



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

The technological transformation of capital markets

Citation for published version:

Diaz-Rainey, I, Ibikunle, G & Mention, A-L 2015, 'The technological transformation of capital markets' Technological Forecasting and Social Change. DOI: 10.1016/j.techfore.2015.08.006

Digital Object Identifier (DOI):

[10.1016/j.techfore.2015.08.006](https://doi.org/10.1016/j.techfore.2015.08.006)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Technological Forecasting and Social Change

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



The technological transformation of capital markets

Ivan Diaz-Rainey*

Department of Accountancy and Finance, School of Business, University of Otago, Dunedin, New Zealand

Gbenga Ibikunle

University of Edinburgh, UK

Anne-Laure Mention

Luxembourg Institute of Science and Technology, Luxembourg

Abstract

Technology has dramatically altered capital markets over the past few decades. Technologically induced innovations such as electronic exchanges, high frequency trading (HFT) and exchange traded funds (ETFs) have made trading in capital markets faster, cheaper and more integrated, yet at the same time market liquidity has become more fragmented and opaque. Further, there are concerns that this new paradigm leads to greater volatility and myopia in the core function of finance (raising capital for entrepreneurial activity). Capital markets are clearly complex adaptive techno-social systems that are undergoing dramatic changes yet they are rarely researched from an innovation research or technological change perspective. In this editorial, we introduce the themes and issues highlighted by the papers in this Special Issue that addresses this gap in the literature. The contributions illuminate the technologies and related innovations that are changing the nature of capital markets. However, technology cannot be seen in isolation from other forces, most notably regulation, organisational innovation and new entrants. Moreover, technology is not only changing existing markets, it is expanding the scope of markets. Thus we conclude that that financialization (the process by which financial markets become increasingly important in the economy and society) is a technology enabled phenomenon – something hitherto largely overlooked by the financialization literature.

Keywords: Financial markets, Information technology, High Frequency Trading, Financialization, electronic exchanges, financial innovation

*Corresponding author: Corresponding author: Tel. + 64 3 479 8117; Fax: + 64 3 479 8171;
Email: ivan.diaz-rainey@otago.ac.nz

1. Introduction

“... HFT [High Frequency Trading] is not technology run amok, but rather a natural evolution of markets towards greater technological sophistication” (Easley *et al.*, 2013 p.XV)

“... fundamental changes related to information technology and the proliferation of financial markets have created a financial landscape that is highly opportunistic, transaction driven, and prone to destabilizing herding behaviour.” (Boot 2012, p.129)

Financial markets are controversial and divisive, not least since the social and economic fallouts from the 2008 Global Financial Crisis (GFC). On the one hand, some see them as the critical lubricant that oils the global economy, while others see capital markets as the spanner in the works to a fairer society. This diversity of views is evident in academic literatures, with finance researchers in general providing an upbeat assessment of markets while more sociological focused contributions generally lamenting the increased importance of finance – with this increased importance being described as financialization.

Generally absent in these literatures is an explicit examination of how technology is transforming capital markets. Anecdotal evidence suggests capital markets are in the midst of a dramatic and technologically driven transformation. Insights into the transformation of capital markets by technology are discernible in the financial press (for instance Popper 2013 and Ostand 2013), non-academic books (Arnuik and Saluzzi 2012; Lewis 2014, Patterson 2012), in publications by industry professional bodies (Preece *et al.* 2012) and in publications by regulatory agencies (ESMA, 2014; IOSCO 2011).

Capital markets are clearly complex adaptive techno-social systems with profound implications for society should they malfunction (Linstone and Phillips, 2013). Yet they are rarely researched from an innovation research or technological change perspective. This Special Issue addresses this gap in the literature and provides an accessible entry point into this important technological transformation. In this editorial, we introduce the themes and issues highlighted by the papers in this Special Issue.

The rest of this editorial is structured as follows. The next section provides context in terms of the role of IT in finance, generally, and then more specifically in the context of capital markets. The following two sections develop the contrasting views about markets evident above, first through the lens of the established finance literature (Section 3) and secondly via critiques of contemporary markets from social and sociological perspectives (Section 4). As intimated above, a limitation of both these literatures is that although they have explored the *effects* of the technological transformation of capital markets they have not shed much light on

how technology has enabled this transformation. In Section 5 we discuss the five papers in the Special Issue which address this gap in the literature. Section 6 provides some concluding remarks.

2. The Context: Finance and IT

Technology within the financial services sector is growing in importance, bringing more and more innovation to the possible interactions with financial service providers and directly influencing and reshaping financial service operations (Mention and Torkkeli, 2012). The use of electronic payments, the processing of transactions, and the interactions with the customer through various online banking platforms, ATMs, CRM applications, and recently mobile applications for daily banking are all examples of technology-induced innovations in the financial services sector.

Information systems and technology play a leading role in the financial services industry for several reasons. Firstly, finance was one among the first sectors to adopt information systems and technology in order to automate processes (Chiasson and Davidson, 2005). Secondly, the financial services industry can be considered as a clear example of a service industry because its fundamental activity is the processing of information and intangible resources (Baets, 1996; Avison et al. 2004). Thirdly, the use of information technology is also known to be relevant as a competitive advantage for this sector (Broadbent and Weill, 1993; Tallon, 2010).

Financial services companies are therefore heavily dependent on their current technology and this creates also possible information security threats. This, coupled with the sensitive data and information that is dealt with in this sector, makes the financial sector a high risk area for information security (Wang et al., 2015).

Technology also has a leading role in transforming the companies active in financial services by integrating discontinuous phases in the value chain. The result of these new combinations and their automated execution are increased performance. These changes require software tools and adequate hardware infrastructure. An example of a successful transformation through technology within the context of financial services can be found in the application of increased customer focused approaches by leveraging knowledge on customers and the digital interactions with customers (Cooper et al., 2000).

From the above discussion it is not surprising that about 91% of finance industry analysts rated technology as either critical or important to the financial services industry (Accenture, 2011.). It is estimated that financial services firms spent between USD 270 billion and USD 460 billion on IT in 2013 globally (Mai, 2012). Further financial services firms spend

more on IT than other industries - IT costs equated to 7.3% of revenues in financial services compared to 3.7% on average in all other industries (Mai, 2012).

2.1 Capital Markets and IT

From the discussion above, it is clear that to date the preponderance of the literature on finance and IT has focussed on the management of innovation where the unit of analysis is the firm (for instance Avison *et al.* 2004; Mention and Torkkeli, 2012). Further, the focus has been on the ‘visible’ parts of finance, namely commercial and retail banking, as well as financial services providers more generally. Emphasis has also been placed on open and collaborative innovation between financial services firms and their technology suppliers (Mention and Torkkeli, 2014; Schueffel and Vadana, 2015). This is what finance literature describes as ‘intermediated’ finance but less is known about how ‘direct finance’ is being changed by IT.

‘Direct finance’ refers to capital markets and the institutions that facilitate access to them such as stock exchanges, securities brokers and investment banks. Thus, relatively little is known in the academic literature about how technology is changing capital markets at a more systemic level (i.e. how technology has changed market “macrostructure”). In prescient contributions Coates (1992) and Werthamer and Raymond (1997) predicted in the 1990s that information technology was on the verge of radically transforming capital markets, while Linstone and Phillips (2013) note that contemporary capital markets are an example of ‘too little understanding chasing too much complexity’, potentially leading to low-likelihood, very high-impact failures or “X-events” as described by Casti (2012).

Beyond these exceptions, and as noted in the introduction, insights into the contemporary transformation of capital markets by IT/technology are principally discernible in the financial press (for instance Popper 2013 and Ostand 2013), non-academic books (Arnuk and Saluzzi 2012; Lewis 2014; Patterson 2012), in publications by industry professional bodies (Preece *et al.* 2012) and in publications by regulatory agencies (ESMA, 2014; IOSCO 2011). From these it is evident that technological change, regulatory reform and financial innovation have dramatically altered capital markets over the past few decades. Technology has increased automation of trading and helped lower the barrier to entry for alternative electronic trading platforms, thus increasing the competition for order flow (see Angel *et al.*, 2011). For instance, ICT technologies have facilitated the spread of high frequency trading (HFT) to an ever increasing number of markets and geographies. HFT has not only increased the speed of trading but also altered the nature of markets, with HFTs often taking on the role of liquidity providers and as such becoming the ultimate market insiders (Diaz–Rainey and Ibikunle, 2012; Hendershott, *et al.*, 2011). Furthermore, ICT technologies and deregulation have facilitated the development of maligned financial innovations (such as credit derivatives and securitized loan

assets) and ones such as Exchange Traded Funds (ETFs) that offer considerable benefits but also sizable risks (Allen, 2012; Brunnermeier, 2009; Diaz–Rainey and Ibikunle, 2012). The combination of ICTs and deregulation have also resulted in ‘liquidity fragmentation’ or ‘market fragmentation’ with the emergence of alternative trading venues and ‘dark pools’ that have resulted in the erosion of market share for traditional regulated exchanges. This in turn has raised concerns about market transparency and regulation (Preece *et al.* 2012). Of these various trends the growth of alternate trading venues and of HFT or automated trading (AT) have played a critical role in re-defining contemporary markets. We discuss each in turn.

Alternative trading venues, market fragmentation and ‘dark’ trading

As noted above, financial markets have undergone transformational changes over the past few decades; however, the last decade has witnessed the most significant changes in the way financial trading platforms operate (see Angel *et al.*, 2011). The changes induced by the declining costs of technology and changes in policy, hold significant implications for market structure in several respects. For example in Europe, the enactment of the Markets in Financial Instruments Directive (MiFID) in 2007 coupled with technological advances in trading systems led to the proliferation of trading venues in Europe (i.e. new electronic competitors to traditional stock exchanges or securities exchanges) (Gomber *et al.* 2015). These include Broker Crossing Networks (BCNs) and Electronic Communication Networks (ECNs) or Multilateral Trading Facilities (MTFs) as they are called in Europe. The growth of alternative platforms, as with AT and HFT, has been largely driven by technology. However, again, policy and the desire to improve competition among trading venues (for example in Europe through MiFID) and the desire to reduce transaction costs by eliminating the middleman have been the main driving forces behind the rise of alternative trading platforms. This competition among trading platforms means that in US equity markets, no one trading venue has more than 20% to 25% of market share (Gomber *et al.* 2015).¹ Though competition amongst trading venues seems most pronounced in the US, it is very much evident in other major capital markets such as those of Germany and the UK.²

Technology as well as increasing the number of trading venues has also altered the nature of trading. Given the incentives for stealth in trading, opaque markets (the so-called ‘dark pools’) have risen and have begun to attract trading order flow away from the ‘lit’ platforms. Dark pools are trading systems that offer no pre-trade transparency. In ‘lit’ platforms the order

¹ The Fidessa Fragmentation Index charts market fragmentation in leading capital markets around the world (see <http://fragmentation.fidessa.com/>). The 20% to 25% estimate is based on Gomber *et al.* 2015 and the Fidessa Fragmentation Index for the US on 8 July 2015 measured by volume for the whole of the US, excluding OTC transactions.

² Again, see the Fidessa Fragmentation Index (<http://fragmentation.fidessa.com/>).

book (buy and sell orders) is visible, while in dark pools it is not, thereby allowing trading by stealth. One of the unintended consequences of integrating these opaque systems with lit trading systems is the ability of dark pool traders to ‘front-run’ the market. Large institutional traders also prefer to trade large blocks via dark pools in order to avoid being front-run (see Zhu, 2014)

In response to the competitive threat of dark pools, traditional exchanges have also introduced facilities for the placement of dark orders (for example, “iceberg orders”), which can interact with displayed orders (see Boulatov and George, 2013). Some have also established their own dark pools in a bid to counter the threat of new players in the market. For example, the London Stock Exchange Group owns Turquoise, a leading dark pool venue in the EU. Some trading platforms allow for the interaction of dark orders with their integrated ‘lit’ platforms. Suppose the execution rule for such interaction is based on price, visibility and time, a dark order could conceivably execute ahead of a displayed one (see Ibikunle, 2015). According to Preece *et al.* (2012), by March 2012, the proportion of overall United States trading volume accounted for by dark trades was 31%. While the proportional figure is less dramatic in other parts of the world, the absolute trading value is staggering nonetheless. For example, according to the Thomson Reuters Equity Market Share Reporter, dark pool and broker crossing activity of all European equities for the 12-month period ending in March 2014 was in excess of €898.22 million, this value is equal to about 9.55% of all equity trades in Europe.

Proliferation of new trading venues has clearly contributed to the fragmentation of trading and the emergence of dark trading, with possible further implications for market efficiency. Expectedly, developments such as market fragmentation have become causes for concern among market participants and regulators generally. The concerns relate to the whether the proliferated market landscape will harm price transparency in the markets. Since ECNs/MTFs are designed to facilitate the electronic execution of trades they are suitable for HFT activities. Thus market fragmentation is closely aligned with the development of HFT. Furthermore, given the anonymity and stealth provided by dark pools, a lot of informed traders using low latency trading strategies prefer them to the traditional trading exchanges and this in turn has made dark pools even more attractive to HFTs.

A paradox that arises in contemporary capital markets from the linkage between HFT and growth of alternative trading venues is that markets are simultaneously more fragmented and integrated at the same time – there has been liquidity fragmentation as new venues have competed with traditional exchanges for trading order flow, yet the law of one price, and hence integration of markets, has been facilitated in this fragmented context by HFT arbitraging away in milliseconds any price differences that may exist between venues.

High Frequency Trading and the ‘flash crash’

Market fragmentation is just one of the several concerns held by market participants in an age of rapid technological innovations in global markets. Perhaps the most significant consequence of rapid technological advancements in financial markets is the advent of high frequency or low latency trading (HFT) and algorithmic trading (AT).

The basic principle underlying HFT and AT is the use algorithms in the automated trading of securities that rely on a combination of hardware and software. HFT and AT are very similar since they both employ advanced computing software in the processing of information and subsequent trading at very high speed. Thus, academic research into both trading types have focused on largely the same issues (see as examples, Brogaard *et al.*, 2014; Hendershott *et al.*, 2011). Also, findings on HFT provide relevant insights for AT and vice versa. However, a fundamental and contextual difference exists between both trading types. HFT is usually referred to in a proprietary context, which translates that HFT firms trade with their own capital, while AT involves trading with investor capital. Furthermore, HFT which is based on taking advantage of trading opportunities over very short timescales, can be considered as a subset of AT. Therefore, the success of HFT is dependent on low-latency communication and decision making (Harris, 2013).

In the mid of the GFC, HFT started to gain attention, despite the fact that it has been used since 1999 in the US financial market. This was partly due to the growth of its use within equity markets and its increased prevalence internationally and in other markets such as commodities. For instance by 2014, HFT in the European Union equity markets accounted for between 24% and 43% of all trading depending on the method of estimation (ESMA, 2014, p. 12).

However, the event that raised most awareness about HFT and its risks was the ‘flash crash’ of 2010. On May 6, 2010 the Dow Jones index lost almost 9% of its value in a few minutes and although it recovered most of its losses during the day, the incident highlighted to investors and regulators how rapidly adverse markets events could unfold in markets increasingly dominated by HFT. Following this event, some commentators suggest that about \$232 billion was withdrawn from US equity mutual funds between May 2010 and January 2012, indicating a major loss of confidence in markets as a result of the ‘flash crash’ (Arnuk and Saluzzi 2012.). Although the exact cause of the ‘flash crash’ remains open to continuing assessments (Diaz-Rainey and Ibikunle 2012; Easley *et al.*, 2011; Kirilenko *et al.*, 2011), whether or not it was initiated by HFT is immaterial. What was evident from the incident was that markets had become heavily reliant on HFT and when they withdrew from the market

liquidity evaporated causing dramatic falls in share prices (see Diaz-Rainey and Ibikunle, 2012; Easley *et al.*, 2011). Moreover, though the ‘flash crash’ was not an “X-event” (see reference to Casti 2012 and Linstone and Phillips 2013 above), it suggested that commentators warnings (not least Patterson 2012) that technological transformed markets may be susceptible to such events may not be wholly wide of the mark.

3. The finance literature

The evolution of capital markets towards high frequency/low latency electronic trading has been associated with the development of a branch of finance research termed ‘market microstructure’. This literature explores how prices are formed in modern electronic markets, usually using high frequency datasets. Although still in its relative infancy, market microstructure research has examined the *effects* of technological transformed markets, including exploring the issues of market fragmentation and HFT discussed above.

With respect to fragmentation, O'Hara and Ye (2011) find that market fragmentation in US equity markets has not necessarily led to the loss of pricing process quality; their analysis presents the US equity trading venues as a single virtual market with multiple entry points (trading venues). A more recent study of the implicit efficient price for FTSE 100 stocks across European platforms by Ibikunle (2015) supports the findings of O'Hara and Ye (2011). Cai *et al.* 2015 explore the interaction between electronic and traditional dealer markets and find that although electronic markets reduce trading costs they are associated with greater volatility.

Turning to the issue of dark pool trading, the balance of the evidence in the microstructure literature suggests dark trading is positive for market quality.³ For example, Zhu (2014) suggests that the addition of a dark pool to existing lit platforms can enhance price discovery, while Ye (2011) find the opposite using a Kyle (1985) framework. Boulatov and George (2013) also employ Kyle-like (as in Kyle, 1985; Kyle, 1989) framework to study the impact of a dark pool on a lit pool within the same market. They find that dark trades are beneficial for market quality. They attribute this favourable effect to the fact that informed traders are forced to provide liquidity since orders are not displayed, and they are therefore more aggressive liquidity providers in a market with hidden liquidity than in one with displayed liquidity. However, in a more recent contribution Preece and Rosov (2014) find that as dark trading increases its marginal benefit decreases and at certain threshold additional dark trading is associated with deteriorating market quality.

³ Markets deemed to possess trading quality are characterised by high levels of transparency, low trading costs, large depths and narrow bid-ask spreads.

Another focus of the microstructure literature has been on the impact of HFT. An important contribution in this respect has been for the literature to highlight that not all HFT is alike. There is considerable variability with respect to their trading strategies such that they diverge in terms of execution speed, liquidity effects, contribution to price discovery and short horizon volatility impact. Benos and Sagade (2012) examine HFTs on the basis of their liquidity provision, distinguishing between “aggressive” (those who mostly consume liquidity) and “passive” (those who mostly supply liquidity) HFTs. Their study suggests variations in trading behaviour such that passive HFTs rotate their trading positions from one second to the next and thus are overall price neutral, while aggressive HFTs trade with the previous 10-second trend. Accordingly, it would seem critical that policy responses concerning HFT discern between those HFTs employing aggressive, and (perhaps) predatory practices, and passive HFTs that provide market liquidity (Diaz-Rainey & Ibikunle, 2012; Harris 2013). However, and as noted earlier in the discussion of the flash crash, even when HFT is passive, it can exacerbate market dislocations if HFT’s withdraw from the market in times of financial stress.

Despite clear problems associated with HFT, the preponderance of the finance literature suggest HFTs have on the balance of things, improved market efficiency (see as examples, Hendershott et al., 2011; Hasbrouck and Saar, 2013). HFT can prove to be a potent force for improving market quality (see Harris, 2013; Diaz-Rainey and Ibikunle, 2012). For instance, Benos and Sagade (2012) show that HFT trades are on average more *informationally* efficient than non-HFTs. As a result of their huge trading volumes, HFTs are increasingly occupying the role previously reserved for traditional market makers/specialists/dealers on financial platforms (see Menkveld, 2013). The improvement in liquidity is evidenced by the statistically significant fall in trading spreads and the cost of trading over the last decade (Chordia et al., 2008; Chordia et al., 2011).

In sum, finance research and in particular the microstructure literature find that the impact of technological transformed markets is positive leading to markets that are faster, cheaper and more integrated yet arguably more volatile. The rigorous nature of this body of research makes these conclusion likely to be valid and reliable yet the literature is open to critiques of being research that operates in a ‘limited domain’ (Swann, 2006) – namely finance research is a mono method discipline of applied empiricism encased in rational agent theory that is ill-suited to capturing the broader drivers of chance and social consequences of markets.

Epistemological critiques by finance researchers of finance research exist (Keasey and Hudson 2007; Focardi and Fabozzi 2012) but the discipline is likely to keep its existing focus in its pursuit of ‘scientific rigour’ as defined by the juxtaposition of rational agent theory and applied empiricism. It is, therefore, not surprising that in the extant finance literature there is rarely explicit treatment of ICT; rather the focus has been on the effects of technology on prices

and other traditional financial markets measures. Consequently, little is known in the academic literature about the technologies being used, and the institutional and regulatory structures and changes that have facilitated the greater use of ICT in contemporary capital markets.

4. Financialization and other social critiques

“MBA or PhD students in their first asset-pricing classes are typically presented with a picture of finance as an efficient allocation machine that puts capital to its best possible use and allows people to share all kinds of risks efficiently. But nowadays, when they walk out of their classroom, these same students need to read no further than the front page of the Financial Times or the Wall Street Journal to see financial markets and intermediaries indicted as the culprits in an enormous misallocation of resources, as witnessed by the huge, vacant real-estate developments in the US, Ireland, and Spain; the massive losses of the banks that funded them; and crippling tax bills for the taxpayers to bail them out.” Pagano (2013, p109)

The positive view of contemporary capital markets evident in the finance literature is not universally shared and the Global Financial Crisis (GFC) has led to a re-examination of the social value of markets from a broader perspective than the epistemological boundaries that finance research typically allows. These critiques emanate from a broad range of sources and academics disciplines, including economics, sociology, management research and political science. They are too varied and disparate to review comprehensively in this short section. We review a few to make in essence two points (1) there is a desire to look at financial markets in a broader social context than the finance literature allows and (2) that these efforts have largely overlooked the role of technology in any detailed or meaningful sense – thus providing the gap this Special Issue seeks to fill.

The GFC has led economists, and indeed some finance researchers, to explore *The Social Value of the Financial Sector* (Acharya *et al.*, 2013). Prominent questions in related debates include whether the benefits of the financial sector outweigh its costs and whether currently we have too much finance (Acharya *et al.*, 2013; Stark, 2013). The latter question is particularly relevant to this Special Issue since the growth of finance would appear to have been enabled by ICT and technology (See below and Section 5).

Kedrosky and Stangler (2011) note that the US financial sector has grown from around 2% of GDP in the 1940s (having peaked in the 1930s to just under 6%) to about 8.5% in 2010. Commentators claim that the growing importance of finance has been associated with a decline

in innovation and entrepreneurial activity (Kedrosky and Stangler, 2011; Lazonick, 2010; Mazzucato, 2013). Indeed some economic research suggests that an overly large financial sector and too much financial innovation can be detrimental to growth and stability (Beck *et al.*, 2014; Frame and White, 2013; Pagano, 2013; Stark, 2013). These conclusions challenge the received wisdom in the economics/finance literatures that more finance and financial innovation are *necessarily* welfare enhancing.

The idea of finance becoming increasingly important is, however, broader than just macroeconomic measures and has been termed ‘financialization’. Financialization is evident at organisational levels (e.g. the demutualisation of organisations or the increased focus on short term returns), sector levels, and it affects not only the size but also the scope of finance (Lazonick, 2010; Mazzucato 2013; Montalban and Sakinc 2013). In the latter case, concerns about financialized commodity markets are an example of the expanded scope of finance. In this case it is clear that financial innovation (such as Exchange Traded Funds – ETFs) facilitated by ICT technologies have in turn enabled financialization by, for instance, allowing household investors the opportunity to invest in commodity markets (see Diaz-Rainey *et al.*, 2011; Diaz-Rainey and Ibikunle, 2012; UNCTAD, 2011).

Not only do we have more finance in terms of scale and scope but as is evident from the finance literature, the nature of financial markets has changed – they are faster, more integrated yet at the same time liquidity is more fragmented. They are untimely more complex and therefore our ability to regulate them has diminished (see earlier discussion of dark trading, HFT, fragmentation and the flash crash). Accordingly there are concerns that low latency finance has caused financial markets to become myopic as epitomised by the growing prevalence of trading over long-term investment (Haldane, 2010; Mazzucato, 2013). Empirical support as to the detrimental effects of this myopia can also be found from Brossard *et al.* (2013) who find that R&D is higher for European firms that have long term institutional investors versus firms that have ‘impatient’ investors. Further, novel and recent finance research shows that firms with greater liquidity and those covered by a greater number of stock analysts, innovated less (Fang *et al.*, 2013; He and Tian, 2013).

Clearly the literature presented in this section paints a less positive view of contemporary capital markets than does the mainstream finance/microstructure literature. Yet this literature is arguably open to the opposite critique that we levelled against the finance literature – namely that it is too broad (or alternatively not broad enough to encapsulate all social costs and benefits) and thus lacks the rigour to come to actionable evidence based conclusion. The two literatures highlight the polarizing effect financial markets tend to have.

From the perspective of this Special Issue, the important point is that neither the finance literature, nor the financialization and other social critiques of markets, address the impact of

technology on financial markets explicitly in their research efforts. Accordingly, this Special Issue seeks to navigate a middle ground between these two literatures. The remit of the Special Issue means that traditional finance contributions are excluded, as are opinion-based critiques of finance that do not delve into the complexities of how the financial system is being changed by technology. In essence, contributions in the Special Issue are grounded in innovation research and show adequate depth of knowledge of the financial system. The call for the Special Issue was open and was advertised widely. Abstract proposals were invited prior to submission and the abstracts of the 3rd edition of the Innovation for Financial Services (Singapore 2013) conference were also reviewed for suitability.

5. The technological transformation of capital markets

The five contributions in the Special Issue have been ordered in such a way as to provide an accessible entry into the technological transformation of capital markets. The first three all provide insights into the companies transforming capital markets and the new electronic ‘market infrastructure’⁴ that is emerging (Ernkvist, 2015; Essendorfer *et al.*, 2015; Panourgias, 2015). The last two contributions focus on two important and relatively recent innovations in finance that have been enabled by the new market infrastructure, namely High Frequency Trading (HFT) (Kauffman *et al.*, 2015) and Exchange Traded Funds (ETFs) (Lechman and Marszk, 2015). Though only a small Special Issue, contributions come from a diverse range of disciplines, approaches and methodologies reflecting TFSC’s open ethos in this respect.

5.1 Summary of Contributions

Ernkvist (2015) provides historical case study evidence on OM, a Swedish 1980s start-up company that is ultimately acquired by NASDAQ and which introduced the world's first commercially successful electronic options exchange. The case study highlights how a for-profit brokerage-technology start-up with relatively limited resources challenged established member-owned physical options exchanges through a ‘double-knot’ of technology and business-model innovation. As such, OM represents one of the pioneers in altering the ‘market infrastructure’ of trading complex financial products such as options from physical trading floors to electronic dimensions.

Essendorfer *et al.* (2015) from a measurement of innovation perspective and using mixed methods (contents analysis and econometric and qualitative analysis) extract market infrastructure patents from the USPTO between 1976 and 2013. They conclude from the pattern

⁴ Essendorfer *et al.* (2015, p2) define market infrastructure as “software or the combination of software and ICT hardware in the trading of securities, commodities and currencies.” **PAGE NUMBER WILL CHANGE – ARTICLE WITHIN THIS ISSUE**

of the resultant time series of market infrastructure patents that a capital markets ‘technological arms race’ started in the late 1990s. Further, they observe that this dramatic increase in financial patents provides researchers and policy markets with a rich insight into how technology is changing capital markets. Accordingly, Essendorfer *et al.* (2015) highlighting, *inter alia*, patents related to the creation of new trading venues, market/liquidity fragmentation, automation of primary markets (when a financial security is first issued), automation of trading, low latency trading (HFT) and regulatory change (See Section 2.1).

Panourgias (2015) takes a techno-social approach to study the integration of European securities settlement systems – the part of the market infrastructure that ensures that trades agreed upon on exchanges are executed correctly e.g. moneys are transferred and legal titles of securities are correctly exchanged. The study charts the evolution and challenges overcome by the firm that would ultimately dominate European security settlement systems, namely Euroclear. From this case, Panourgias (2015, **p20 PAGE NUMBER WILL CHANGE – ARTICLE WITHIN THIS ISSUE**) concludes that the transformation of capital markets is being driven by “*a complex dynamic interaction and mutual shaping amongst technology, regulation, commercial and geopolitical competition, new product and services development, and growth in demand.*”

Kauffman *et al.*, (2015) apply a technology ecosystem path of influence model that to the context of HFT. The model uses graphical coding to chart the technology, services, infrastructure and stakeholder influences on the development of HFT. Accordingly the paper provides an accessible overview into the development of HFT ecosystem over the last few decades. Finally, Lechman and Marszk (2015) empirically explore the relationship between ICT diffusion and the development of Exchange Traded Funds (ETF) in a mix of developed and developing countries. Starting in 1989, ETFs are an important contemporary financial innovation since they have challenged established investment vehicles, notably the mutual fund/unit trust (open-ended funds) and investment trusts (close-ended funds). From their description of ETFs, Lechman and Marszk (2015) highlight that ETFs are enabled by the use of ICTs both on the demand side (by those that buy the funds) and the supply side (by the firms that create the funds). This hypothesised relationship is empirically verified in their analysis, since they find a positive relationship between ICT diffusion and ETF market development.

5.2 Themes

From the five contributions five broad themes are apparent, namely;

- Technology, competition and the new Market Infrastructure
- Organisational innovation and new entrants
- Regulation
- Internationalisation and integration

- Financialization

We discuss each in turn.

Technology, competition and the new Market Infrastructure

The contributions highlight technologies and related innovations that are changing the market infrastructure and nature of capital markets. From all five contributions it is clear that the preponderance of this transformation is simply driven by the application of ICT technologies in a capital market context. This combination of software and ICT hardware results in the redefinition of ‘place’ to an electronic dimension (Ernkvist, 2015; Essendorfer *et al.*, 2015; Panourgias 2015), often leading to patents (Essendorfer *et al.* 2015) and/or the development of new financial innovations (Kauffman *et al.*, 2015; Lechman and Marszk, 2015). Thus for technologists this is not necessarily a particular exciting transformation, however, some examples of the application of leading-edge technologies is apparent from Kauffman *et al.*, (2015) who note that in their quest for speed (low latency) HFTs are experimenting with microwave data transmission technology and using microchips that can execute trades in nanoseconds. Further, Essendorfer *et al.* (2015) identify finance patent using leading-edge innovations, including one that uses neural networks in selecting securities for a portfolio.

Finally, it was noted in Section 2.1 that in ‘intermediated’ finance (basically traditional commercial banking) the management of innovation literature has emphasised that a great deal of the innovation occurring in the sector is open and collaborative. It is clear from Essendorfer *et al.* (2015) and Kauffman *et al.* (2015) that in the context of ‘direct finance’ (i.e. capital markets) the nature of technological innovation is much more competitive, often taking the form of a zero-sum game. This winner-takes-all type of technological rivalry is most obvious in the context of ‘front office’ trading systems such as HFT. However, more collaborative approaches are evident in the ‘back office’ of capital markets (i.e. post trade settlement processes) (see Panourgias 2015).

Organisational innovation and new entrants

Schumpeterian theory suggests that technologically driven transformations are driven by new firms and unsurprisingly new entrants are prominent in the contributions to the Special Issue (Ernkvist, 2015; Essendorfer *et al.*, 2015). More specifically, Essendorfer *et al.* (2015) derive a list of the leading 20 market infrastructure patenting firms which contains a mix of new entrant software/technology firms, hybrid firms (brokerage/technology) and a number of established incumbents. Top of this list by some margin is Trading Technologies International – a software firm established in 1994. However, the number of new entrant software/technology firms in the list is relatively small, with a more prominent group being historically small brokerage firms that have morphed into hybrid technology/brokerage firms to challenge the large incumbent

investment banks and exchanges. Indeed, the case of OM (Ernkvist, 2015) is an example of such a firm, OM started out originally as a small brokerage firm but ultimately morphed into an exchange systems technology/software firm. The fact that OM is ultimately acquired by NASDAQ highlights how the more responsive incumbents have tried to address, via strategic acquisitions, the competitive challenge posed by the hybrid/morphed firms and new entrant software firms (Essendorfer *et al.* 2015).

Regulation

A recurring theme in all five contributions was regulation and regulatory change as an enabler or impediment to the technological transformation of capital markets. For instance, Kauffman *et al.* (2015) observe that the introduction of a new regulation (Regulation National Market System or Reg. NMS) accelerated the development of HFT. This is because Reg. NMS encouraged new trading venues which in turn led to the fragmentation of liquidity on which HFT thrived on (See related discussion in section 2.1 on the relationship between new trading venues and HFT). Lechman and Marszk (2015) note that regulatory permissiveness is an important factor in ETF market development; citing the examples of Mexico and South Korea as countries where regulatory flexibility facilitated market development, whereas in the case of Brazil regulatory restrictions curtailed the development of the ETF market. Finally, Ernkvist (2015) highlights how even relatively small firms set on market transformation can, through ‘proactive corporate political entrepreneurship’, influence regulatory developments in line with their strategic interest. Thus an innovative firm’s ability to influence regulatory reform processes may be as big a determinant on its ultimate success as more conventional commercial influences. This is not perhaps that surprising since capital markets are highly regulated.

Internationalisation and integration

It is well known that financial markets are becoming more international and integrated. The contributions in this Special Issue show how technology and related organisational innovations have played a major role in this. For instance, it is clear that the need to be technologically competitive through economy of scale or by redefining markets has played a major role in the international consolidation of the securities exchanges business (Ernkvist, 2015; Essendorfer *et al.*, 2015) and in the integration of settlements systems across national boundaries (Panourgias, 2015). Further, Lechman and Marszk (2015) show how ETFs, which emerged in developed countries, have gradually spread to some developing economies as the diffusion of ICT innovations in their economies have increased.

Financialization

Finally, it is clear from the contributions that technology and related financial and organisational innovations are not only changing existing markets; they are expanding the scope of markets. Thus financialization is closely tied to, and enabled by, technological change. Recalling that financialization can happen at multiple levels (See Section 4), numerous examples emerge from the contributions. At the organisational level, Ernkvist's (2015) case study highlights how technologically savvy and commercially astute for-profit private exchanges challenged traditional mutual and state-owned exchanges, leading to the complete redefinition of the role of an exchange as 'just another' for-profit businesses. A similar transformation from co-operative entities towards larger for-profit publicly listed corporations with the scale to absorb large ICT development costs is apparent in Panourgias's (2015) account of the integration of European settlement systems.

At a more aggregate level, Essendorfer *et al.* (2015) provide examples of finance patents related to commodity markets and to the entertainment industry. The patents help create financial products that derive their value from the performance of both these sectors, thereby making this sectors more easily accessible to investors. Similarly and as noted in Section 4, ETFs have been an important financial innovation that have significantly enlarged the investment universe for individual investors. The development of ETFs means that "mom and pop" investors can now get investment exposure to a vast array of markets including oil, grains, and metals markets. This implies financialization at the household level and at the sector or market segments they are gaining exposure to. The empirical relationship that Lechman and Marszk (2015) establish between ETFs and ICT diffusion highlights that this critical contemporary financial innovation and the financialization it has engendered is enabled by technology.

From the preceding discussion it is clear that financialization (the process by which financial markets become increasingly important in the economy and society) is a technology enabled phenomenon – something hitherto largely overlooked by the financialization literature.

6. Conclusion and limitations

In this editorial for the Special Issue we note that capital markets are clearly complex adaptive techno-social systems that are undergoing dramatic changes. Surprisingly, they are rarely researched from an innovation research or technological change perspective. The papers in this Special Issue seek to address this gap in the literature and, therefore, open a new academic front in the understanding of how technology is changing capital markets. All five contributions in the Special Issue represent a step forward in this respect but collectively they do not represent

a new front – rather what we have in the Special Issue is a border skirmish. Given the importance of capital markets and the pace at which they continue to be transformed by technology, our understanding of these changes is just beginning. One of the challenges of conducting research in this area is the need for expertise to straddle both finance and innovation research. Further, research funders need to grasp the importance of this emerging area if we are to fully understand the social, economic and financial implications of technologically transformed capital markets. We hope this Special Issue plays some role in raising awareness of this important area and that our small border skirmish ultimately escalates into a full blown academic front.

Acknowledgements

The Managing Guest Editor, Ivan Diaz-Rainey, would like to thank Professor Fred Phillips for his guidance and support with this Special Issue. The usual disclaimer applies.

References

- Accenture, 2011. Banking Technology Vision: The technology waves that are reshaping the banking landscape. Available at: <http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture-Banking-Technology-Vision-Reshaping-Landscape.pdf>
- Allen, F., 2012. Trends in Financial Innovation and their Welfare Impact: An Overview. *European Financial Management* 18, 493-514.
- Acharya, V. V., Beck, T., Evanoff, D. D., Kaufman, G. G., & Portes, R. (Eds.) (2013) *The social value of the financial sector: too big to fail or just too big?*. World Scientific Publishing Co. Pte. Ltd..
- Angel, J. J., Harris, L. E. & Spatt, C. S., 2011. Equity Trading in the 21st Century. *Quarterly Journal of Finance* 01(01), 1-53.
- Arnuk, S.L. and Saluzzi, J.C., 2012. *Broken Markets - How High Frequency Trading and Predatory Practices on Wall Street are Destroying Investor Confidence and Your Portfolio*, FT Press: New Jersey.
- Avison, D., Jones, J., Powell, P. and Wilson, D., 2004. Using and validating the strategic alignment model. *The Journal of Strategic Information Systems* 13(3), 223-246.
- Baets, W.R.J., 1996. Some empirical evidence on IS Strategy Alignment in banking. *Information & Management* 30(4), 155-177.
- Beck, T., Chen, T., Lin, C., & Song, F. M., 2014. Financial innovation: The bright and the dark sides. Working Paper, Available at SSRN.
- Benos, E. & Sagade, S., 2012. High-frequency trading behaviour and its impact on market quality: evidence from the UK equity market. Bank of England Working Paper Series. London: Bank of England.
- Boot, A. W., 2014. Financial sector in flux. *Journal of Money, Credit and Banking* 46(s1), 129-135.
- Boulatov, A., George, T. J., 2013. Hidden and Displayed Liquidity in Securities Markets with Informed Liquidity Providers. *Review of Financial Studies* 26(8), 2096-2137.
- Broadbent, M., Weill, P., 1993. "Improving business and information strategy alignment: Learning from the banking industry", *IBM Systems Journal* 32(1), 162-179.
- Brogaard, J., Hendershott, T. & Riordan, R., 2014. High-Frequency Trading and Price Discovery. *Review of Financial Studies* 27(8), 2267-2306
- Brossard, O., Lavigne, S., & Sakinc, M. E., 2013. Ownership structures and R&D in Europe: the good institutional investors, the bad and ugly impatient shareholders. *Industrial and Corporate Change* 22(4), 1031-1068.
- Brunnermeier, Markus, K., 2009. Deciphering The Liquidity And Credit Crunch 2007-2008. *Journal of Economic Perspectives* 23, 77-100.

- Cai, C. X., Harris, J. H., Hudson, R. S., Keasey, K., 2015. Informed Trading and Market Structure. *European Financial Management* 21(1), 148-177.
- Casti J.L., 2012. *X-Events: The Collapse of Everything*, Harper Collins Publishers,
- Chiasson, M.W. and Davidson, E., 2005. Taking Industry Seriously in Information Systems Research, *MIS Quarterly* 29(4), p. 591-605.
- Chordia, T., Roll, R., Subrahmanyam, A, 2008. Liquidity and market efficiency. *Journal of Financial Economics* 87(2), 249-268.
- Chordia, T., Roll, R., Subrahmanyam, A, 2011. Recent trends in trading activity and market quality. *Journal of Financial Economics* 101(2), 243-263.
- Coates, V. T., 1992. Technology and US stock markets: Social and institutional change. *Technological Forecasting and Social Change* 41(1), 1-12.
- Cooper, B.L., Watson, H.J., Wixom, B.H., Goodhue, D.L., 2000. Data warehousing supports corporate strategy at First American Corporation, *MIS Quarterly* 24(4), 547-567.
- Diaz-Rainey, I., Ibikunle, G., 2012. A taxonomy of the 'dark side' of financial innovation: the cases of high frequency trading and exchange traded funds. *International Journal of Entrepreneurship and Innovation Management* 16(1), 51-72.
- Diaz-Rainey, I., Siems, M, Ashton, J, 2011. The financial regulation of energy and environmental markets. *Journal of Financial Regulation and Compliance* 19(4): 355-369.
- Easley, D., López de Prado M., O'Hara., M, 2013. (Eds) *High-Frequency Trading - New Realities for Traders, Markets and Regulators*, Risk Books, London
- Easley, D., Lopez de Prado, M. M. & O'Hara, M., 2011. The Microstructure of the Flash Crash: Flow Toxicity, Liquidity Crashes, and the Probability of Informed Trading. *Journal of Portfolio Management* 37(2), 118-128.
- Ernkvist, M., 2015. The double knot of technology and business-model innovation in the era of ferment of digital exchanges: The case of OM, a pioneer in electronic options exchanges. *Technological Forecasting and Social Change*. **[IN THIS ISSUE]**
- ESMA, 2014., High-frequency trading activity in EU equity markets, ESMA Economic Report Number 1, European Securities and Markets Authority, Paris.
- Essendorfer, S., Diaz-Rainey, I., & Falta, M., 2015. Creative destruction in Wall Street's technological arms race: Evidence from patent data. *Technological Forecasting and Social Change*. **[IN THIS ISSUE]**
- Fang, V. W., Tian, X., & Tice, S., 2014. Does stock liquidity enhance or impede firm innovation? *The Journal of Finance* 69(5), 2085-2125.
- Focardi, S. M., Fabozzi, F. J., 2012. What's Wrong with Today's Economics? The Current Crisis Calls for an Approach to Economics Rooted More on Data Than on Rationality. *The Journal of Portfolio Management* 38(3), 104-119.

- Frame, W. S., & White, L. J., 2013. "Reexamining Financial Innovation after the Global Financial Crisis" in Acharya, V. V., Beck, T., Evanoff, D. D., Kaufman, G. G., & Portes, R. (Eds.). *The social value of the financial sector: too big to fail or just too big?* (pp.215-228). World Scientific Publishing Co. Pte. Ltd..
- Gomber, P., Sagade, S., Theissen, E., Weber, M. C., Westheide, C., 2015. Distinct Dark Markets and the Determinants of their Trading Volume, Paper presented at the 7th IFABS Conference, Hangzhou, China
- Haldane, A., 2010. *Patience and finance*. Remarks at the Oxford China Business Forum, Beijing, [Online]. Available: <http://www.bis.org/review/r100909e.pdf>
- Harris, L., 2013. What to Do about High-frequency Trading. *Financial Analysts Journal* 69(2), 6-9.
- Hasbrouck, J., Saar, G., 2013. Low-latency trading. *Journal of Financial Markets*, 16(4), 646-679.
- He, J. & X. Tian, 2013. The Dark Side of Analyst Coverage: The Case of Innovation. *Journal of Financial Economics* 109(3): 856-878.
- Hendershott, T., Jones, C. M. & Menkveld, A. J., 2011. Does Algorithmic Trading Improve Liquidity? *The Journal of Finance* 66(1), 1-33.
- Ibikunle, G., 2015. Informativeness of Quotes and Time-varying Price Discovery. University of Edinburgh Business School Working paper. Edinburgh.
- IOSCO, 2011. Consultation Report on Regulatory Issues Raised by the Impact of Technological Changes on Market Integrity and Efficiency, International Organization of Securities Commissions (IOSCO), Technical Committee, Consultation Report.
- Kauffman, R. J., Liu, J., Ma, D., 2014. Innovations in financial IS and technology ecosystems: High-frequency trading in the equity market. *Technological Forecasting and Social Change*. **[IN THIS ISSUE]**
- Keasey, K., Hudson, R., 2007. Finance theory: a house without windows. *Critical Perspectives on Accounting* 18(8), 932-951.
- Kedrosky, P., Stangler, D., 2011. *Financialization and its entrepreneurial consequences*. Ewing Marion Kauffman Foundation Research Paper.
- Kirilenko, A. A., Kyle, A. S., Samadi, M., Tuzun, T., 2011. The Flash Crash: The Impact of High Frequency Trading on an Electronic Market. SSRN eLibrary Working Paper.
- Kyle, A. S., 1985. Continuous Auctions and Insider Trading. *Econometrica* 53(6), 1315-1335.
- Kyle, A. S., 1989. Informed Speculation with Imperfect Competition. *The Review of Economic Studies* 56(3), 317-355.
- Lazonick, W., 2010. Innovative business models and varieties of capitalism: Financialization of the US Corporation. *Business History Review* 84(04), 675-702.
- Lewis, M., 2014. *Flash boys: a Wall Street revolt*. WW Norton & Company,.

- Lechman, E., Marszk, A., 2015. ICT technologies and financial innovations: the case of Exchange Traded Funds in Brazil, Japan, Mexico, South Korea and the United States. *Technological Forecasting and Social Change*. [IN THIS ISSUE]
- Linstone, H. A. & Phillips, F., 2013. The simultaneous localization – globalization impact of information/communication technology. *Technological Forecasting and Social Change* 80(7): 1438-1443.
- Mai, H., 2012. IT in banks: What does it cost? DB Research. Deutsche Bank AG, Frankfurt, Germany.
- Mazzucato, M., 2013. Financing innovation: creative destruction vs. destructive creation. *Industrial and Corporate Change* 22 (4): 851-867.
- Menkveld, A. J., 2013. High frequency trading and the new market makers. *Journal of Financial Markets* 16(4), 712-740.
- Mention, A.-L., Torkkeli, M., 2012. Drivers, processes and effects of financial innovation: a research agenda, *International Journal of Entrepreneurship and Innovation Management* 16 (1/2), 5-29.
- Mention, A.-L., Torkkeli, M. 2014. “Innovation in Financial Services: Unveiling Ambiguity” in Mention, A.-L. & Torkkeli, M. (Eds). *Innovation in Financial Services: A Dual Ambiguity* (pp.1-11). Cambridge Scholars Publishing.
- Montalban, M., Sakinç, M. E., 2013. Financialization and productive models in the pharmaceutical industry. *Industrial and Corporate Change* 22(4), 981-1030.
- O'Hara, M. & Ye, M., 2011. Is market fragmentation harming market quality? *Journal of Financial Economics* 100(3), 459-474.
- Ostand, E., 2013. ‘Lasers, microwave deployed in high-speed trading arms race’, Reuters, 1 May, Available online <http://www.reuters.com>
- Patterson, S., 2012. *Dark pools: High-speed traders, AI Bandits, and the threat to the global financial system*. Random House Digital, Inc.
- Pagano, M., 2013. Finance: economic lifeblood or toxin? in Acharya, V. V., Beck, T., Evanoff, D. D., Kaufman, G. G., & Portes, R. (Eds.). *The social value of the financial sector: too big to fail or just too big?*. (pp.109-146) World Scientific Publishing Co. Pte. Ltd.
- Panourgias, N. S., 2015. Capital markets integration: A sociotechnical study of the development of a cross-border securities settlement system. *Technological Forecasting and Social Change*. [IN THIS ISSUE]
- Popper, N., 2013. ‘On Wall Street, the Rising Cost of Faster Trades’, The New York Times, 13 August, Available online <http://www.nytimes.com>
- Preece, R., Rosov, S., 2014. Dark Trading and Equity Market Quality. *Financial Analysts Journal*, 70(6), 33-48.

- Preece, R., Schacht, K. N., Allen, C. J., Rosov, S., 2012. *Dark Pools, Internalization, and Equity Market Quality*. Charlottesville, VA: CFA Institute.
- Schueffel, P., Vadana, I. 2015. Open Innovation in the Financial Services Sector – A Global Literature Review, *Journal of Innovation Management*, 3(1), 25-48.
- Stark, J., 2013. Public policy options”, in Acharya, V. V., Beck, T., Evanoff, D. D., Kaufman, G. G., & Portes, R. (Eds.). *The social value of the financial sector: too big to fail or just too big?*, (pp.511-517) World Scientific Publishing Co. Pte. Ltd..
- Swann, G. P., 2006. *Putting econometrics in its place: a new direction in applied economics*. Edward Elgar Publishing.
- Tallon, P.P., 2010). A Service Science Perspective on Strategic Choice, IT, and Performance in U.S. Banking. *Journal of Management Information Systems* 26(4), 219-252.
- UNCTAD, 2011. *Price formation in financialized commodity markets: The role of information*, United Nations Conference on Trade and Development, New York.
- Wang, J., Gupta, M. and Rao, H.R., 2015. Insider threats in a financial institution: Analysis of attack-proneness of information system applications, *MIS Quarterly* 39(1), p. 91-112.
- Werthamer, N. Richard, Raymond, Susan U., 1997. Technology and finance: The electronic markets. *Technological Forecasting and Social Change* 55(1), 39-53.
- Ye, M., 2011. A glimpse into the dark: price formation, transaction costs and market share of crossing network. University of Illinois Working paper.
- Zhu, H., 2014. Do Dark Pools Harm Price Discovery? *Review of Financial Studies* 27(3), 747-789.