Market Fragmentation in Europe[1]

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Executive Summary

The European equity trading landscape of 2022 is a complex mix of exchanges, dark pools, dealers, and auctions. The once dominant national stock exchanges are now part of global exchange groups that compete with investment banks and high-frequency trading (HFT) firms to match the orders of retail and institutional investors. Is this diverse trading environment in the best interests of investors? Academic research has taken on this question from many angles, both theoretically and empirically.

This paper surveys the findings of the market fragmentation literature, with a special focus on European equity market quality. I discuss why markets fragment, what the potential market quality effects are, and what this implies for the European context. The objective is to provide a concise review that captures the implications for current policy in Europe.[1] Market quality is, of course, a broad concept, which is defined here primarily in terms of liquidity (bid–ask spreads, depth, and resiliency to shocks) and efficiency (referring to price discovery and volatility).

To set the stage, the report begins by briefly describing the venue types prevailing in Europe and how their respective market shares have developed since the introduction of the *Markets in Financial Instruments Directive* (MiFID) 15 years ago. See Section 1. The data show that the volume share of lit markets did not decrease from 2008 to 2022, but became more evenly distributed between auctions, regulated markets, and multilateral trading facilities (MTFs). The fragmentation tended to be higher for larger stocks. Regulated markets lost market share in the early years of the sample (2008–2012), but by 2022 they had regained the lost ground. The dark market share

[1] The fragmentation of financial markets has been a research topic for decades, generating hundreds of papers. It is impossible to give all these contributions justice in a short survey. Many of them are inevitably omitted. The included references should be viewed as my best effort to provide a representative picture of the state of research. An excellent earlier literature review on market fragmentation is provided by Gomber, Sagade, Theissen, Weber, and Westheide (2017). In addition to covering the substantial research produced since their work was written, my review differs in that it focuses specifically on the market quality implications for European markets.

increased too, since regulation limited the scope of off-exchange trading. Against this backdrop, I review the academic literature, see Section 2.

Given the diversity of trading platforms, the impact of market fragmentation of course depends on how the trading volume is split between the various mechanisms. For example, the introduction of a dark pool that attracts 5% of the trading volume cannot be expected to have the same consequence as an MTF with similar market share. In this paper, a key distinction is between *lit market fragmentation* (the competition between regulated markets and MTFs) and *dark market fragmentation* (the competition arising from more opaque trading mechanisms, such as dark pools, periodic auctions, and systematic internalisers).

Evidence on lit fragmentation. The entry of MTFs subjected European equity markets to increasing lit fragmentation over the past 15 years. New exchanges can attract order flow by charging lower fees and by offering niche services to investors, but the fragmentation of trading interests can make liquidity more expensive. The net effect of competition on fees and fragmentation of liquidity supply is not obvious.

This review shows that the lit fragmentation have been beneficial to European equities markets. Due to that prices at competing and geographically dispersed exchanges are kept tightly together by cross-market arbitrageurs and market makers, as well as the order routing technology that brokers use to comply with best execution agreements, the potential negative effects are limited. The competing exchanges that provide pre-trade transparent trading of European equities can be viewed as different entry points to a consolidated market.

The impact of fragmentation varies across securities and investors. In particular, the degree of fragmentation and also the benefits thereof are lower for smaller stocks. Furthermore, for investors who connect only to the regulated market, the liquidity impact of fragmentation is limited or even negative. From a policy perspective, it is thus desirable to facilitate investors' ability to compare prices across exchanges, and to route their orders accordingly.

Cross-market arbitrage activity contributes to keeping prices in sync, but also incurs economically significant costs to liquidity suppliers. Every time prices change, fast arbitrageurs can profit by trading against stale limit orders that market makers would otherwise revise a split second later. If the profitability of such arbitrage can be reduced, liquidity can improve. One way to achieve that is to impose constraints on the aggressive orders that are essential to arbitrage strategies.

Evidence on dark fragmentation. Trading in dark markets tends to be cheaper than at exchanges, but it is associated with higher execution uncertainty. This attracts investors with low sensitivity to the trade delays, such as passive mutual funds, agents who trade for liquidity reasons, and participants with large positions and unique information (e.g., activist hedge funds). Less patient investors (e.g., those trading on short-term information) prefer lit markets. In Europe, retail investors also tend to trade in lit markets.

The trader segmentation between lit and dark markets implies that any policy that influences the degree of market transparency is subject to trade-offs between investor groups. Increasing the requirements of pre-trade transparency would disadvantage groups trading in the dark and benefit investors at lit exchanges, and vice versa.

Theoretical models show that dark trading reduces the liquidity at exchanges, but also improves price discovery. Empirically, the evidence is mixed and set back by poor trading data availability. Policymakers could facilitate studies of dark trading by making transaction records with high time stamp granularity and detailed venue information available to academic research.

Several empirical studies of dark pools outside Europe find that block trades in dark mechanisms do not undermine market quality. This lends support to the large-in-scale waiver of pre-trade transparency, which is currently applied in Europe.

The introduction of MiFID II in January 2018 brought substantial changes to dark trading in Europe. The academic evidence shows that the dark volume caps (DVCs, see Section 1) led to migration of flows to periodic auctions and other dark mechanisms. It had little impact on market quality. Another important change brought by MiFID II is that banks and trading firms formed systematic internalisers to execute flows that had previously been allowed off-exchange. Empirical evidence on this shows that platforms operated by HFT firms can undermine lit market liquidity.

1 The European Equity Market Landscape

European equity markets have lately been subject to two major directives regarding the organization of trading. MiFID has been applicable since November 2007, and its revision, known as MiFID II, has been in force since January 2018.

Lit markets. Equity trading in Europe used to be split between listing exchanges, referred to as *regulated markets*, and *over-the-counter* (*OTC*) activity. Many stocks had dual listings, but, other than that, on-exchange trading was centralized. With MiFID, the listing exchanges were subjected to competition from a new type of trading venue, known as a *multilateral trading facility* (MTF). Like regulated markets, MTFs operate limit order book markets that disseminate order prices and volumes in real time. This pre-trade transparency is the motivation for referring to regulated markets and MTFs jointly as *lit markets*. The main difference between the two is that MTFs do not have their own listings, but offer trading of stocks listed at regulated markets.

Regulated markets open and close the trading day with call auctions, and some also run scheduled intraday auctions. I categorize such auctions as lit markets. *Periodic auctions* are not considered to be lit, for reasons clarified below.

Dark markets. MiFID also opened up the establishment of *dark pools*. *Dark pools* is not an official term in European legislation. It refers to mechanisms that operate without pre-trade transparency, which is allowed according to the *reference price waiver*. Under MiFID, the reference price could be the best bid, the best ask, or the midpoint of the two, prevailing in a lit market at the time of trade. According to MiFID II, only the midpoint is allowed as the reference price. Pre-trade transparency can also be waived under the *large-in-scale waiver*. This states that large trades, defined relative to a threshold based on the average daily turnover, are exempt from pre-trade transparency.[2]

A *systematic internaliser* (*SI*) is a single-dealer platform where an investment firm quotes a bid–ask spread and takes one side of each trade. SIs already existed under MiFID, but were sparingly used. Under the *share trading obligation* of MiFID II, investment firms in Europe must conduct their proprietary trading at a trading venue or an SI. Most investment firms therefore registered to become SIs. SIs are required to publish two-way quotes on a continuous basis for volumes of at least 10% of standard market size. They are not required to publish quotes for volumes that exceed standard market size. Due to their limited pre-trade transparency, I categorize them together with dark pools as *dark markets*.

A third type of dark market, the *periodic auction*, emerged in Europe in response to the *double*

[2]There are two more waivers of the pre-trade transparency requirement in MiFID. The *negotiated trade waiver* applies to off-exchange systems where the transaction prices are within the prevailing volume-weighted spread or, when no such spread is available, within a preset price range or subject to conditions that allow deviations from the current market price. The *order management facility waiver* allows lit exchanges to exempt hidden orders and iceberg orders from being visible in the limit order book. For an overview of the waivers and dark trading in Europe, see Comerton-Forde (2017).

volume caps (DVCs) introduced by MiFID II. According to DVCs, if a dark pool has a market share exceeding 4% in a given stock measured over the last 12 months, trading in that venue is suspended for the following six months. Similarly, if the volume of all dark pools exceeds 8% of the total trading in a stock over the last 12 months, all such trading is suspended for six months.[3] Periodic auctions, which are short-duration call auctions that can be triggered as often as several times a second, offer a way around the caps. They are pre-trade transparent in the sense that indicative prices and volumes are transmitted to the market in real time during the batching period, but individual buy and sell orders are not visible. They are also similar to dark pools in the sense that they allow orders to be priced in reference to the midpoint of the lit market. I therefore categorize them as dark.

Off-exchange. Outside lit and dark markets, there are OTC trades and *off-book on-exchange* trades, together categorized as *off exchange*. Off-book on-exchange trades are those whose counterparties negotiate the price bilaterally and then report the trade to the market in a formalized way. Such trades are exempt from pre-trade transparency based on the negotiated trade waiver. OTC includes any other trades.

Fragmentation in Europe from 2008 to 2022. What is the state of market fragmentation in Europe? How has it developed since the introduction of MiFID? To set the stage, I provide statistics on how trading volumes are distributed across the mechanisms described above for six example stocks in Figure 1.[4] I include two stocks, one from the European Union (EU) and one from the United Kingdom, from each market capitalization segment (large cap/mid cap/small cap).[5]

Several interesting patterns emerge:

- Regulated markets, including continuous trading as well as auctions (regulated markets plus auctions in the figure), lost market share in the first years of MiFID, around 2008–2012, particularly for large caps and mid caps. By 2022, however, they had regained much of the lost ground, partially due to the increasing popularity of auctions.[6]

[3]The market shares triggering DVCs, as well as suspensions, concern trades under the reference price waiver and the negotiated price waiver. Trades subject to the large-in-scale waiver are unaffected.

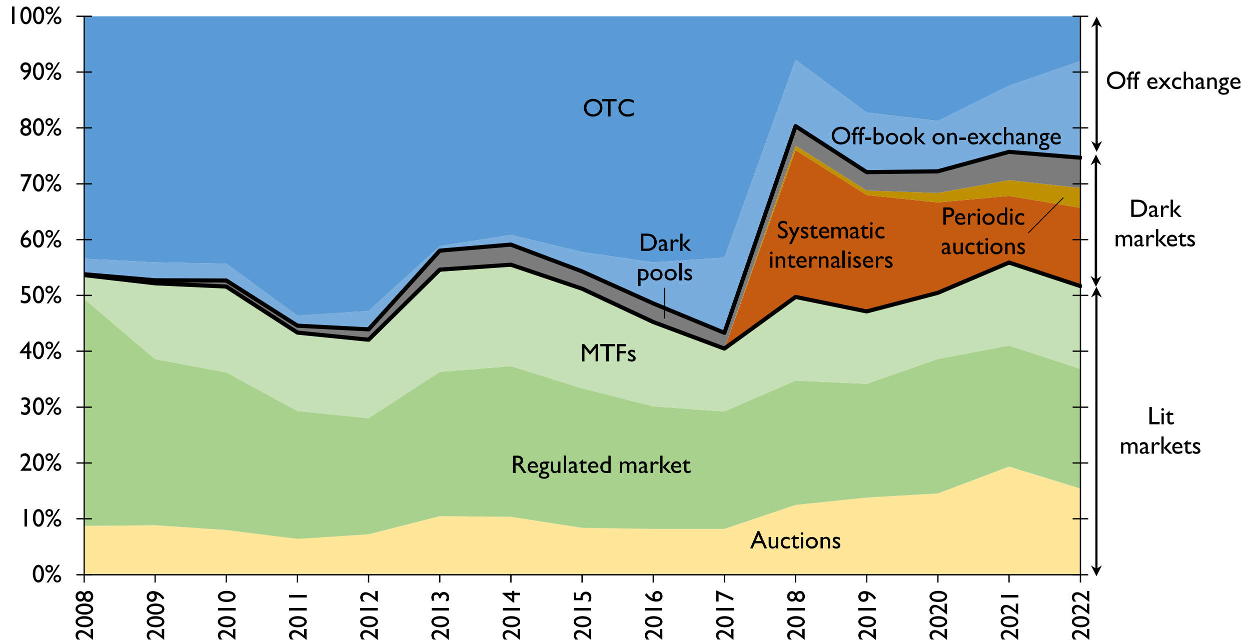
[4]As recommended by the Association for Financial Markets in Europe, non-price forming trades are excluded (`https://www.afme.eu/publications/reports/details/The-landscape-for-European-equity-trading-and-liquidity`). On-book large-in-scale trades are counted as dark pool trades.

All lit trades that are not at the primary venue are defined as lit MTF trades. The database does not identify trades in broker crossing networks before MiFID II. Although such trades are best characterized as dark, because of this data restriction, they are in the OTC category. According to Comerton-Forde (2017), broker crossing networks constituted about half of the European dark trading in 2011–2017.

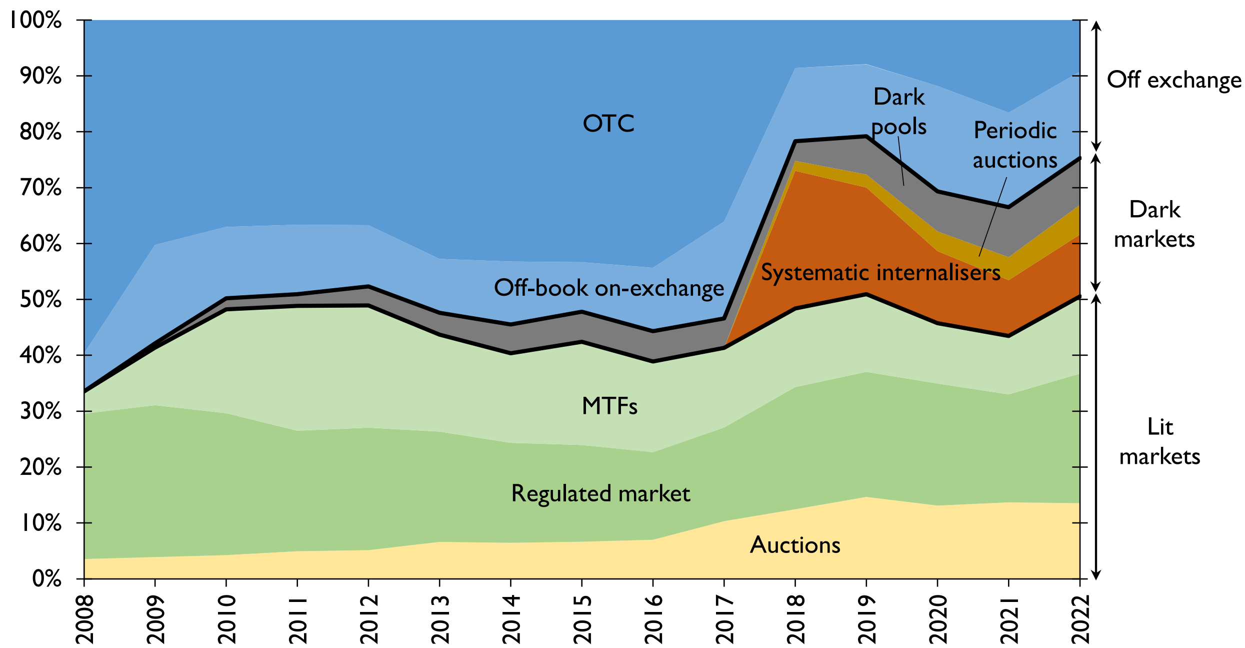
[5]Although the example stocks are chosen to be representative of each segment, the patterns described may vary across stocks. A comprehensive study of all stocks in the EU and the United Kingdom is beyond the scope of this report.

[6]Comerton-Forde and Rindi (2021) show that this increase in European auction trading is primarily due to closing auctions, partially driven by interest from index investors.

- The fraction of volume in lit markets did not decrease over the period, and, for several of the example stocks, it increased substantially. For example, the lit market share in the stock LLOY increased from one-third in 2008 to half of the volume in 2022 (see Panel b).
- The market share that MTFs gained in the early years of MiFID persisted in 2022.
- Dark markets increased their share of the total volume in what appears to have been primarily through the migration from off exchange to SIs during MiFID II (in line with the share trading obligation). The market share of dark pools increased too, but this could be due to a shortcoming in the data (see footnote 4).
- Following the introduction of DVCs, the market share of periodic auctions was of the same order of magnitude as that of dark pools.
- The UK example stocks displayed a lower lit market share than those from the EU. In particular, the market shares of dark pools and periodic auctions were larger in the UK. These differences preceded the UK exit from the EU at the end of 2020.
- Fragmentation in lit as well as dark markets was lower in small caps than in larger stocks.

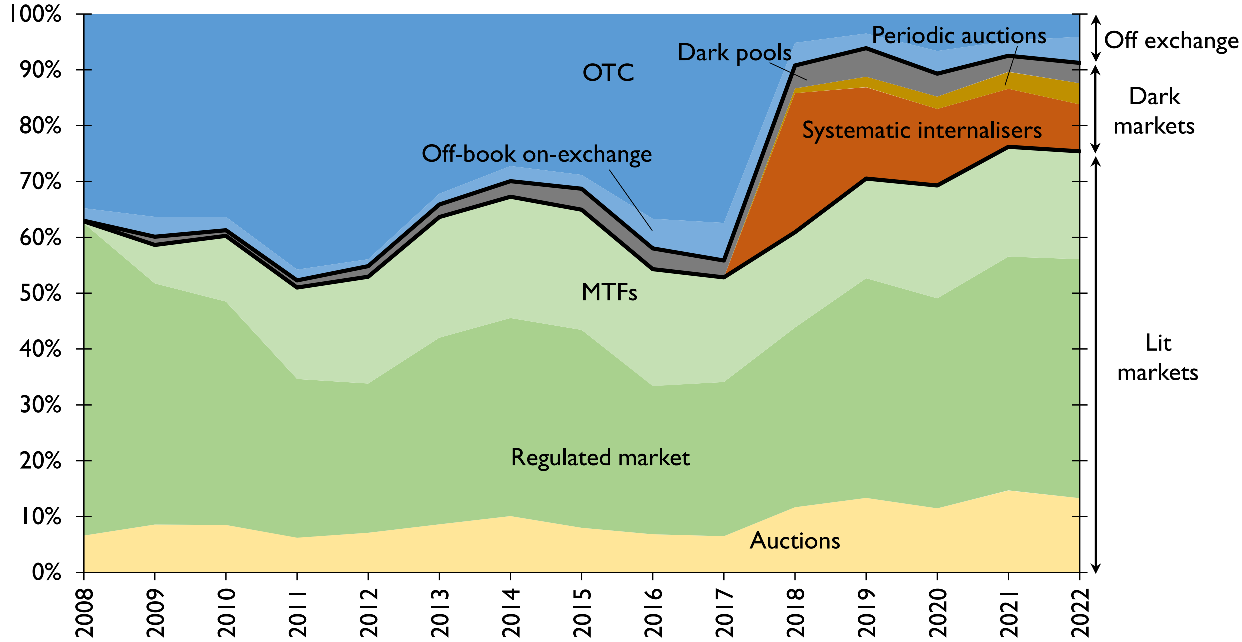


(a) EU large-cap stock: `OREP`

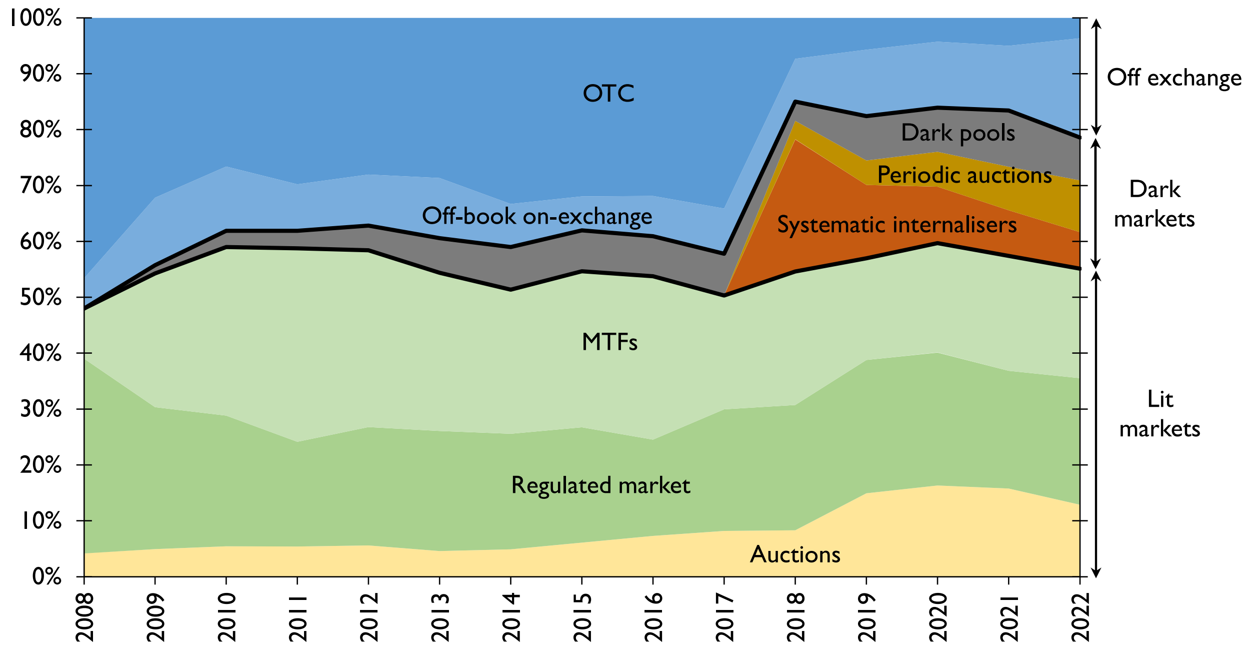


(b) UK large-cap stock: `LLOY`

Figure 1: The European Equity Market Landscape. Panels (a) and (b) show the data for two large-cap stocks from the EU and the UK, L'Oreal SA (`OREP`) and Lloyds Banking Group PLC (`LLOY`), respectively. Panels (c) and (d) present two mid-cap stocks from the EU and the UK, Suedzucker AG (`SZUG`) and Man Group PLC (`EMG`), respectively. Panels (e) and (f) present two small-cap stocks from the EU and the UK, Brunel international NV (`BRUN`) and BARR PLC (`BAG`), respectively. Data source: *Equity Market Share Reporter*. The statistics for 2022 are based on trades from January to May. For further details on trade categorization, see footnote 4. **Continued on next page.**

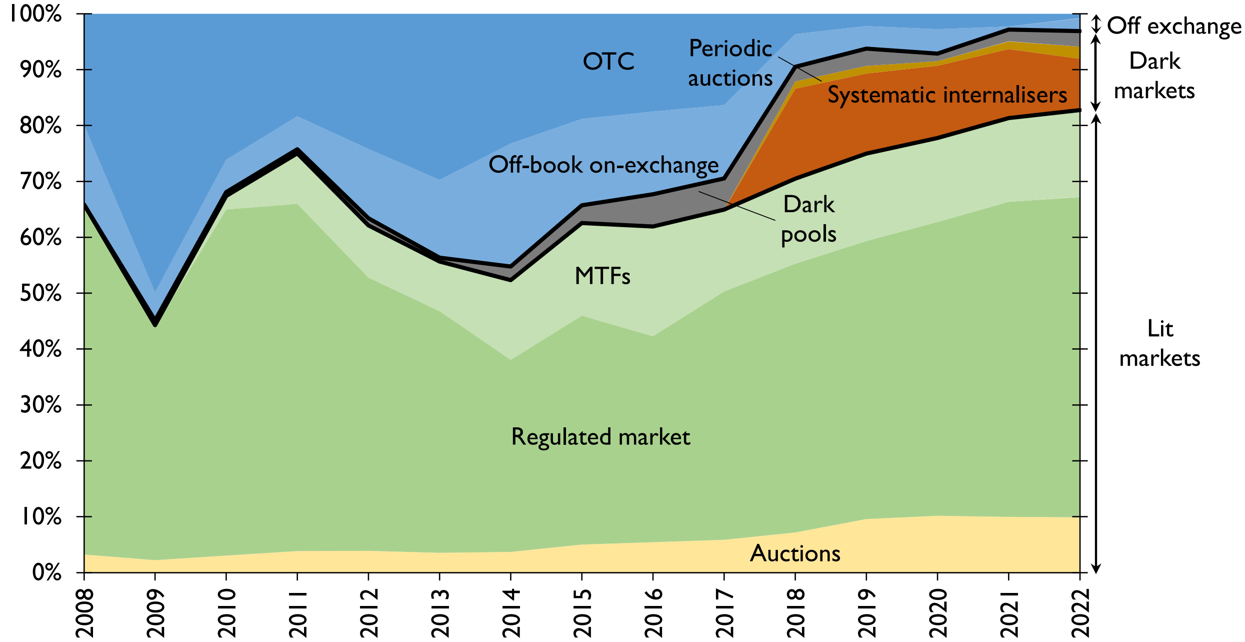


(**c**) EU mid-cap stock: `SZUG`

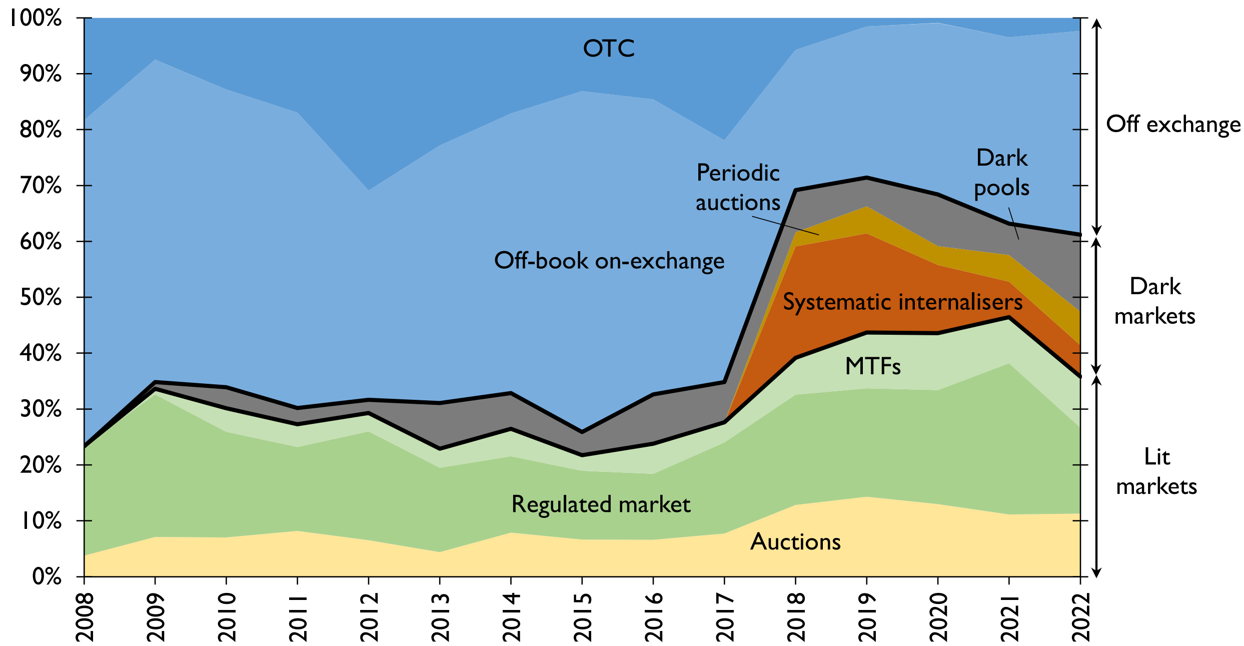


(**d**) UK mid-cap stock: `EMG`

Figure 1: The European Equity Market Landscape (continued from previous page).



(e) EU stock: `BRUN`



(f) UK stock: `BAG`

Figure 1: The European Equity Market Landscape (continued from previous page).

2 Fragmentation and Market Quality

Buyers and sellers of financial securities face search costs, because they are dispersed in time and space. The point of a stock market, broadly defined, is to solve their coordination problem. It matches buyers to sellers and determines a price at which they can agree to trade. The more investors it attracts, the greater the probability of matching interests and efficient prices (Pagano, 1989; Chowdhry and Nanda, 1991). Liquidity begets liquidity. This is known as positive network externalities and makes the market for exchanges a potential natural monopoly. The diverse trading landscape of secondary markets presented above, however, shows that such economies of scale are counteracted by other forces.

Financial market participants range from retail to institutional, from uninformed index trackers to alpha-seeking hedge funds, and from short-sighted HFT firms to long-term investing pension funds. Even if a centralized market offered superior liquidity and efficiency in the aggregate, it would be unlikely to be optimal for all types of investors (Harris, 1993). Furthermore, although an exchange monopoly may be optimal in matching aggregate trading interests, it can be expected to charge uncompetitive fees and to have weak incentives for innovation. Competition in secondary market trading diverts flows away from the main markets at the promise of lower costs and customized matching mechanisms.

2.1 Fragmentation between Lit Markets

Competition between limit order markets. When investors decide where to route their orders, a key variable is the *cost of liquidity*, defined here as the cost of immediate execution. The cost of liquidity may be decomposed into the fee charged by the exchange (a direct component) and the spread paid to the liquidity provider (an indirect component). Because the latter is determined by the participants of the exchange, the most obvious tool for a new exchange is to charge lower fees. If an exchange can attract investors with lower fees, this may trigger the virtuous cycle where liquidity begets liquidity, as described above. Colliard and Foucault (2012) show that reduced exchange fees lead to tighter bid–ask spreads.

The importance of fees as a competitive tool is leveraged by the *tick size*, the minimum increment that determines admissible prices. When the bid–ask spread equals one tick, liquidity providers are unable to raise their bids or lower their offers. That is, the tick size is binding, and the cost of liquidity for small orders is fully determined by the fees. Some exchanges then compete by paying rebates to liquidity providers and charging fees to liquidity demanders. This is known as *maker-taker fees*. Colliard and Foucault (2012) find that maker-taker fees can improve the gains of trade, but that trading can become slower as more investors opt for passive orders. Foucault, Kadan, and Kandel (2013) show that maker-taker fees work as a tool for exchanges to incentivize liquidity suppliers to quickly replenish the order book after a large trade.[7]

[7] In the absence of a tick size, differences in the fee charged to liquidity suppliers and demanders would be neutralized by differences in quoted prices (Colliard and Foucault, 2012; Chao, Yao, and Ye, 2019). Chao, Yao, and Ye (2017) show in a sample of US exchange-traded funds from 2010 to 2011 that tick size drives lit market fragmentation. When the tick size becomes less binding, the degree of market fragmentation is reduced.

Malinova and Park (2015) analyze the introduction of maker-taker fees in Toronto, finding that the effective bid–ask spread net of fees is unchanged but that traders switch to more aggressive trading strategies.[8] Panayides, Rindi, and Werner (2017) investigate pan-European and UK stocks following fee reductions at MTFs run by BATS Europe in 2013. They show that a fee change at one venue influences market shares and market quality at all the exchanges that compete for the same order flow. The directions of the effects vary in the cross-section of stocks. For example, traders in large stocks are more sensitive to maker fee changes, whereas the taker fee is more important for small caps.[9]

In the early years of MiFID, exchanges in Europe also competed on the tick size itself. Foley, Meling, and Ødegaard (2022) show that exchanges that cut the tick size were able to significantly boost their market share and reduce the cost of liquidity. This type of competition was, however, stalled as the exchanges agreed to harmonize tick sizes in Europe in 2009.

Trading speed is another factor in the competition between exchanges. Menkveld (2014) shows that the emergence of MTFs in the European equity markets relied on low fees in combination with high trading speeds. He describes a symbiotic relation between European MTFs and HFT market making firms in 2007–2008. The speed of trading boosts the MTF market share by attracting HFT firms who benefit from the inter-market competition. Further analysis on trading speed competition between exchanges is provided by Menkveld and Zoican (2017) and Pagnotta and Philippon (2018). Cespa and Vives (2022) model the industrial organization of the exchange industry more broadly.

Parallel prices. Within an exchange, orders are typically executed according to price–time priority. For buy orders, for example, this means that the order with the highest price is executed first. If there are several orders at the same price, time priority implies that the earliest submitted order is executed first. However, the execution priority rules are not enforced *across* exchanges. In Europe, price priority is to some extent maintained because best execution rules lead brokers to route to the exchange with the best price (net of fees). This is an important difference to the US market, where the Order Protection Rule to some extent force exchanges to route incoming market orders to the venue with the best price (regardless of fees). Time priority is not maintained across exchanges in either jurisdiction, implying that liquidity providers can "jump the queue" by entering orders in the less liquid of competing markets.

[8]The effective bid–ask spread is closely related to the bid–ask spread that is observable in price quotes. To capture the fact that transactions do not always execute at the price quotes, it measures the difference between the actual trade price and the midpoint of the prevailing bid–ask spread.

[9]The literature includes several other aspects of exchange fees. First, some US exchanges apply *inverse fee schedules*, meaning that rebates are paid to liquidity takers and fees are paid by the liquidity providers. Comerton-Forde, Grégoire, and Zhong (2019) find that trading activity on platforms with such fee schedules leads to improved market quality, especially when the tick size is binding. To my knowledge, there are no exchanges with an inverted fee structure in Europe. Second, maker rebates can be conditioned on the continuous supply of quotes at competitive prices in baskets of stocks. Ding, Suardi, Xu, and Zhang (2021) find that such a scheme introduced at Nasdaq Stockholm is beneficial to liquidity. Third, exchange fee structures can cause agency problems, since brokers may be tempted to route orders to maximize rebates rather than minimize the cost to the client (Battalio, Corwin, and Jennings, 2016; Cimon, 2021).

Foucault and Menkveld (2008) show in a model of two competing limit order book markets that the ability to queue-jump incentivizes liquidity providers to post limit orders in both. This leads to greater consolidated depth in the fragmented market than in a centralized system (i.e., the liquidity aggregated across the two venues is greater than the liquidity in a centralized venue). The depth effect is confirmed by Foucault and Menkveld (2008) in an event where the London Stock Exchange started trading Dutch stocks in 2004. Menkveld (2013) provides an in-depth view of how an HFT firm runs an integrated market maker operation across two exchanges that trade the same Dutch stocks (at Euronext and Chi-X in 2007–2008).

Another way to interpret the lack of time priority across venues is that it reduces the incentives to undercut prices, leading to reduced liquidity. Bernales, Garrido, Sagade, Valenzuela, and Westheide (2022) model this channel and show that it is counteracted by another effect of fragmentation. If aggressive orders with price impact do not reach all markets simultaneously, adverse selection is reduced, making liquidity provision cheaper. They show that which effect dominates depends on volatility. In a sample of EU mid-cap and large-cap equities in France and Germany in 2012, Bernales et al. (2022) show that fragmentation is beneficial to liquidity at times of elevated volatility (and vice versa).

That adverse selection is lower in more fragmented markets is due to that liquidity providers, when they see a trade at one venue, are able to cancel limit orders for the same security at other venues. In a sample of FTSE 100 stocks in 2009, van Kervel (2015) documents that such cancellations exceeded 60% of the executed trade volume. He argues that the cancellations are rational responses to potentially informed trades that undermine the expected profitability of existing limit orders. This effect is distinct to the phenomenon referred to as ghost liquidity, where the same trading interest is posted at several venues. In the latter case, the liquidity provider responds to the execution of one order by withdrawing all other orders. In a sample of trading in European stocks from 2013, Degryse, De Winne, Gresse, and Payne (2020) report that ghost liquidity constitute merely 4% of the consolidated depth.

Fragmented markets require investors to connect to all platforms to access all liquidity. The technology to do so is referred to as *smart order routing* (SOR). Van Kervel (2015) models the liquidity supply in two competing limit order markets where some traders have SOR ability and other do not. He predicts that a higher prevalence of SOR technology implies higher adverse selection costs, reducing liquidity. The data support this effect, in that the consolidated depth in FTSE 100 stocks decreases with the amount of fast trading. Chen and Duffie (2021) show that the use of SOR makes trader aggressiveness higher in fragmented markets than in centralized markets. They conclude that this feature of fragmented markets leads to greater price efficiency. In a centralized market, traders could opt to split their orders over time instead of across venues, slowing down the incorporation of information into prices.

Price dislocations. In fragmented markets, prices for one security can differ across platforms. Due to the pre-trade transparency of limit order book markets, such deviations are inherently short-lived, since HFT firms constantly scan the markets for arbitrage opportunities. Nevertheless, these deviations have important implications for liquidity supply. For example, consider a stock that is traded at two exchanges. Whenever its value changes, liquidity suppliers at both exchanges rush to change their price quotes. Because the exchanges operate in continuous time, the price changes are never quite simultaneous. If only by a split second, the price at one exchange inevitably moves before the price at the other. Budish, Cramton, and Shim (2015) show that prices that appear to the human eye to move in lockstep lose their correlation when viewed at a millisecond frequency.

The time difference between responses to news across platforms constitutes an arbitrage opportunity that fast traders, often referred to as snipers, try to seize. Foucault, Kozhan, and Tham (2017) show that such arbitrage is costly to market makers, who, in response, reduce the liquidity supplied. Similarly, in a model by Baldauf and Mollner (2021), fragmented markets allow fast traders to pick off the stale quotes of market makers every time the price changes. On the empirical side, Aquilina, Budish, and O'Neill (2022) study speed races in a sample of FTSE 350 stocks in 2015 with message data from London Stock Exchange. They show that the race between snipers (who submit market orders) and market makers (who try to cancel their stale quotes) last only 5–10 millionths of a second, but account for around one-fifth of the trading volume. They estimate that the elimination of latency arbitrage could reduce the cost of liquidity by 17%. Along the same lines, Shkilko and Sokolov (2020) study the use of microwave connectivity between New Jersey and Chicago and find that latency arbitrage activity undermines liquidity.[10]

Some exchanges try to limit latency arbitrage by changes to the market design. The most well-known case is Investors Exchange (IEX) in the US market, whose *access delay* is colorfully described in the popular book *Flash Boys*, by Michael Lewis. In that case, incoming market orders are delayed by 0.35 milliseconds, such that market makers have time to revise their orders before they are sniped. A variety of access delays have been implemented elsewhere (see Figure 2). Access delays differ in whether they affect all traders and order types (symmetric or asymmetric; see the horizontal axis in the figure) and if the duration of the delay is deterministic or random (see the vertical axis in the figure).

The success of access delays hinges primarily on the fact that they are asymmetric. Budish, Cramton, and Shim (2015) and Baldauf and Mollner (2020) show that a delay on aggressive orders (that arbitrageurs use), but not passive orders or cancellations, can eliminate latency arbitrage. This allows market makers to quote tighter bid–ask spreads. A symmetric delay is not expected to address latency arbitrage (Budish, Cramton, and Shim, 2015). If the delay duration is random, it undermines the ability of SOR to access all liquidity across venues simultaneously (Baldauf and Mollner, 2020). Brolley and Cimon (2020) add that the latency delay implies execution uncertainty, which can lead informed investors to migrate to venues without delays.

Empirical evidence mostly confirms the benefits of asymmetric access delays. Chakrabarty, Huang, and Jain (2020) and Hu (2019) show that the IEX "speed bump" led to improved liquidity in US equities. Khapko and Zoican (2021) use lab experiments to investigate the impact of access delays. They find that an asymmetric delay reduces investments in low-latency technology by 20%. Whether the delay is random or not does not influence this result. An exception to the above evidence is the work of Chen, Foley, Goldstein, and Ruf (2017), who find that the introduction

[10] For a review of HFT and its impact on market quality, see Menkveld (2016).

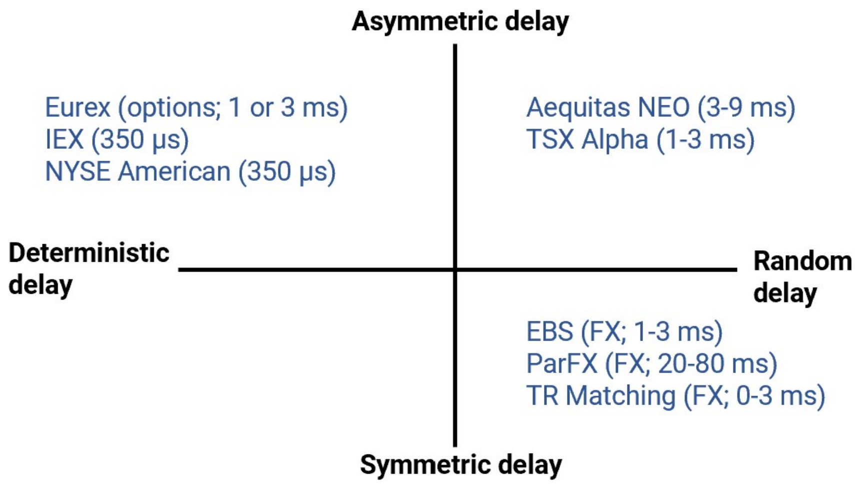


Figure 2: Access delays. This figure shows how currently implemented access delays differ in terms of being deterministic or random (displayed along the horizontal axis) and symmetric or asymmetric (vertical axis). For each market, the duration of the delay is stated within parentheses (*ms* and μs are the abbreviations for milliseconds and microseconds, respectively). For cases in which the market is not for equities, the asset class is also provided. Source: Baldauf and Mollner (2020, Table IA.III of the Internet Appendix) and the author.

of random and asymmetric access delays at TSX Alpha in Canada did not improve liquidity, even though it improves profitability in fast market making.

In Europe, a related case is the MTF Aquis, which, in 2016, banned all market orders sent by proprietary traders. This may be viewed as an extreme form of an asymmetric access delay. Qu (2021) compares liquidity at Aquis to that of competing exchanges. She reports that the ban reduces the adverse selection cost for market makers, who respond by increasing the market depth.

A more drastic market design change is advocated by Budish, Cramton, and Shim (2015). They argue that latency arbitrage is inherent in continuous markets, since the fastest trader can pick off the quotes of slower investors. Their proposed solution is to replace continuous limit order book markets with high-frequency batch auctions, where the advantage of speed is less valuable. Indriawan, Pascual, and Shkilko (2020) empirically study the opposite: a transition from a batch auction market in Taiwan to a continuous limit order book market. Consistent with latency arbitrage activities, they find that this change leads to higher trading volumes and reduced liquidity.

Overall effect on market quality. Empirical academic studies are often geared to identify the effect of a particular feature, rather than the general effect of market fragmentation. The identification of fragmentation effects on market quality is complicated by reverse causality: it is reasonable to expect market quality to also drive market fragmentation. The greater liquidity of more fragmented stocks, a pattern seen in Figure 1, can thus not be taken as evidence of causality. Furthermore, the symbiotic relation between MTFs and HFT described above makes it difficult to disentangle the effect of fragmentation from that of fast and automated trading. Empirical studies dedicate great effort to control for such confounding factors, but are nevertheless cautious in interpreting the results as proof of causality.

For European markets, Degryse, de Jong, and van Kervel (2015) study the liquidity of Dutch large caps and mid caps around the introduction of MiFID (2007–2009). They measure liquidity before and after the regulatory reform and report that lit market fragmentation improves the consolidated depth by 49%. Gresse (2017) studies the same regulatory event in a sample of large-cap and mid-cap stocks from France and the UK. She reports that liquidity improves both in terms of the bid–ask spread and in terms of depth.

The liquidity effect of lit fragmentation increases with firm size. Gresse (2017) finds that the liquidity effect of fragmentation is weaker for mid-cap stocks. In a study of European small caps and mid caps in 2009–2019, Lausen, Clapham, Gomber, and Bender (2021) report that such stocks are less likely to face lit market fragmentation and that fragmentation has no effect on the market quality of infrequently traded stocks. Haslag and Ringgenberg (2022) study differences across market capitalization segments in the US equity market. They find that, while it improves the liquidity of large-cap stocks, its effect for small caps is even negative.

The liquidity improvement associated with lit fragmentation depends on traders' ability to route orders to the venue with the best price. The positive impact reported by Degryse, de Jong, and van Kervel (2015) holds for consolidated liquidity. For investors who connect to the regulated market only, the impact of fragmentation is the opposite; that is, *local* liquidity is reduced. The improved liquidity documented by Gresse (2017), in contrast, holds for both consolidated and local liquidity. In a sample of Swedish large-cap stocks in 2013, Dzieliński, Hagströmer, and Nordén (2016) show that the effective bid–ask spread paid by institutional clients is around 0.40 basis points wider than it would be if their orders were routed to the venue with the best price. That corresponds to 15% of the spread. The cost of suboptimal order routing for retail clients amounts to 0.34 basis points (11% of the spread).

Aitken, Chen, and Foley (2017) analyze Australian equities in 2011–2013, when the MTF Chi-X challenged the incumbent exchange. Thanks to a gradual introduction of Chi-X trading, they are able to benchmark the effects of treatment stocks to a group of stocks that were unaffected by the introduction. They find that fragmentation boosts liquidity, with a tighter spread for stocks that are not tick constrained and greater depth for tick-constrained stocks. In addition, they find that lit fragmentation improves market efficiency and reduces market volatility. Opposite to the evidence in Europe and the US, the effect is consistent across firm size segments.

Whereas the literature on fragmentation and market quality in normal times is rich, little is known about its role in times of market stress. One exception is the study by Menkveld and Yueshen (2019), who study the Flash Crash of May 6, 2010, when US equity prices fell by 5%–6% only to recover within half an hour. The widespread uncertainty at the time of the crash led many participants to temporarily withdraw from the market. Menkveld and Yueshen (2019) document that cross-market arbitrage was broken during the crash, indicating that fragmented markets are potentially fragile. Félez-Vinas (2019) presents more positive evidence. In a study of Spanish stocks in 2013–2015, she shows that fragmentation makes the market more resilient to liquidity shocks, both in normal times and when it is under stress. Foucault, Kadan, and Kandel (2013) model the incentives for liquidity suppliers to quickly replenish liquidity after trades.

In terms of how transaction volumes are distributed across trading venues, European equity market fragmentation is at a historic high. An alternative view, proposed by Mendelson (1987), is to base fragmentation on the extent to which all individual traders' orders are considered when transaction prices and volumes are determined. According to that view, the degree of fragmentation of European lit markets is arguably low. With parallel prices maintained by cross-market liquidity suppliers and addressed by SOR and with price dislocations being arbitraged away at lightning speed, the exchanges that compete for pre-trade transparent order flows can be viewed as different entry points to a consolidated market.[11]

Policy implications. The entry of MTFs subjected European equity markets to increasing lit fragmentation over the past 15 years. New exchanges can attract order flow by charging lower fees and by offering niche services to investors, but the fragmentation of trading interests can make liquidity more expensive. The net effect of competition on fees and fragmentation of liquidity supply is not obvious.

This review shows that the lit fragmentation have been beneficial to European equities markets. Due to that prices at competing and geographically dispersed exchanges are kept tightly together by cross-market arbitrageurs and market makers, as well as the order routing technology that brokers use to comply with best execution agreements, the potential negative effects are limited. The competing exchanges that provide pre-trade transparent trading of European equities can be viewed as different entry points to a consolidated market.

The impact of fragmentation varies across securities and investors. In particular, the degree of fragmentation and also the benefits thereof are lower for smaller stocks. Furthermore, for investors who connect only to the regulated market, the liquidity impact of fragmentation is limited or even negative. From a policy perspective, it is thus desirable to facilitate investors' ability to compare prices across exchanges, and to route their orders accordingly.

Cross-market arbitrage activity contributes to keeping prices in sync, but also incurs economically significant costs to liquidity suppliers. Every time prices change, fast arbitrageurs can profit by trading against stale limit orders that market makers would otherwise revise a split second later. If the profitability of such arbitrage can be reduced, liquidity can improve. One way to achieve that is to impose constraints on the aggressive orders that are essential to arbitrage strategies.

2.2 Fragmentation between Lit and Dark Markets

Investor preferences for dark mechanisms. Central to the order routing decision is the trade-off between the cost of trading and the likelihood of finding a counterparty. Whereas lit markets are

[11] O'Hara and Ye (2011) arrive at a similar conclusion for the US equity market.

relatively expensive, they provide immediacy, in that a counterparty is virtually always available. Dark mechanisms, in contrast, are relatively cheap, but feature execution uncertainty. The uncertainty is due to that dark markets are pre-trade opaque, they do not disclose what trading interests are available. Accordingly, investors sending their order to a dark market do not know if it will be filled, let alone how long it will take.

In a model by Hendershott and Mendelson (2000) that features a dark market parallel to a lit market, the immediacy versus cost trade-off leads to a segmentation of investors across the mechanisms. Liquidity traders that place a relatively low value on immediacy are better off trading in the dark, whereas investors with short-term information flock to the lit mechanism. Zhu (2014) shows that, when given the choice between a dark pool and an exchange, informed traders tend to route their orders to the latter, because they would struggle to find a counterparty in the dark. This is because the informed tend to trade in the same direction.

Menkveld, Yueshen, and Zhu (2017) hypothesize a dynamic pecking order, where investors turn first to low-cost dark pools and only migrate to lit markets for immediacy as they become more impatient. They find support for such priorities in a sample of US equities from 2010, with rich information, in particular, on different types of dark pool trades. Neumeier, Gozluklu, Hoffmann, O'Neill, and Suntheim (2021) present consistent evidence for institutional traders in 80 liquid UK stocks in 2020. As seen in Figure 3, in the beginning of a parent order execution (when less than 20% is executed, to the left in the figure), almost half (46.8%) of the trading volume take place in dark pools. The dark pool market share decreases with the fraction of the parent order that is executed. In the last 20% of the parent order execution, less than 30% is routed to dark pools. They also find that dark market trading benefits institutions. The higher the proportion executed in dark markets, the lower the implementation shortfall.

Further evidence consistent with the pecking order hypothesis is presented by Gomber, Sagade, Theissen, Weber, and Westheide (2022), who analyze a large sample of EU large-cap stocks. They find that lit exchanges record higher market share when information asymmetries are high, such as the time around earnings announcements. Dark pools also see elevated market shares at those times, whereas fewer trades are matched in the OTC markets.

The attraction of uninformed investors to dark mechanisms is known as *cream skimming*. A basic insight in market making is that, when orders from informed and uninformed traders are indistinguishable and routed to the same market, both groups pay the same bid–ask spread (Glosten and Milgrom, 1985; Kyle, 1985). The liquidity provider expects to incur losses when trading with the informed and covers these with profits expected from trading with the uninformed. If the latter can credibly signal that they are uninformed, however, they can obtain better prices by routing their orders elsewhere.[12] This creates an economic rationale for dark markets that attract uninformed investors (Röell, 1990; Battalio and Holden, 2001). Lee and Wang (2021) show that the dealers' ability to offer better prices to less informed investors leads to that securities with more uninformed investors have higher market share for dealers.

[12]Glosten (1994) shows theoretically that limit order book markets should be immune to cream skimming if the competing exchange is anonymous.

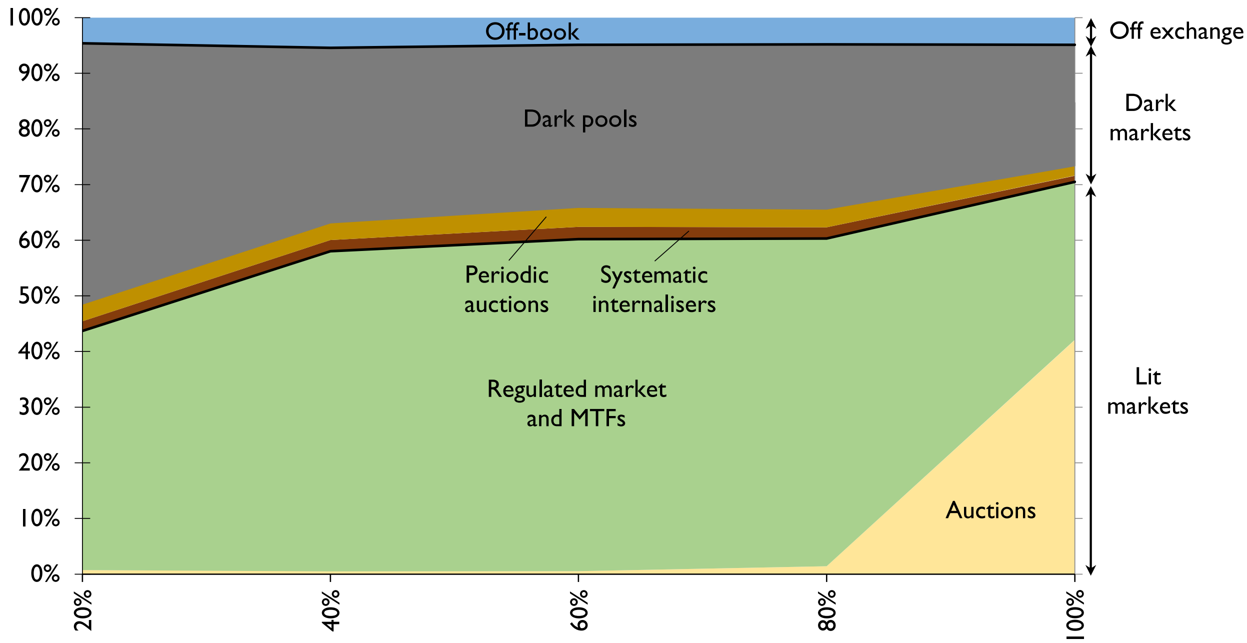


Figure 3: The Pecking Order of Trading Venues. This figure is an adaptation of institutional order routing data presented by Neumeier et al. (2021, Figure 4.1). It shows how institutional investors split their trades across venue types, depending on what fraction of the parent order has been executed. The horizontal axis shows the quintiles of parent order execution, such that the leftmost bars show the results for the first 20% of the execution, the next bar for the second quintile of trades, and so on. The vertical axis shows how child trades are distributed across trading venue types. The data underlying the figure are a sample of institutional trades in liquid UK stocks in 2020. Parent orders are inferred by summing the trades from each participant of each broker, stock, and date. Stock dates when DVCs are in effect are excluded.

In the US equity market, a prominent example of cream skimming is payments for order flow. Brokers are paid to route retail trade flows, which on average are expected to be uninformed, to market makers instead of lit markets (for empirical analyses of this, see Easley, Kiefer, and O'Hara, 1996; Battalio, 1997; Battalio, Greene, and Jennings, 1997; Bessembinder and Kaufman, 1997). In Europe, according to the *European Securities and Markets Agency*, payments for order flow are not compatible with MiFID II. Most retail order flows therefore execute in lit markets.

Hagströmer and Menkveld (2022) analyze the relative informativeness of trades in UK large-caps in 2021. They show that the information revelaed in trades at the regulated exchange is an order of magnitude greater than for trades in dark markets. This is consistent both with that informed traders route to venues with high immediacy (pecking order hypothesis) and with that some dark mechanisms are able to screen out informative trades (cream skimming). The latter channel is corroborated by that systematic internalisers, where dealers know who they trade with, have less informative trades than dark pools, which are anonymous.

Another key attraction of dark markets is that regulators allow them to execute trades at a finer price grid than in lit markets. When the lit market tick size is binding (i.e., when the bid–ask spread equals one tick), liquidity providers form long queues at the best bid and ask prices, which leads to long waiting times for the execution of limit orders. In this situation, midpoint execution in dark pools is appealing (Buti, Consonni, Rindi, Wen, and Werner, 2015; Buti, Rindi, and Werner, 2017). Similarly, dark pools are relatively more attractive when the lit market is more liquid (Buti, Rindi, and Werner, 2017). In empirical studies based on US equities, Kwan, Masulis, and McInish (2015) and Buti, Rindi, and Werner (2022) confirm these predictions.

Effects on market liquidity and market efficiency. When uninformed flows are diverted away from the lit market, as implied by cream skimming, the remaining flow may be more informed. The direct consequence is worse liquidity in the lit market, but better price discovery. As market makers become more exposed to informed trading, they respond by increasing the price of liquidity (with wider spreads and lower depth). At the same time, the increased concentration of information makes it easier to reveal, leading the market price to converge more quickly to the fundamental value. This follows from the classic theoretical models of Glosten and Milgrom (1985) and Kyle (1985) and is articulated in the dark pool model of Zhu (2014). Indirectly, however, the reduced liquidity faced by informed traders can undermine the incentives to acquire information in the first place. This counteracts the direct effects of cream skimming and makes the net effect ambiguous.

Empirical research on dark market fragmentation faces similar issues as described above. That more liquid stocks have a greater dark market share, as seen in Figure 1, should not be interpreted as a causal relation (in either direction). Any market quality assessment must account for how investors make their order routing decisions.

Taking the issues above into account, the empirical evidence on the market quality effects of dark trading is mixed. Consistent with order flow segmentation, Comerton-Forde and Putniņš (2015) find that dark trades in Australian stocks in 2008–2011 were less informative than trades at the lit exchange. Similarly, Hatheway, Kwan, and Zheng (2017) find that dark pool trades in a sample of US stocks in 2011 were less informed than exchange trades. Both papers show that dark trading leads to reduced liquidity (wider bid–ask spreads) at the lit exchange. Hatheway, Kwan, and Zheng (2017) report that a 10% rise in the dark market share leads to a 9% increase in lit market effective bid–ask spreads. They also find that the dark market share is negatively related to price efficiency. Comerton-Forde and Putniņš (2015) find a tipping point in the dark market share at around 10%, above which dark trading reduces market efficiency. O'Hara and Ye (2011), in contrast, find that dark trading activity in US stocks is positively associated with market liquidity and market efficiency. Along the same lines, Barclay, Hendershott, and McCormick (2003) find that trades in US electronic communication networks, which resemble dark pools, are more informative than in lit exchange flows.

In European stock markets, Degryse, de Jong, and van Kervel (2015) find that the market share of dark and off-exchange trading is negatively associated with the depth in the lit market. Gresse (2017), however, finds that dark trading is not detrimental to market liquidity. Ibikunle, Aquilina, Diaz-Rainey, and Sun (2021a) study the impact of dark pools on the market quality of UK stocks in 2010–2015. They analyze adverse selection risk and informational efficiency in the aggregate across lit and dark markets, finding that dark trading improves both measures. The impact is nonlinear. For dark market shares exceeding 9% for liquid stocks (and up to 25% for less liquid securities), the impact becomes negative.

A potential reason for the mixed results is that there are many types of dark trading and the data available to researchers are often not granular enough to uncover such differences. An exception involves the work of Comerton-Forde, Malinova, and Park (2018), who analyze the effect of a Canadian rule change in 2012 that restricted dark pools to midpoint trading. With the aid of detailed proprietary data from the Canadian regulator, they are able to document that the change led retail flows to migrate from dark pools to lit markets. They show that as market makers follow retail investors, liquidity in the lit market improves. However, the granularity of the data allow the researchers to show that the improvement in aggregate market quality does not benefit all traders. Due to the maker-taker fee structure in lit markets, the changes lead to higher fees paid by retail investors (who tend to be liquidity takers), whereas HFT market making firms benefit by earning rebates.

Foley and Putniņš (2016) study the same Canadian regulatory event, as well as a similar change in Australian dark pool trading. They report that dark pools where liquidity can be supplied at the best bid and ask prices are associated with tighter lit market bid–ask spreads. Dark pools restricted to midpoint trading, on the other hand, do not influence lit market liquidity.

The execution quality of dark pools may also differ, depending on who is allowed to trade there. Whereas exchange-operated dark pools tend to have no access restrictions, dark pools run by brokers often screen the participants. For example, they can deny access to HFT firms. Using data from Australia in 2017–2019, Brugler and Comerton-Forde (2022) show that broker-operated dark pools are associated with less information leakage and lower adverse selection costs.

Large dark trades. Block trades have a long tradition of off-exchange execution and have, accordingly, been covered extensively in academic research. Since dark trade data typically convey volumes, the role of trade size can also be analyzed empirically. In Europe, large dark trades have special status through the large-in-scale waiver.

Pagano (1989) finds that, when an OTC market is available, traders cluster according to the size of their trading interest. For example, relatively large traders are then better off searching for counterparties off exchange. Grossman (1992) rationalizes the coexistence of exchanges and OTC markets with the argument that off-exchange dealers serve as repositories of latent trading demands. The knowledge of client trading interests enables them to quote better prices than on-exchange dealers. Madhavan (1995) adds that frictions to information about transactions across markets are beneficial for some market participants. He finds that large and informed traders who split their trades across time can obtain better prices in fragmented markets. This creates a demand for opaque markets.

Duffie and Zhu (2017) refer to markets where the price is fixed (as in midpoint dark pools and periodic auctions) as *size discovery mechanisms*. Since such markets, by definition, do not have a price impact, they attract large trades. They show that size discovery mechanisms can improve the allocative efficiency of the market, since other methods for trading large blocks (e.g., splitting an order into many small orders over time) imply delayed price discovery. Antill and Duffie (2021), in contrast, point out that size discovery–augmented price discovery mechanisms (e.g., a block-trading dark pool operating in parallel with a lit exchange) reduces lit market depth and price efficiency, since investors then wait for size discovery trades.

Ye and Zhu (2020) point out that the order segmentation result of Zhu (2014) depends on the composition of informed trading. Whereas the model of Zhu (2014) features infinitely many informed traders, Ye and Zhu (2020) model a situation with only one large informed trader. The large informed trader uses the dark pool to avoid revealing information. Opposite to Zhu (2014), Ye and Zhu (2020) predict that the dark pool market share *increases* with the value of private information. In practice, the private information described by Zhu (2014) may be thought of as accessible to anyone willing to pay for the data and effort. Ye and Zhu (2020), in contrast, model how a trader may act on unique information that cannot be inferred from public sources. An example they cite is hedge fund activists.

Empirically, Ye and Zhu (2020) report that the dark pool market share is 13% higher in weeks when a stock is subject to hedge fund activist activity (using regulatory filings in US equities). They also find that price discovery in lit markets is negatively related to such dark pool activity. Comerton-Forde and Putniņš (2015) find that block trades in Australian equities do not harm price discovery, as opposed to regular, smaller dark trades. Similarly, Hatheway, Kwan, and Zheng (2017) find that the execution of large trades in the dark in US stocks reduces the detrimental effects that they find for dark pools. Dark pool trading can also boost price discovery in the sense that more information is generated. Brogaard and Pan (2022) show that constraints on dark trading (as part of the US tick size pilot) discourages information acquisition.

Given that large dark trades do not appear to undermine market quality, a relevant question is whether there is a trade size threshold above which dark trades are benign. To my knowledge, no academic research addresses that question.

Market fragmentation under MiFID II. As seen in Figure 1, MiFID II has strong implications for the fragmentation of European equities, particularly for dark markets. Three empirical papers analyze the effects of caps on dark pool trading. Both Johann, Putniņš, Sagade, and Westheide (2019) and Neumeier et al. (2021) find that the DVCs lead to migration to other dark markets (particularly to periodic auctions), rather than lit markets. The study by Johann et al. (2019), based on public data on more than 1,000 stocks in 2018, shows that the market quality impact of DVCs is close to zero for liquidity, as well as market efficiency. Neumeier et al. (2021) measure the implementation shortfall in institutional trading and report that DVCs have no significant effect on that either. Ibikunle, Li, Mare, and Sun (2021b), in contrast, find that the DVCs reduce the liquidity and informational efficiency of FTSE 350 stocks in 2018.

The most dramatic market share change around the introduction of MiFID II is seen for SIs. The availability and granularity of data on SI trades is low, but Aramian and Nordén (2020, 2021) are able to shed light on the mechanism using regulator-collected data on Swedish large-cap stocks.

Aramian and Nordén (2020) focus on SIs run by HFT firms, which are responsible for half of the SI trades and 23% of the dollar volume. A key finding is that activity at HFT-run SIs is detrimental to lit market liquidity. This is because HFT firms manage inventory positions obtained in SIs by reducing their liquidity supply and by trading more aggressively in the lit market. Aramian and Nordén (2021) show that SI trades have less price impact than comparable trades at exchanges, indicating that SIs work as a cream skimming mechanism.

The studies by Aramian and Nordén (2020, 2021) and Neumeier et al. (2021) exemplify how access to regulatory data facilitate the analysis of dark markets. In particular, the ability to track the activities of the same trading firm at different venues is important to understand the effects of market fragmentation.

Policy implications. Trading in dark markets tends to be cheaper than at exchanges, but it is associated with higher execution uncertainty. This attracts investors with low sensitivity to the trade delays, such as passive mutual funds, agents who trade for liquidity reasons, and participants with large positions and unique information (e.g., activist hedge funds). Less patient investors (e.g., those trading on short-term information) prefer lit markets. In Europe, retail investors also tend to trade in lit markets.

The trader segmentation between lit and dark markets implies that any policy that influences the degree of market transparency is subject to trade-offs between investor groups. Increasing the requirements of pre-trade transparency would disadvantage groups trading in the dark and benefit investors at lit exchanges, and vice versa.

Theoretical models show that dark trading reduces the liquidity at exchanges, but also improves price discovery. Empirically, the evidence is mixed and set back by poor trading data availability. Policymakers could facilitate studies of dark trading by making transaction records with high time stamp granularity and detailed venue information available to academic research.

Several empirical studies of dark pools outside Europe find that block trades in dark mechanisms do not undermine market quality. This lends support to the large-in-scale waiver of pre-trade transparency, which is currently applied in Europe.

The introduction of MiFID II in January 2018 brought substantial changes to dark trading in Europe. The academic evidence shows that the dark volume caps (DVCs, see Section 1) led to migration of flows to periodic auctions and other dark mechanisms. It had little impact on market quality. Another important change brought by MiFID II is that banks and trading firms formed systematic internalisers to execute flows that had previously been allowed off-exchange. Empirical evidence on this shows that platforms operated by HFT firms can undermine lit market liquidity.

3 Concluding Remarks

The academic evidence indicates that lit market fragmentation makes European equity markets more liquid and efficient, particularly for large stocks. The evidence on dark fragmentation, in contrast, is mixed. It is unclear from current studies whether the dark market share in European equity markets is too high or too low. The evidence suggests, however, that dark trade mechanisms are beneficial for the execution of large positions.

The topics covered in this review reflect where academic researchers have concentrated their efforts to date. An area that deserves more attention is the complexity implied by fragmentation. Europe currently has hundreds of platforms offering equity trading, and monitoring liquidity in those is a daunting task. How this complexity influences investors' ability to optimize their trading strategies and government agencies' ability to perform market surveillance has not been addressed so far. The consequences of fragmentation in times of market stress are also an interesting area for further research. Finally, more work (and better data) is required to understand the impact of different types of dark mechanisms and the mix thereof in European markets.

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