market makers in off-exchange such as Citadel and Virtu gained significant volume share. Figure 2 depicts the change in the market share from 2011 to 2021 in the U.S. equity market. Combined with the increased trading volume shown in Figure 1, it is clearly implicit that the volume in the U.S. equity market has significantly increased in the past ten years, while the markets also have become highly fragmented. Moreover, Figure 2 suggests two trends in terms of fragmentation: first, the competition among exchanges intensified as the number of securities exchanges increased from 13 to 16 within ten years. The merger and acquisition activity has blown in the past ten years, as many regional exchanges such as Boston Stock Exchange (BEX) and Chicago Exchange (CHX) were acquired by the big national exchange groups. In addition, other new independent exchanges, such as the Investors Exchange, MIAX Pearl exchange and Members exchanges, and the Long-Term Stock Exchange, were launched in recent years to increase the competition. Second, the off-exchange trading gained a significant proportion (increased from 30.28% to 44.24%), while the volume share for traditional primary exchanges steadily decreased during the past two years. For example, the market share for NYSE and NASDAQ dropped 3.64% and 2.35%, respectively.
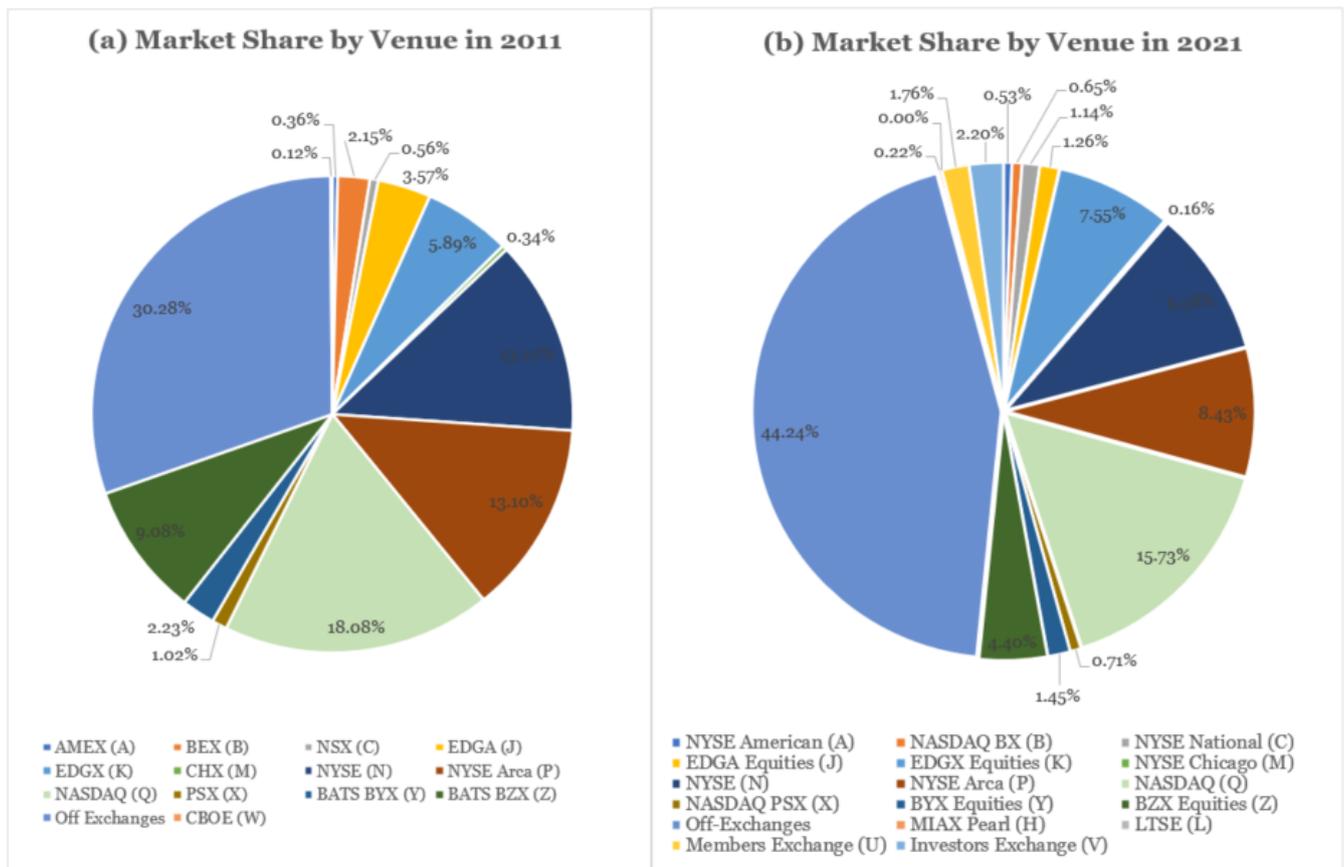
Figure 2. The average market share by venue in 2011 vs. 2021. This figure presents the changes in the market share by venue in 2011 (panel **a**) vs. 2021 (panel **b**). The market share is calculated as the volume executed on a particular market venue divided by the total volume on all venues. The volume data by the exchange is obtained from the CBOE's U.S. Equities Market Volume Summary (https://www.cboe.com/us/equities/market_share, accessed date: 20 August 2021).

2.2. The Conequences of the Market Fragmentation

The equilibrium in the early theoretical market microstructure studies does not incorporate the multiple venue consideration. Early theoretical studies, such as the multi-markets strategic trading model by Chowdhry and Nanda (1991) and the limit order auction markets model by Glosten (1994), assume that the liquidity supply is competitive. Therefore, combined with the order matching system and large tick size, these models imply that a fragmented market should not affect the quotes. However, many empirical studies in the same period disagreed with the theoretical suggestions. For instance, Easley et al. (1996) and Hasbrouck (1995) observe that different markets obtain significant differences in information contents of order flow, hence arguing that the market fragmentation impacts market quality. Still, the theoretical predictions and empirical findings on market fragmentation are mixed. The conclusions about fragmentation on market quality are diverse and differ according to the factors considered.

The directive consequence of market fragmentation is the intensified competition across trading venues. Several studies suggest that the competition that raised from the fragmentation can improve the market quality by reducing fees, promoting innovation, and hence improving quality (Chao et al. 2017). For example, Macey and O'Hara (1997) suggest that the multi-venues environment allows traders to have a chance to compare the execution quality under each venue, and ultimately the trader could achieve the best execution. Biais et al. (2000) theoretically examine competition among liquidity suppliers and limit order trading in a decentralized market. Their model assumes that market makers are risk-neutral, and the model predicts that the trading volume increases under a high

decentralized market. Furthermore, Buti et al. (2017) analyze competition between a limit order book and a dark pool. Their model implies that the introduction of a dark pool increases trading volume. Overall, both Biais et al. (2000) and Buti et al. (2017) predict that the fragmentation could increase overall market volume.

Nevertheless, there is still an ongoing debate on whether market fragmentation improves or harms liquidity. The supporters who discuss the impact of fragmentation on liquidity mainly focus on the competition perspective, given that the fragmented market increase the competition, hence it could push the exchanges to lower their fee, thus promote the liquidity (see the theorical prediction by Colliard and Foucault (2012); Pagnotta and Philippon (2018), and empirical supports by Boehmer and Boehmer (2003); De Fontnouvelle et al. (2003); Nguyen et al. (2007); O'Hara and Ye (2011); Menkveld (2013); He et al. (2015); Foucault and Menkveld (2008)). Conversely, the negative view of the impact of fragmentation on liquidity stresses the information asymmetry perspective. A fragmented market increases adverse selection, hence harms liquidity. The theories were developed by Chowdhry and Nanda (1991) and Dennert (1993) and supported empirical studies can be found in Bessembinder and Kaufman (1997b); Amihud et al. (2003); Hendershott and Jones (2005); and Bennett and Wei (2006). For instance, recent theoretical work by Baldauf and Mollner (2021) examines the market relegation effects by allowing exchanges to adjust the trading fees in responding to competition and adverse selection, and their empirical tests in the Australian market support theoretical predictions that fragmentation increases the arbitrage opportunities, hence increases adverse selection. In addition, a theoretical model by Yin (2005) postulates that increased search costs due to fragmentation decrease competition among liquidity providers and harm liquidity and price discovery.

Alongside the two contradictory views above, several studies argue that the relationship between fragmentation and liquidity should be U-shaped. Degryse et al. (2015) suggest that market fragmentation improves the liquidity in lit-exchanges while harming liquidity in off-exchanges[3]. Gresse (2017) empirically tests whether positive or negative effects dominate the fragmentation on liquidity. The results show the spreads substantially decrease in both lit fragmentation and dark trading venues after the implementation of MiFID in Europe[4], suggesting the benefits from market competition outweigh the negative effect from information asymmetry. Wittwer (2021) studies the welfare effects of connecting the disconnected markets and the model predicts that market fragmentation decreases market depth. Chen and Duffie (2021) extend Wittwer's model by increasing the number of exchanges in the equilibrium. Chen and Duffie (2021) confirm Wittwer's (2021) prediction and further show that market fragmentation also alters trader's strategy to submit a more aggressive order, hence increasing allocative efficiency. Ultimately, overall price informativeness increases.

To sum up, there are exhaustive discussions about the impact of fragmentation on liquidity. However, as suggested by Barardehi et al. (2019), traditional liquidity measures may underestimate the liquidity provision under the current fast-trading environment. Therefore, to better estimate trading cost and understanding the impact of the liquidity under the fragmented market, it is still worthy to compare the liquidity among lit- and off-exchanges by using the new liquidity measures, such as the average per-dollar price impacts of fixed-dollar volume that was proposed by Barardehi et al. (2019).

Alongside liquidity, market volatility by fragmentation is another important dimension that is worth emphasizing. Prices under fragmented markets are more disposed to order imbalances, while increase transitory volatility. The Biais (1993) model conducts theoretical research comparing centralized and fragmented markets and provides two predictions: first, the fragmented markets should increase stock price volatility since the information is fragmented. Second, the spread should be less volatile in fragmented market. Easley et al. (1996) and Bessembinder and Kaufman (1997a) assume heterogeneous information in the model and show that trading fragmentation leads to information fragmentation, which in turn results in higher volatility and wider spreads. Ultimately, both of the works suggest that fragmentation leads to cream-skimming effects and harms

markets. In empirical tests, Madhavan (2012) examines the Flash Crash and finds that more fragmented stocks had a more significant negative impact during the Flash Crash in 2010. By contrast, Boneva et al. (2016) empirically tests the effect of fragmentation on volatility for the London Stock Exchange and finds that fragmentation lowers overall volatility. In addition, Boneva et al. (2016) further separates the overall fragmentation into dark trading and visible fragmentation and suggests that the effects of dark trading and visible fragmentation on market quality are different. For further discussion towards venue competition under a fragmented trading environment, readers may refer to a literature survey by Gomber et al. (2017), who review the literature that focus on examining the economic arguments and motivations underlying market fragmentation.

3. The Determinants of the Trading Venue Choice

This section reviews a body of theoretical and empirical studies about possible determinants of the trading venue choice. This overview emphasizes that the trader's routing choice is influenced by many factors other than simply by transaction cost. Table 2 provides the information on the fee model for U.S. National Exchanges. Table 3 at end of this section summarizes studies on potential determinants of order routing decisions and Appendix A presents market microstructure empirical studies on order routing decisions.

Table 2. U.S. national exchanges fee schedule.

Exchange	Fee Model	Adding Liquidity	Removing Liquidity	Net Fee
NYSE America	Maker–Taker	(0.0045)–0.0002	0.0002	(0.0043)–0.0002
Bats EDGX	Maker–Taker	(0.0017)	0.00265	0.00095
NYSE Chicago	Maker–Taker	(0.002)	0.003	0.001
NYSE	Maker–Taker	(0–0.0029)	0.00275–0.003	0.00015–0.003
NYSE Arca	Maker–Taker	(0.0015) Tape A	0.003	0.0015
		(0.002) Tape C	0.003	0.001
Nasdaq	Maker–Taker	(0–0.00305+)	0.003	<0.003
Bats BZX	Maker–Taker	(0.002) Tape A	0.003	0.001
		(0.0025) Tape C	0.003	0.0005
Nasdaq OMX PSX	Maker–Taker	(0.0023)	0.003	0.0007
IEX	Flat	0.0003	0.0003	0.0006
Bats BYX	Taker–Maker	0.0019	(0.0005)	0.0014
Nasdaq OMX BX	Taker–Maker	0.0024	0.0003–(0.0027)	(0.003)–0.0027
NYSE National	Taker–Maker	$0.001–$0.0028	(0.0002–0.003)	(0.002)–0.0026
Bats EDGA	Taker–Maker	0.003	(0.0024)	0.0006

Note: 1. Tape A is NYSE-listed stocks. Tape C is NASDAQ-listed stocks; 2. ATS fees are individually negotiated between the ATS operator and the participant. This table presents all 13 U.S. national exchange fee schedules for per share price $1.00 or above at 8 January 2019. Rebate indicated by parentheses. For some exchanges, the fee and rebates vary based on the trading volume per order. Data are from each exchange's respective website.

First of all, trading venue choice is fundamentally influenced by the trading system structure (market design) in each exchange. The focus of the studies on the type of the trading system has evolved along with the trading system itself. Early papers on trading system structure mainly compare call markets vs. continuous markets and suggest that the call markets improve the information efficiency of overall market welfare, while continuous markets could be complements for call auction markets. The theoretical discussion can be found in Brennan and Cao (1996) and Vayanos (1999), and empirical studies can be found in Amihud and Mendelson (1991); Neal (1992); Biais et al. (1999); and Corwin and Lipson (2000). With the market innovation through time, the discussion of market design shifts to the limit order market and hybrid market. Some theoretical studies include Foucault (1999); Parlour and Rajan (2003); Foucault et al. (2005); Goettler et al. (2005); Hendershott and Moulton (2011), and the recent work by Budish et al. (2019). Notably, there is an uptrend discussion about the role of human intermediation in market design. For example, Venkataraman (2001) argues that the floor-based market structure with human intermediation (ex. NYSE) has lower execution costs than an automated limit

order market. Additionally, Bessembinder and Venkataraman (2004) suggest that a central market (downstairs market) has relatively more information and smaller trades than the dealership market (upstairs trading), and traders strategically choose across markets to minimize the expected execution costs. Brogaard et al. (2021) examine the market quality around the COVID-19 pandemic when NYSE suspended floor trading and show that floor trading improves liquidity and price discovery.

Table 3. Overview of studies on potential determinants of order routing decisions.

Determinants of Order Routing Decisions		Theorical Studies	Empirical Tests
Execution Cost	Transaction Fee		
		Limit order trading model with fixed or endogenized fee	Colliard and Foucault (2012)	Cardella et al. (2017); Malinova and Park (2015); Battalio et al. (2016b); Jørgensen et al. (2018); Comerton-Forde et al. (2018); Clapham et al. (2021)
		Limit order trading model with differentiating maker & taker fee	Foucault et al. (2013)	
		Limit order trading model with fee exogenously	Cimon (2021)	
	Execution Quality	Inventory model	Biais (1993); De Frutos and Manzano (2002)	Boehmer et al. (2007); Battalio et al. (2016a); Peterson and Sirri (2003); Thomas et al. (2021); Boehmer et al. (2005); Garvey et al. (2016); Ernst et al. (2021); Thomas et al. (2021)
		Single period strategic trade model	He et al. (2006)	
		Dynamic model	Pagano and Röell (1996); He et al. (2006); Degryse et al. (2009); Maglaras et al. (2015); Colliard and Foucault (2012)	
	Information Risk	Two-period strategic trade model	Ye (2011)	Grammig et al. (2001); Jain et al. (2003); Jiang et al. (2012); Nimalendran and Ray (2014); Garvey et al. (2016); Hatheway et al. (2017)
		Two-period sequential trade model	Zhu (2014)	
		Limit order trading model	Foucault et al. (2007)	
Trader Type	Informed vs. Uninformed Traders	Strategic trade model	Kyle (1985)	Kavajecz and Odders-White (2004); Garvey and Wu (2011); Jones and Lipson (2004); Ready (2014); Chakravarty et al. (2012); Barber et al. (2008); Chevalier and Ellison (1999); Coval and Stafford (2007); Gao and Lin (2015); Han and Kumar (2013); O'Hara (2015); Boehmer et al. (2021); Jain et al. (2021)
		Two-period strategic trade model	Ye and Zhu (2020)	
	Fast vs. Slow Traders	Search and bargaining model	Üslü (2019)	Brogaard et al. (2015); Hasbrouck and Saar (2013); Hendershott et al. (2011)
		Sequential trade model	Biais et al. (2015)	
		Continuous limit order trading model	Budish et al. (2015); Baldauf and Mollner (2020)	
		Dynamic model	Roşu (2019)	
	Trader's Behavior and Strategy	Limit order trading model	Parlour and Seppi (2003)	Garvey et al. (2016)
		Symmetric continuous limit order trading model	Kyle et al. (2018)	

Table 3. *Cont.*

Determinants of Order Routing Decisions		Theorical Studies	Empirical Tests
Market Condition and Stock Characteristics	Market Condition	Two-period sequential trade model	Zhu (2014)	Jiang et al. (2012); Vuorenmaa (2014); He et al. (2015); Barclay et al. (2003); Jurich (2021); Anselmi et al. (2021)
	Stock Characteristics	Strategic trade model	Baruch and Saar (2009)	Harris (2003); Nguyen et al. (2005); He and Lepone (2014); Garvey et al. (2016)
Trading Technologies		Continuous limit order trading model	Baldauf and Mollner (2020); Brolley and Cimon (2020)	Hau (2001); Aitken et al. (2017); Brogaard et al. (2015); Frino et al. (2014)

Figure 3 shows the current U.S. equity structure. Based on pre-trade opacity, the trading venues can be separated into lit- and off-exchanges. A lit-exchange refers to an exchange where quote information (bid and ask) are posted publicly. Currently, all U.S. national securities exchanges are lit-exchanges. In contrast, an off-exchange refers to a venue that does not provide price quotation information. Based on pricing structure, lit-exchanges can be further separated into maker–taker, taker–maker and other pricing structure. Maker–taker exchanges can also be referred to as "traditional exchanges", where the exchange charges fees for traders who take away liquidity (market order) and provides a rebate for traders who provide liquidity (limited order). A taker–maker exchange is also called an "inverted exchange" or "inverted fee exchange", where exchanges charge fees for traders who provide liquidity and provide a rebate for traders who take away liquidity. Besides maker–taker and taker–maker exchanges, some exchanges, such as the Investors Exchange (IEX), adopt a flat-fee model that charges a fixed fee regardless the type of order.
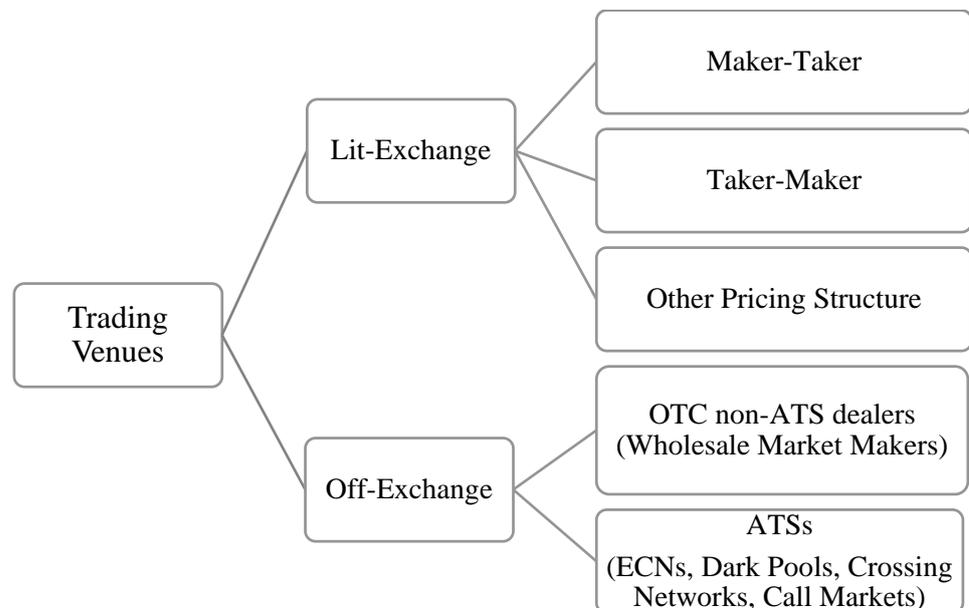

Figure 3. The U.S. Equity Market Structure.

Alternative Trading System (ATS) is an off-exchange that matches the buyer and seller without going through an intermediary. It includes several types, and the most prevalent one is the Electronic Communication Network (ECN), which pairs the buyer and seller directly by a computer algorithm. A dark pool is a type of ATS that provides anonymity

for trading large orders with automated execution. It is generally used by institutional investors. Crossing networks (CNs) are similar to dark pools for large trading. Unlike other venues, where buyer and seller determine price, call markets execute buyer and seller orders at a predetermined price at predetermined time intervals. Alongside ATSs, wholesalers (market makers) can also be broadly included in the off-exchange definition, and they provide liquidity by buying and selling stocks as a counterparty. The Financial Industry Regulatory Authority (FINRA) classifies wholesalers as over-the-counter (OTC) non-ATS dealers.

Overall, different trading system structures provide different degrees of transparency and execution quality. This is associated with different levels of the execution costs[5] and investors always seek for maximizing profit with minimized execution costs (Bertsimas and Lo 1998).

In the following subsection, we discuss studies on the trading venue choice and execution costs from three dimensions: direct transaction cost, execution quality cost and adverse selection cost.

3.1. Execution Cost

3.1.1. Transaction Fee

Perhaps the most important determinant for trading venue choice is the direct transaction fee. Intuitively, order routing decisions should be negatively affected by the fee that exchanges charge.

Table 2 demonstrates the fees structure across competing exchanges. Due to competition, exchanges usually modify their pricing on a monthly basis[6]. The national exchanges in the U.S. are operated under three types of pricing model: (1) the maker–taker (MT) model or traditional model, where the traders pay a certain fee for taking liquidity and getting a rebate for generating liquidity; (2) the taker–maker (TM) model or inverted model, in which offering rebates to the liquidity taker and charging a fee to liquidity maker; and (3) the flat fee model, where traders pay for transactions despite taking or providing liquidity. Angel et al. (2015) point out that in order to maximize profit, brokers strategically send their marketable orders to inverted fee exchanges to gain taker rebates or sell to wholesale dealers to capture the spread and send their limit orders to traditional exchanges to gain maker rebates. Unlike the lit-exchanges, the Alternative Trading System (ATS)[7] operator and market makers in off-exchanges operate either by negotiating fees individually with the participants or under the payment for order flow (PFOF) model.

In theoretical development, Colliard and Foucault (2012) propose limit order trading models with a fixed or endogenized fees, and their model predicts that the change in total execution fees should affect trading volume. Foucault et al. (2013) extend the model by differentiating fees between makers and takers. Hendershott and Mendelson (2000) show that dark pools[8] obtain a relative cost advantage. Cimon (2021) develop a theoretical model to support the empirical study of broker's routing incentives by Battalio et al. (2016b) and confirm that brokers' route order decision is primarily based on the fee, rather than execution quality.

Many empirical studies have tested the effect of the fee schedule on trading activities (Clapham et al. 2021; Comerton-Forde et al. 2018). For example, Cardella et al. (2017) suggest that although the take fee and make fee both reduce trading activities, the magnitudes in reduction are different. Battalio et al. (2016b) examine the fee schedule on broker routing decision and find that brokers have incentives to route the order to the venue which provides the highest rebate. The effect of fee and rebate on liquidity provider incentives on volume is also confirmed in other national markets. For example, Malinova and Park (2015) examine the introduction of the liquidity incentive program (maker-taker fee) on the Toronto Exchange, and Jørgensen et al. (2018) investigate the induction of the fee on Oslo Stock Exchange.

3.1.2. Execution Quality

Alongside direct transaction costs, routing decisions may also be influenced by the execution quality, such as the liquidity, price discovery, spreads, fill rate, execution speed, and order cancellation rate. Many studies compare the execution quality and cost for electronic and traditional exchanges[9]. Maglaras et al. (2015) focus on investors who queue orders and propose a multiclass queueing model of the limit order book (LOB) to investigate the trading optimization decision. Boehmer et al. (2007) examines the exchanges' market execution quality report on the trading volume and finds that the exchange with better execution quality (lower cost and higher fill rate) subsequently attracts more order flow. The recent study by Ernst et al. (2021) also reaches the same conclusion by examining the effect of publishing off-exchange trade reports.

Liquidity perhaps is the key component in the execution quality because it directly measures execution risk, and greater liquidity reduces information asymmetry and improves price accuracy (Fox et al. 2019). A low liquidity venue could imply a low probability to execute the order (high execution risk). Many studies suggest the off-exchange with pre-trade opacity should have a relatively higher degree of execution risk than the lit-exchange, which displays the quote information on the order book. Degryse et al. (2009) build a dynamic multi-period model to examine the competition between dealer markets and dark pools and analyze the routing choice for dark pool orders under different transparency requirements. In addition, Degryse et al. (2009) incorporate endogenous liquidity supply and demand in their model, and their model predicts that the order flow depends on the degree of transparency. Biais (1993) incorporates transparency into a one-period inventory model to examine the market performance for fragmented and centralized market structures under the Bertrand price competition assumption. De Frutos and Manzano (2002) extend the Biais (1993) model by lifting the restriction to allow the dealer to be risk-aversion. De Frutos and Manzano (2002) show that the risk-averse dealer has less incentive to compete in a high pre-trade transparency market when the counterparty's ex-ante quote is available. Overall, both Biais (1993) and De Frutos and Manzano (2002) suggest that the posted quotes reduce uncertainty, and the greater pre-trade transparency may have detrimental effects on liquidity.

In contrast, Pagano and Röell (1996) predict that greater transparency in the market mechanism should enhance the liquidity and lower the trading cost for uninformed traders. The experimental study by Flood et al. (1999) presents a different finding that the reduced search costs by pre-trade transparency reduces uncertainty, thus it facilitates trading, and improves liquidity. Menkveld et al. (2017) suggest that the pre-trade opacity for off-exchanges raises the execution uncertainty. For that reason, lowering pre-trade transparency may result in a higher execution risks when there is a liquidity shock.

Boehmer et al. (2005) empirically study pre-trade transparency by examining the introduction of the NYSE's OpenBook service, and their results indicate that improvement in pre-trade transparency enhances liquidity. Garvey et al. (2016) find the time-to-execution is much longer in dark venues than in lit venues, and the average fill rate of marketable order executed at dark venues is lower than at lit venues. Thomas et al. (2021) show that dark trading decreases liquidity and increases the post-earnings-announcement drift (PEAD). Battalio et al. (2016a) empirically investigate the trading cost differences between payment for order flow (PFOF) and the maker–taker models in the option markets and suggest that the maker–taker model provides a better unadjusted relative effected spread than the PFOF model. Peterson and Sirri (2003) compare the exchanges execution quality in 1996 within a four-week sample by analyzing the effect of order preferencing. Their results show that NYSE, which was the primary market, obtains better quotation and execution quality for market orders with smaller effective spreads than other regional exchanges. Moreover, Peterson and Sirri (2003) further show that the preferencing regional exchanges have narrow effective spreads and higher execution probability than no preferencing regional exchanges.

Furthermore, Colliard and Foucault (2012) developed a theoretical model, showing that investors may shift their preference to limit orders with less fill rate in response to lower trading cost. Ultimately, the investor can be worse off. He et al. (2006) modeled and empirically examined the impact of internalization procedure (preferencing) on execution quality, and critics that the overall market order execution quality worsens as more uninformed order flow routed and internalized in off-exchanges.

3.1.3. Information Risk (Adverse Selection)

One of the distinguishing features among trading systems is anonymity. Exchanges with anonymity features should be preferred by traders who do not want to publicly disclose their position. For example, institutional investors utilize ATSs to place large size order for preventing information leakage. Theoretical models predict that anonymity attracts more informed orders and thus aggravates the adverse selection problem (Benveniste et al. 1992; Fishman and Longstaff 1992; Forster and George 1992; Röell 1990). Lipson (2003) suggests that the information of the order flow is not similar across venues. Foucault et al. (2007) propose a limit order trading model that explicitly connects anonymity with information asymmetry. Foucault et al. (2007) show that anonymity improves liquidity when the fraction of informed trading is small. Grammig et al. (2001) empirically test stocks that are simultaneously traded at both the floor trading system and anonymous electronic cross-network on the Frankfurt Stock Exchange and find that the non-anonymous floor trading system has less informed trading than the anonymous electronic market.

There are rich studies that explicitly compare the order informativeness in lit- vs. off- exchanges. The current theoretical studies provide two different predictions[10]: Ye (2011) uses a strategic trading model developed by Kyle (1985) to examine the impact of split informed trades across venues and suggests that the introduction of dark pools reduces volatility and price discovery. In contrast, Zhu (2014) uses the sequential trade model developed by Glosten and Milgrom (1985) to explore the relation between the dark pool participation with adverse selection and argue that the introduction of the dark pool should improve price discovery. Ye (2011) assumes that that only informed traders can select venues. Zhu (2014) extends the model of Ye (2011) by allowing both informed and uninformed traders under a self-selection mechanism in choosing venues. Zhu (2014) shows that the execution risk in the dark pool is high for informed traders as they tend to trade in the same direction. As a result, lit-exchanges should be a better choice for the informed investor. Based on the above prediction, Zhu (2014) suggests that the lit-exchanges should have more informed order flow, and dark exchanges should attract more uninformed order flow.

The empirical evidence points towards a different conclusion. Grammig et al. (2001) examine the relationship between anonymity and informed trading in the German stock market, and show how anonymity attracts informed trading. In contrast, Jiang et al. (2012) investigate the information quality of the order flow in lit- and off-exchanges and find that the order flow executed in off-exchanges is less informed than in lit-exchanges. Garvey et al. (2016) examine the information contents in marketable orders executed in both lit and dark venues, and their results reveal that the trade at lit-exchange contains information towards future price direction while the trade at off-exchange does not. Nevertheless, Hatheway et al. (2017) argue that as dark venues segment the market by attracting the uninformed order flow away from lit markets, dark venues may engage in cream-skimming, harming market quality.

Conversely, Jain et al. (2003) argue that the probability of informed trading is no different on the anonymous market than on the non-anonymous market since the informed traders may split orders and send them to multiple venues. The empirical test by Nimalendran and Ray (2014) supports Jain et al. (2003) in that the informed trader tends to split orders between lit and off-exchanges. In addition, Nimalendran and Ray (2014) find that the order executed in lit-exchanges provides some price discovery.

The above studies discuss the information asymmetry based on the nature of the market design, while the information asymmetry changes with the new information dissemination. For example, the announcement reveals new information to the market, changes the information asymmetry, and updates the investors' belief towards the estimated investment future cash flow (Bamber et al. 1997; Barron et al. 2005; Choi 2019; Chung et al. 2013; Dugast 2018; Kim and Verrecchia 1994). The changes in belief can be reflected in stock price, volume, and volatility around the macroeconomic and firm news (Chae 2005; Kurov et al. 2019). Menkveld et al. (2017) document the shift of trading volume from dark pools to lit-exchanges after macroeconomic news announcements. Indriawan (2020) shows the difference in the trading volume and market quality for ASX and Chi-X in the Australian market around macroeconomic news announcements. Cox (2020) examines the dynamics of the market fragmentation around earnings announcements and finds that the proportion of the off-exchange volume increases around the earnings announcements. Mishra et al. (2021) confirm Cox (2020), and further show that the dynamic of the fragmentation is different around earnings and repurchasing announcements. The off-exchanges trading volume share increases around scheduled earnings announcements, but it does not change around unscheduled repurchasing announcements.

3.1.4. Summary and Further Discussions

The evidence discussed in the above sections suggest that the trader's routing order decision is directly influenced by the execution cost, and the execution cost can be viewed from three dimensions: the transaction cost, the execution quality, and the information asymmetry cost. Traders may strategically choose the venue for profit maximization. McAleer et al. (2017) review the theoretical, econometric and statistical models that connect the decision sciences and financial economics.

In fact, several studies suggest that the final venue choice decision may depend on multiple trade-offs between the cost, execution probability, and information asymmetry risk. For instance, Boehmer (2005) compares the SEC rule 1Ac1-5 execution quality report for NYSE and Nasdaq and finds that Nasdaq has a greater execution cost but faster execution speed than NYSE. The findings in Boehmer (2005) infer that the final venue choice decision may depend on multiple trade-offs between cost, execution probability, and information asymmetry risk. Friederich and Payne (2007) examine the trade-off on routing decisions and suggest that the investor's routing decision is driven by execution and information risks. The order routing decreases when the venue has a high execution risk, high asymmetry information risk, and/or low liquidity. An influential paper by Menkveld et al. (2017) proposes a pecking order hypothesis in explaining the routing decision. Menkveld et al. (2017) suggest that the investor prefers to trade at low-cost-low-immediacy venues (ex. dark pools) on days without information shocks and will switch to high-cost but high-immediacy venues (ex. lit-exchanges) if there is an information shock with increased liquidation urgency. Yet, Brolley (2020) argues that the trade-off between cost vs. immediacy has already existed through marketable vs. limit orders in lit-exchanges, and the limit orders are a natural substitute to dark orders. Thereby, the trade-off consideration for the investor is between immediacy vs. price improvement. Instead of choosing venues, investors strategically choose order types to limit the execution risk. For further discussion about the microstructure models about the information asymmetry and liquidity, we refer the reader to Madhavan (2000) and Biais et al. (2005) for a comprehensive microstructure literature survey.

3.2. Trader Type and Trading Strategies

In the previous section, we discussed how the routing venue choice is influenced by the market design and associated varieties of risk. This section moves our discussion to the market participant and presents theoretical and empirical papers about the role of trader type and trader strategy on the routing decision.

3.2.1. Informed vs. Uninformed Trader

Based on the information that traders could obtain, theories separate the traders as informed and uninformed traders. Traditional microstructure models tend to view individuals and institutions differently based on the level of information that traders could obtain. The institutions are viewed as informed investors, while individuals hold heterogeneity beliefs and are often thought of as uninformed traders. Kavajecz and Odders-White (2004) and Garvey and Wu (2011) suggest the focus of trade-offs among the transaction cost, the execution risk, and the adverse selection risk are different based on the types of the investor. Informed traders should be more concerned with the trade-off between the cost and execution risks as they already have the private profit information, while uninformed traders may focus more on the trade-off between the cost and adverse selection risk. Jones and Lipson (2004) examine the retail order flow in NYSE and find that retail order flow has better execution quality than non-retail order flow.

Earlier research focuses on examining the impact of informed trades, proxied by institutional trades, on the market. According to the strategic trade model developed by Kyle (1985), informed traders camouflage their trading by breaking their trade sizes. Ye and Zhu (2020) extend Kyle's (1985) strategic model to examine the informed trader's choice between lit- and off-exchanges by allowing order splitting for the informed investor. Ye and Zhu (2020) show that informed traders increase dark pool utilization to hide the information. Ready (2014) empirically examines the institutional orders in two block dark pools and finds that those with high information have less probability of executing in dark pools. In practice, the institutions generally make the soft dollar agreement with a particular broker to minimize execution costs. These soft dollar brokerage firms will be more favored by institutional investors (Conrad et al. 2001). In addition, Chakravarty et al. (2012) show that the informed institutional investor applies the intermarket sweep order (ISO) by breaking up large orders and sending them over to multiple trading venues to maximize fragmentation arbitrage profits and hide information.

On the other hand, under most microstructure theoretical discussions, the retail investors were treated as uninformed noise traders and it is assumed that the trade direction from the retail traders would be equally distributed (Shleifer and Summers 1990; Easley et al. 2002; Foucault et al. 2011; Zhu 2014). However, much empirical evidence points out that retail trading also conveys information about future stock prices[11]. The empirical studies show that retail investors have less liquidity constraints, lower agency costs, and smaller trades than institutional investors (Barber et al. 2008; Chevalier and Ellison 1999; Coval and Stafford 2007). Notably, retail investors are attracted by stocks with lottery features (Gao and Lin 2015; Han and Kumar 2013).

In addition, as many behavioral finance and asset pricing papers discuss[12], retail investors' trading also obtains a strong herding pattern. Readers may refer to Patel et al. (1991); Wermers (1999); Barber et al. (2008) and McAleer et al. (2018a) for more discussion towards herding behaviors. Hasso et al. (2021) exploit an exogenous 2021 GameStop frenzy event and confirm that retail investors prefer highly volatile stocks with lottery features. Moreover, Dimpfl and Jank (2016) show that the retail investor's attention further subsequently raises stock market volatility.

Given the critical role of retail trading flow, one natural question that is raised: where does the retail trading volume go? In the U.S. market, the orders placed by retail investors are not directly reaching the limit order book. Retail investors mainly place orders through retail brokers, and retail brokers make the routing decision. At the same time, retail brokers have the incentives to route order based on size of the commission and rebates (Battalio et al. 2016b; Cimon 2021). As a result, O'Hara (2015) and Boehmer et al. (2021) document most marketable orders placed by retail investors in the U.S. equity market are either internalized or executed by wholesale market makers, which belong to off-exchanges. Jain et al. (2021) study the impact of the zero-commission event for retail brokers on the routing, and they find that the retail brokers which newly announced zero commission policytend to route more orders to the off-exchange market maker in order to gain the payment for

order flow. Significantly, given the GameStop trading frenzy by the retail investors in 2021[13], the role of retail trading on the overall market quality and price discovery has raised attention. A promising direction for future research may explore the interaction between the retail investor's attention, market fragmentation, and routing order decisions.

3.2.2. Fast vs. Slow Trader

Based on trading speed, microstructure theories separate the traders as fast and slow traders[14]. Traders compete with each other by the reaction speed to new information. Fragmentation induces high-frequency trading in order to take the information advantage. In particular, with technology innovation, some traders utilize algorithmic trading to respond to a market event at the millisecond level (referred as the high-frequency trader).

Many theoretical studies focus on discussing the impact of high-frequency trading on market quality and overall welfare. For instance, Üslü (2019) applies the search-and-bargaining model to discuss the impact of exogenous heterogeneity in investors' search speed. The model by Biais et al. (2015) allows the interaction between fast and slow traders and shows that the information advantages from faster traders could result in adverse selection for the slower traders. Budish et al. (2015) provide a model to examine the high-frequency trading on the market design and social welfare. Baldauf and Mollner (2020) extend Budish et al. (2015) to include high-frequency trading into the information acquisition procedure by endogenizing the informed trading and HFT reaction. Furthermore, the theoretical model proposed by Roşu (2019) allows one to examine informed trading at different speeds.

Many empirical studies show the positive relationship between high-frequency trading (HFT) and market quality in lit- and off-exchanges. The HFT could potentially lower the adverse selection cost, improve market quality under liquidity, price discovery, and the short-term volatility dimensions (Brogaard et al. 2015; Hasbrouck and Saar 2013; Hendershott et al. 2011). Van Van Kervel (2015) argues that increased number of faster traders could result in more order cancellations in a relatively high-latency venue, creating frictions and harming slow traders. Shkilko and Sokolov (2020) show that the differential in a traders' trading speed harms market quality.

With technology enabling faster speeds, fast traders can actively seek latent liquidity across venues to make an arbitrage profit. Hasbrouck and Saar (2009) document a trading "fleeting orders" phenomenon, namely submitting a limit order and quickly canceling within a second. Hasbrouck and Saar (2009) explain that increased numbers of "fleeting orders" results from new dynamic trading strategies. Additionally, some studies point out that venues with a maker–taker pricing structure may be more favored by faster traders as they could place the limited order to earn the rebates faster than anyone else, and venues with a taker–maker pricing structure may be less attractive to fast traders since the taker–maker venues allow slow trader to pay the maker fee and jump to the head of the queue (O'Hara 2015; Ye and Yao 2014).

3.2.3. Trader's Behavior and Strategy

Trading strategies could also affect the order routing decision since the trade timing and the selected trade venue can materially affect the trader strategy's success and estimated return. Theoretical models generally use the CAAR model to formalize an investor's optimal trading strategy to maximize the expected utility, and the reader may refer to McAleer et al. (2016b) who summarize the investors' utility models and related implications. An experimental work by Frydman et al. (2014) confirms the disposition effect and find that the investor's decision-making procedure is consistent with the predictions of realization utility. Therefore, the effect of changes in trading behavior on routing preference could be a promising direction for future research.

Parlour and Seppi (2003) propose a limit order trading model to incorporate the strategic behavior of traders. Their model assumes trader's strategies depend on the market current state, and they predict that widened spread leads traders to place more

limit orders and fewer market orders. Kyle et al. (2018) propose a symmetric continuous-time model to incorporate the heterogeneity belief among investors and trade speed to trade strategies. Glode and Opp (2020) endogenizes the trader's expertise in the model and show that the trader's expertise matters in choosing between the limit-order markets and over-the-counter (OTC) markets[15]. Garvey et al. (2016) empirically examine the trader's expertise on the routing venue choice and suggest that traders with better skill are more likely to participate in off-exchange trading.

3.2.4. Summary and Further Discussion

Alongside the execution cost, studies suggest that the order route decision is also influenced by the types of traders and their trading behavior. On the dimension of the trading information. The studies suggest informed traders prefer to trade in dark pools to hide information, and they are more likely to split orders to smaller sizes and send them over to multiple venues to maximize profits. On the other hand, most orders placed by uninformed traders (retail investors) are internalized or executed in off-exchanges by market makers. On the dimension of the trading speed, the studies show that the fast trader uses a technological advantage to fleet across venues to seek latent liquidity and get arbitrary profit.

Traders' expertise and their trading behavior may influence the order routing decision as well. However, connecting trader's behavior with the routing venue choice is an important question and yet has not been well explored. Investors' sentiment is widely studied through the lens of behavioral finance, as much as the anomalies germane to the asset pricing literature[16]. Thus, it will be worthwhile for future research to link sentiment with the trader's behavior on the routing venue choice. Especially, as discussed in McAleer et al. (2016a), there are not many theoretical models developed to link behavioral and financial economics to health and medical science. McAleer (2020) discusses risk management measures, such as Global Health Security Index, which could potentially link the market uncertainty with the country's health security. Still, given the ongoing COVID-19 Pandemic, the health condition and environment's impact on risk aversion and trading behavior remains largely undefined and is an important direction for future research.

3.3. Market and Stock Characteristics

3.3.1. Market Condition

Changes in the market condition alter the order routing decision. McAleer et al. (2016c) examines the global financial crisis in the past two decades and observe a positive relationship between the volatility of stock returns and crisis. Theoretical prediction suggests that the informed trading increases in off-exchanges while overall off-exchange volume share decreases when the bid-ask spread is wider and market volatility is higher (Zhu 2014). Several empirical studies support the predictions in Zhu (2014)[17]. Vuorenmaa (2014) explicitly discusses the lit and dark liquidity around the Global Financial Crisis. Jiang et al. (2012) find that the trading volume shifts from off-exchange to lit-exchanges when the prices are volatile. Furthermore, He et al. (2015) confirm Jiang et al.'s (2012) finding under the international context.

Barclay et al. (2003) show that ECNs attract more informed trades in the active and volatile markets. Jurich (2021) shows a negative relation between market volatility and the off-exchange trading volume share. Anselmi et al. (2021) examines the dynamics of the market fragmentation during the COVID-19 pandemic period and find that orders are trading in a more concentrated way and they are moving to a venue with high transparency in the time of market stress. They also observe the overall order flow shifts from the dark to lit-exchanges.

3.3.2. Stock Characteristics

Baruch and Saar (2009) develop a model linking asset returns with a firm optimal listing choice. The model shows that on which primary market to list matters for the asset

returns. Furthermore, Baruch and Saar (2009) suggest that listing stocks in a market where similar stocks are traded could substantially reduce the information asymmetry, increasing stock value. Harris (2003) suggests that the exchanges operate under ECNs attract more NASDAQ-listed securities. Nguyen et al. (2005) examines the launch of the Archipelago Exchange, which was an ECN, and find that it captures fewer NYSE-listed stocks but more NASDAQ-listed stocks.

He and Lepone (2014) show that the dark pools trading volume is positively related to trade size and negatively related to price. Garvey et al. (2016) confirm that the order size is an important influence for a trader's decision to choose off-exchanges and argues that trading large orders in off-exchanges may present front-running.

3.3.3. Summary and Further Discussion

Market condition and stock characteristics potentially affect investor's routing order decision. Theory suggests that higher market volatility reduces trading at off-exchanges and the listing venue and order size matters for routing decision. The evidence is largely in line with these predictions.

3.4. Trading Technologies

The technology innovation on trading speed significantly reduces the latency of information transmission and execution. In this section, we will start with the literature on the fragmentation with trading technology innovation and briefly discuss the theoretical prediction and empirical studies about the impact of the technology on the exchanges[18], namely speed competition and colocation, on the market quality. For a broad discussion on the impact of technology on the financial market, readers may refer to comprehensive reviews by McAleer et al. (2015) about econometrics with informatics and data mining and by Menkveld (2016) and Zaharudin et al. (2021) about HFT trading.

Menkveld (2014) argues that both high-frequency trading (HFT) and market fragmentation resulted from technology innovation. With improved technology, search costs decrease, making the trading floor's operation more profitable, facilitating more venues to enter the market, thus increasing fragmentation. Technology innovation also lowers the information latency, along with the fragmented markets, makes HFT possible.

3.4.1. Speed Race (Low Latency)

To increase the market share, exchanges also compete on the speed to respond to submitted orders. A decrease in communication response speed decreases latency arbitrage, attracting more volumes (Chakrabarty et al. 2021). The limit order book model by Baldauf and Mollner (2020) incorporates the random communication latency within the exchange system. Brolley and Cimon (2020) extend a model from Baldauf and Mollner (2020) by assuming that the market makers were endogenously affected by latency delay. Biais et al. (2015) predict that speed arms race pushes venues to extensively invest in speed technology innovation,

3.4.2. Co-Location

With the development of technology and algorithm trading, introducing the colocation services by securities exchanges becomes necessary due to competition. Hau (2001) explains that traders located close to the financial center will have more information advantages than those who do not. The introduction of co-location allows an exchange to reduce latency further, attracts more algorithm trading volumes, and enhances liquidity (Aitken et al. 2017; Brogaard et al. 2015; Frino et al. 2014).

3.4.3. Summary and Further Discussion

So far, many studies on the relation between technology innovation and orders routing have focused on the interaction with high-frequency trading and market quality. The effect of big data on trader behavior is still unexplored. A review of the theoretical models, econo-

metrics, as well as statistical models about the connection on the big data, computation science, psychology, decision-making, and finance is well beyond the scope of our paper, and we refer the reader to the excellent survey by McAleer et al. (2018b), who provide a comprehensive review of the literature that connects big data, finance, and psychology in both theoretical and empirical way.

4. Regulatory Reforms

Implementation of any equity market regulations could facilitate the fragmentations, change venue's execution quality, and alter traders routing venue preference. In this section, we discuss the major regulatory reforms in the U.S. equity market that impact the market trading environment and present the studies examining the impact of these policies on the routing venue decision.

4.1. Order Handling Rules in 1997

In order to promote the quote competition, the U.S. Securities and Exchange Commission (SEC) implemented new order handling rules (OHRs) on NASDAQ's dealer market in 1997, requiring market makers to display customer limit orders in their quotes[19]. Barclay et al. (1999) and Weston (2000) show that implementing OHRs reduced spreads and dealers' rent, suggesting improved market quality. However, Rhee and Tang (2013) argue that, in the long-term, forcing quote competition by policy results in dealers altering their competition strategy from quote competition to payment for order flow competition. They observe a weaker correlation between the trading volume and quote competitiveness after the implementation of the OHRs.

4.2. Decimalization in 2000

In order to promote the price competition, the SEC mandated all exchanges to adopt the decimalization system in 2000, with a reduction in minimum tick size from the previous $1/16 ($0.0625) to $0.01[20].

The implementation of the decimalization results reduced the trade execution costs, increased quote competition among the exchanges, and narrowed the spreads, thus improving market quality. Under the revenue maximization model developed by Chordia and Subrahmanyam (1995), the reduction in tick size will negatively impact the volume internalization. Kandel and Marx (1999) extend Chordia and Subrahmanyam (1995) by treating spreads, preference trades, and vertical integration as equilibrium outcomes. Their models suggest the decrease in tick size results in asymmetric effects on endogenous variables, such as numbers of market makers, due to the change in the equilibrium.

Decimalization changes trader's order submission strategies as well. Changes in minimum tick size alter traders' behavior by lowering trader's ex-ante cost, resulting in more market orders and fewer limit orders. Traders now place fewer large limit order sizes and cancel limit orders more frequently (Bacidore et al. 2003; Bessembinder 2003; Chakravarty et al. 2005; Chung et al. 2004; Huang et al. 2010).

Goldstein et al. (2010) examine the effects of decimalization on venue competition and suggests that the impact is heterogeneous across venues. The quote competition further weakens, and the competition among venues switches to best quote improvements. Tang et al. (2011) further support Goldstein et al. (2010) about the decline in the quote competitiveness and point out the reason is the reduction in the number of 100-share NBBO-matching quotes posted by NASDAQ. Garvey et al. (2016) find that traders are more likely to route to off-exchanges venue after the decimalization as the cost aspect of routing decision is now marginalized.

4.3. Reg NMS Rule 611 "The Order Protection Rule (OPR)" and Reg NMS Rule 612 "Minmum Pricing Increment" in 2005

To encourage competition among traders and to improve market liquidity, the SEC implemented the Order Protection Rule (OPR) for intermarket price protection[21]. Based

on OPR requirements, each exchange has to "establish, maintain, and enforce written policies and procedures reasonably designed to prevent the execution of trades at prices inferior to protected quotations displayed by other trading centers, subject to an applicable exception". OPR differentiates exchanges based on the execution speed. The rule classifies electronic exchanges, such as NASDAQ, as the fast market and prohibits it to trade through better prices on other fast markets. At the same time, the restriction does not apply to slow market, which is floor-based exchanges. Many studies raised concerns that the implementation of OPR may negatively impact the market quality (Blume 2007; O'Hara 2004). As OPR fundamentally changes exchanges' execution probability and speed. Chung and Chuwonganant (2012) find OPR negatively impacts the execution quality in NYSE and AMEX; as a result, they observe an increased trading volume in NASDAQ. Meanwhile, OPR alters trader's trading strategies. Spatt (2018) points out that OPR encourages traders to split orders across venues to achieve the best execution.

The Reg NMS rule 612 "Minimum Pricing Increment" rule prohibits all trading venues to display, rank, or accept orders priced at more than two decimal places for stocks that trade greater or equal to $1.00, while allowing the broker-dealers who operate in off-exchanges (OTC non-ATS markets) to offer price improvement in sub-penny increments[22]. As a result, traders can now utilize off-exchanges to bypass existing limit order queues and execute orders more quickly. Kwan et al. (2015) empirically document a remarkable gain in the market share for off-exchanges after the implementation of the Reg NMS rule 612, suggesting minimum pricing increment policy yields a significant competitive advantage for off-exchanges.

4.4. SEC Tick Size Pilot Program in 2015

To examine the impact of the tick sizes on the market quality for small-capitalization firms, in 2016, SEC and FINRA jointly launched a 2-year pilot program, which increases the minimum tick size from $0.01 to $0.05 for three pilot groups[23]. The main interest of the pilot focuses on whether the changes in tick size improves liquidity. In contrast, many empirical studies and the SEC report find that this pilot resulted in a negative impact on market liquidity and cost (Albuquerque et al. 2020; Griffith and Roseman 2019; SEC 2018). Given the operational concerns, the SEC issued a termination of the Pilot two days before the planned expiration date[24].

However, from the venue competition perspective, several studies show that the tick size pilot has a heterogeneous impact on exchanges. For instance, Comerton-Forde et al. (2019) study the effect of the tick size pilot for inverted fee exchanges and finds that the price discovery process is improved in inverted fee exchanges under the trade-at rule. Consequently, the trading volume share shift to inverted fee exchanges. Cox et al. (2019) reach the same conclusion as Comerton-Forde et al. (2019) that inverted fee exchanges gain more volume share under the tick size pilot. Additionally, Cox et al. (2019) observe that the shift in volume share was from both traditional fee exchanges (maker–taker) and off-exchanges, suggesting that the tick size changes reduce the risk of an informed trader exposing an order.

5. Conclusions

With the rapid development of technology and the regulation reforms, trading in the U.S. equities markets is increasingly fragmented. Equity trading in the U.S. is dispersed across 16 national exchanges, more than thirty alternative trading systems, and numerous broker-dealers and wholesalers. On the one hand, the intensified competition lowers the transaction fee and ultimately benefits market participants. On the other hand, varying levels of venue transparency and the heterogeneity in the transaction speeds have raised the risk of adverse selection. Thus, examining routing order decisions is an important topic that is worth exploring. This paper provides a better understanding of the potential driving factors underlying routing order decisions under fragmented markets and identifies several promising directions for future research.

We survey a large and growing theoretical and empirical literature about the channels and determinants of routing venue choice under a highly fragmented equity market. The literature referenced in this paper carries important implications for policymakers, regulators, and exchange operators: under highly fragmented markets, routing order decisions are complex and influenced by many factors. First, the routing order decision is fundamentally affected by the market structure design. Different trading system structures provide different liquidity provisions and different degrees of transparency, resulting in differences in terms of execution quality. Execution decisions could be influenced by transaction costs, execution quality, and adverse selection concerns. Moreover, the decision procedure involves multiple trade-offs among the transaction costs, execution quality, and the risk of adverse selection. The nature of the trade-off varies by the type of investor. The informed trader pays more attention to the trade-off between transaction cost and execution quality, while the uninformed trader focuses on the trade-off between the transaction cost and the adverse selection cost. Second, the routing venue choice is influenced by the types of traders as well as their strategies. Informed traders are more likely to split their orders and send them across exchanges to camouflage their trading and maximize their profits. Meanwhile, in the U.S. market, uninformed retail investors mainly place orders through retail brokers, and retail brokers' routing order decisions are influenced by the order-processing cost. Due to the practice of payment for order flow, most retail uninformed marketable orders are routed in off-exchanges by market makers. Third, the routing order decision depends on market conditions and stock characteristics. Order flow moves to exchanges with higher transparency during periods of high market volatility. In addition, stock listing venues and trade size substantially affect routing choices. Finally, the routing order decision is systematically shaped by technological development and regulatory reforms. We have shown that regulatory reform changes the venue's execution quality and hence alters traders' routing venue preference.

Author Contributions: Conceptualization, S.M. and L.Z.; methodology, S.M. and L.Z.; validation, S.M. and L.Z.; formal analysis, L.Z.; investigation, L.Z.; resources, L.Z.; writing—original draft preparation, L.Z.; writing—review and editing, S.M.; visualization, L.Z.; supervision, S.M.; project administration, S.M. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: All used data are mentioned in the list of references.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of market microstructure empirical studies on order routing decisions.

Authors	Year	Data Source	Sample Period	Methodology	Findings
Cardella, Hao and Kalcheva	2017	SEC Filings and NYSE's Trade and Quote (TAQ)	1 January 2008–31 December 2010	Multivariate regression analysis	The magnitudes of decreasing in trading activities of take fee and make fee are different
Malinova and Park	2015	A proprietary trader-level dataset from Toronto Stock Exchange (TSX)	1 August 2005–30 November 2005	Panel regression analysis	An increase in the total exchange fee on Toronto Stock Exchange increases its cum fee effective spread and lowers the limit order fill rate
Battalio, Corwin and Jennings	2016	Order data from major broker–dealer's smart order routing systems and NYSE's Trade and Quote (TAQ)	1 October 2012–30 November 2012	Univariate analysis and multivariate regression analysis	Brokers' route order decision is primarily based on the fee rather than execution quality

Table A1. *Cont.*

Authors	Year	Data Source	Sample Period	Methodology	Findings
Jørgensen, Skjeltorp and Ødegaard	2018	Orderbook from Oslo Stock Exchange (OSE) and Thomson Reuters Tick History database	1 January 2010–31 December 2011	Difference in differences analysis	The introduction of a fee on excessive order-to-ratios at the Olso Stock Exchange does not affect the market quality
Comerton-Forde, Malinova and Park	2018	A proprietary transaction-broker level dataset from Investment Industry Regulatory Organization of Canada (IIROC)	1 August 2012–30 November 2012	Multivariate regression analysis and two-stage least squares regression	Reducing retail order segmentation enhances liquidity in lit-exchanges
Clapham, Gomber, Lausen and Panz	2021	Refinitiv Tick History database	1 May 2016–28 February 2017	Difference in differences analysis	The order routing decisions are influenced by fee rebates
Boehmer, Jennings and Wei	2007	NYSE's Trade and Quote (TAQ) and the SEC Dash-5 reports	1 June 2001–31 June 2004	Fixed effects regression	The routing decisions are associated with execution quality
Battalio, Shkilko and Van Ness	2016	Options Price Reporting Authority (OPRA) and NYSE's Trade and Quote (TAQ)	1 March 2010–31 June 2010	Fixed effects regression	Retail brokers have the incentives to route order based on size of the commission and rebates
Peterson and Sirri	2003	NYSE SOD file, BSE BEACON system, CHX order data, CSE preferencing dealers, PSE trading floors and PHLX's market surveillance department	1 October 1996–30 November 1996	Univariate analysis and ordered probit regression	NYSE, which was the primary market, obtains better quotation and execution quality for market orders with smaller effective spreads than other regional exchanges
Boehmer, Saar and Yu	2005	NYSE's Trade and Quote (TAQ), System Order Data (SOD) and Consolidated Equity Audit Trail Data (CAUD)	1 January 2001–31 May 2001	Wilcoxon signed rank test and multivariate regression analysis	Improvement in pre-trade transparency enhances market liquidity
Garvey, Huang and Wu	2016	A proprietary data from a U.S. direct market access (DMA) broker	1 October 1999–31 May 2006	Two-stage hackman model	The time-to-execution is much longer in dark venues than in lit venues, and the average fill rate of marketable order executed at dark venues is lower than at lit venues
Ernst, Sokobin and Spatt	2021	NYSE's Trade and Quote (TAQ)	1 January 2019–31 December 2020	Fixed effects regression	The exchange with better execution quality (lower cost and higher fill rate) subsequently attracts more order flow

Table A1. *Cont.*

Authors	Year	Data Source	Sample Period	Methodology	Findings
Thomas, Zhang and Zhu	2021	NYSE's Trade and Quote (TAQ)	1 January 2019–31 June 2018	OLS regression and two-stage least squares regression	The dark trading decreases liquidity and increases the post-earnings announcement drift (PEAD)
Grammig, Schiereck and Theissen	2001	Transaction-level dataset from IBIS and Frankfurt Stock Exchange	1 June 1997–31 July 1997	Private information (PIN) model by O'Hara (2004)	The non-anonymous floor trading system has less informed trading than the anonymous electronic market
Jain, Jiang, Mclnish and Taechapiroon-tong	2003	Transaction-level dataset from London Stock Exchange	1 January 2000–31 December 2000	Private information (PIN) model by Easley et al. (1996) and cross-sectional regression	The probability of informed trading is no different on the anonymous market than on the non-anonymous market since the informed traders may split orders and send them to multiple venues
Jiang, Mclnish and Upson	2012	NYSE's Trade and Quote (TAQ)	1 January 2008–30 June 2008	MRR regression by Madhavan et al. (1997)	Trading volume shifts from off-exchange to lit-exchanges when the prices are vola-tile
Nimalendran and Ray	2014	NYSE's Trade and Quote (TAQ)	1 June 2009–31 December 2009	Multivariate regression analysis	Informed trader tend to split order between lit and off-exchanges and the order executed in lit-exchanges provides some price discovery
Hatheway, Kwan and Zheng	2017	Thomson Reuters DataScope database	1 January 2011–31 March 2011	Two-stage hackman model	Dark venues may harm the market quality by attracting uninformed order flow away form lit market
Kavajecz and Odders-White	2004	NYSE SuperDOT dataset	1 July 1997–30 September 1997	Univariate analysis and multivariate regression analysis	Technical analysis and moving average indicators are significantly related to the state of liquidity on the limit order book
Garvey and Wu	2011	A proprietary order-level data from a U.S. broker-dealer and Thomson Reuters Tick History database	1 October 1999–31 July 2003	OLS regression	The focus of trade-offs among transaction cost, execution risk, and adverse selection risk are different based on the types of the investor
Jones and Lipson	2004	A proprietary order-level data from NYSE	1 November 2002–30 November 2002	Vector autoregression	Retail order flow has better execution quality than non-retail order flow

Table A1. *Cont.*

Authors	Year	Data Source	Sample Period	Methodology	Findings
Ready	2014	NASDAQtrader.com, Ancerno database and NYSE's Trade and Quote (TAQ)	1 July 2005–30 September 2007	Panel regression analysis	Institutional orders with high information have less probability of executing in dark pools
Chakravarty, Jain, Upson and Wood	2012	NYSE's Trade and Quote (TAQ)	1 August 2007–31 May 2008	MRR regression by Madhavan et al. (1997)	The informed institutional investor applies the intermarket sweep order (ISO) by breaking up large orders and sending them over to multiple trading venues to maximize fragmentation arbitrage profits and hide information
Barber, Odean and Zhu	2008	NYSE's Trade and Quote (TAQ) and Institute for the Study of Security Markets (ISSM) transaction data	1 January 1983–31 December 2001	Univariate portfolio analysis and Fama-Macbeth cross-sectional regression	The signed smaller trades provide a reasonable proxy for individual investor's activity, and over both short and long horizons, retail trade imbalances forecast future returns
Chevalier and Ellison	1999	Morningstar	1 January 1992–31 December 1994	Multivariate regression analysis	The agency issues within the mutual fund companies can be attributed to career concerns
Coval and Stafford	2007	Spectrum mutual fund holdings database	1 January 1980–31 December 2004	Fama-Macbeth cross-sectional regression	The institutional price press creates an incentive to front-run
Gao and Lin	2015	Website of the bank that holds the rights to administer the lottery and trading data from Taiwan Economic Journal	1 January 2002–31 December 2009	OLS regression	Individual investor tends to trade stocks as a gambling activity
Han and Kumar	2013	NYSE's Trade and Quote (TAQ) and Institute for the Study of Security Markets (ISSM) transaction data	1 January 1983–31 January 2000	Fama-Macbeth cross-sectional regression	Stocks with lottery features (high volatility, high skewness, and low prices) are heavily traded by retail investors
Boehmer, Jones, Zhang and Zhang	2021	NYSE's Trade and Quote (TAQ)	1 January 2010–31 December 2015	Fama-Macbeth cross-sectional regression	Most marketable orders placed by retail investors in the U.S. equity market are either internalized or executed in by wholesale market makers in off-exchange

Table A1. *Cont.*

Authors	Year	Data Source	Sample Period	Methodology	Findings
Jain, Mishra, O'Donoghue and Zhao	2021	SEC Rule 605, SEC Rule 606 and NYSE's Trade and Quote (TAQ)	1 June 2019–29 February 2020	Univariate analysis and multivariate regression analysis	Retail brokers who newly announced zero-commission policy tends to route more orders to the off-exchange market maker in order to gain the payment for order flow
Brogaard, Hagströmer, Nordén and Riordan	2015	A proprietary dataset for the exchange colocation service subscription and Thomson Reuters' Tick History database	1 August 2012–31 October 2012	Probit regression and panel regression	Enhanced speed from colocation upgrade benefits market liquidity
Hasbrouck and Saar	2013	NASDAQ OMX ITCH dataset	1 October 2007–31 December 2007 and 1 June 2008–30 June 2008	Multivariate regression analysis	Increased low-latency activity improves traditional market quality measures
Hendershott, Jones and Menkveld	2011	NYSE System Order Data (SOD)	1 December 2002–31 July 2003	Two-stage regression	Improving in market's automation and speed reduces cost of immediacy and improves price discovery
He, Jarnecic and Liu	2015	Thomson Reuters Tick Historydatabase	1 March 2007–31 October 2011	Fixed effects regression	Trading volume shift from off-exchange to lit-exchanges when the prices are volatile
Barclay, Hendershott and McCormick	2003	Nasdaq National Market	1 June 2000–30 June 2000	Variance decomposition by Hasbrouck (1991)	ECNs attract more informed trades in the active and volatile markets
Jurich	2021	Cboe Global Markets and NYSE's Trade and Quote (TAQ)	1 September 2018–30 September	Multivariate regression analysis	There is a negative relation between market volatility and off-exchange trading volume share
Anselmi, Nimalendram and Petrella	2021	Fidessa database	1 July 2019–31 July 2020	Fixed effects regression	Market order flow at the COVID-19 pandemic is more concentrated and moves to a venue with high transparency
Nguyen, Van Ness and Van Ness	2005	The SEC Dash-5 reports, Transaction Auditing Group (TAG) and Market System Inc.	1 April 2002–31 October 2002	Multivariate regression analysis	A launch of the Archipelago exchange, which is an ECN, captures fewer NYSE-listed stocks but more NASDAQ-listed stocks

Table A1. *Cont.*

Authors	Year	Data Source	Sample Period	Methodology	Findings
He and Lepone	2014	A proprietary dataset from the Australian Securities Exchange (ASX) and Thomson Reuters Tick History database	1 July 2010–31 December 2010	Multivariate regression analysis	The dark pools trading volume is positively related to trade size and negatively related to price
Hau	2001	A proprietary transaction-level dataset from the German Securities Exchange	1 September 1998–31 December 1998	Spectral Decomposition and multivariate regression analysis	Traders located close to the financial center will have more information advantages than those who do not
Aitken, Cumming and Zhan	2017	Capital Market Cooperative Research Centre (CMCRC)	1 January 2003–31 December 2011	Univariate analysis and multivariate regression analysis	There is a positive relationship between colocation and high-frequency trading
Frino, Mollica and Webb	2014	Thomson Reuters Tick History Database	1 August 2011–31 August 2012	Multivariate regression analysis	The introduction of col-location enhances liquidity on the Australian Securities Exchange

Notes

[1] Market fragmentation in this paper refers to trading fragmentation such that one equity could trade simultaneously on multiple exchanges.

[2] Order routing is a handling order process by which an order is sent to a selected exchange.

[3] Lit-exchange or lit venue refers to an exchange where quote information (bid and ask) are posted in publicly. Whereas off-exchange or dark venue refers to a venue that does not provide quote information. Trading at off-exchange can be refer as "dark trading".

[4] The Markets in the Financial Instruments Directive (MiFID) was created by the European Union in 2004 to promote the of European financial markets.

[5] See Atkins and Dyl (1997); Hu and Murphy (2021); Jain (2005); and Bessembinder and Rath (2008).

[6] See Nasdaq 2018 10K report, available at http://ir.nasdaq.com/financials/annual-reports, accessed on 23 August 2021.

[7] Alternative Trading System (ATS) is a type of off-exchange that matches buyer and seller without going through a middleman.

[8] Dark pools are a type of ATS that provide anonymity for trading large orders with automated execution. It is generally used by intitutioanl investors.

[9] See Bessembinder and Kaufman (1997a); Conrad et al. (2003); Barclay et al. (2003).

[10] Theoretical discussion can be found in Hendershott and Mendelson (2000); Ye (2011); Degryse et al. (2009); Zhu (2014) and Buti et al. (2017).

[11] See Dorn et al. (2015); Kaniel et al. (2008, 2012) and Kelley and Tetlock (2013).

[12] See McAleer et al. (2020) for the survey of anomalies in stock market.

[13] In January 2021, GameStop's stock (GME) experienced a surge in demand from retail investors who were influenced by the discussion in social media platforms such as Reddit. GameStop's share price jumped 2000% in a few days (from $16 to $347 within one month).

[14] For example, Zhu (2014) assumes the liquidity investors face heterogeneous delay costs.

[15] OTC market is a type of the off-exchange, where the buyer and seller trade with each other directly, often non-anonymous.

[16] See Baker and Wurgler (2006); Baker et al. (2016) and McAleer et al. (2019).

[17] See Comerton-Forde and Putniņš (2015); Degryse et al. (2015) and Garvey et al. (2016).

[18] The impact of the technology on the trader is discussed on Trader Type and Trading Strategies section.

[19] See https://www.sec.gov/rules/sro/nd9821o.htm, accessed on 23 August 2021.

[20] See https://www.sec.gov/rules/other/decimalp.htm#seci, accessed on 23 August 2021.

[21] See https://www.sec.gov/rules/final/34-51808.pdf, accessed on 23 August 2021.

[22] See https://www.sec.gov/divisions/marketreg/subpenny612faq.htm, accessed on 23 August 2021.

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