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Structured interviews of computer-based traders

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Structured interviews of computer-based traders[1]

Daniel Beunza, Yuval Millo and Juan Pablo Pardo-Guerra

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[1] Study commissioned by the Foresight Project, UK Department of Business, Innovation and Skills.

Abstract

This report summarizes the perspectives of senior market participants in computer-based trading. It is based on semi-structured interviews of fourteen senior executives predominantly in the UK, other parts of Europe and the US, conducted during October-December of 2011. The questionnaire is composed of six themes: technology, innovation, practices, social networks, risks and the future of computer-based trading. Technology, informants explain, is at the core of computer-based trading. But this technology is disruptive, leading to a split in adoption between established industry incumbents and nimbler entrants. Furthermore, the high cost of the required investments has created another split between leaders and laggards, with non-experts relying on the tools and algorithms developed by the leaders. After several years of rapid investment in hardware and software, technology is no longer the sole driver of the industry. Innovations are now less likely to come from technological changes than from regulation, novel instruments, or changes in the way organizations behave. In characterizing computer-based trading, one key practice is the reliance on models and timely data. For that reason, once a market situation does not fit the model, the algorithm is stopped. Data feed delays have the same effect. Social networks play an important part of a computer-based trader: although trading is left to algorithms, the humans that guide them rely extensively on their business contacts. Traders use shallow ties with brokers and business acquaintances, often with the exchanges, to gain a sense of the market. They also rely on deep relations with trusted ex-colleagues for sensitive information such as participation in crises. In discussing the risks of computer based trading, interviewees believe that the Flash Crash is not an immediate danger in Europe. They also emphasized that informal communications play a critical role in helping market participants deal with outages. The future that they see is one of greater efficiency, but also greater interconnectedness.

1. Introduction

This report explores the present state of computer-based trading, primarily in the United Kingdom. Our respondents used various terms to refer to related phenomena, including computer-based trading, algorithmic trading, automated trading and high-frequency trading, but this report uses the term ‘computer-based trading’ following the convention used in the Foresight Project.

The findings in this report derive from in-depth interviews of senior market participants involved in computer-based trading. These have been analyzed from a sociological and organisational perspective, building on the emerging literature on the social studies of finance.[2] Our goal has been to provide an ‘insider’s perspective’ on computer trading. We have included insiders’ opinions about the present and future, about key challenges and opportunities, about the values and perspectives of insiders, and about the role of the human in automated trading.

The report is organized in four sections. First, we describe the methods used to collect and analyse the data. We then report the results from our interviews with senior market participants. These results are arranged according to six themes we identified as the ones that

[2] See MacKenzie and Millo (2003), Beunza and Stark (2004, 2012) and Pardo-Guerra (2010).

help to capture critical aspects of computer-based trading. These are technology, innovation, practices, social networks, risks and the future.

2. Methods

Our data consists of fourteen interviews with senior market participants involved in computer-based trading in various ways. These interviews are primarily oriented at capturing the current practices of practitioners, but they also include evaluations of the future of computer-based trading.

The study began with the elaboration of a semi-structured interview questionnaire based on an analysis of the literature on computer-based trading and the themes that emerged from the driver reports conducted by the Foresight Project. The distinctive element of our questionnaire is an emphasis on the *practices* that characterize computer-based trading.[3] By focusing the study on identifying practices ('what do you do?') rather than abstract drivers or future scenarios ('what will happen?'), the authors hope to build on the current knowledge base of practitioners. This emphasis stems from the recognition that there are known methodological difficulties in asking interviewees for their views of the future when the future is uncertain, or from industry drivers when the industry is itself in state of flux: informants may have biases, or may fail to take into account critical information. As Tufano (2003) argues, it may be impossible to identify *ex ante* the sources of successful innovations. Another distinctive feature of a sociologically grounded study is the inclusion of social networks in the questionnaire.

The questionnaire was presented to the Lead Experts group of the Foresight team and then adapted to incorporate its feedback. In line with this feedback, interviewees were also asked one question on the future of computer-based trading. The final questionnaire is included in Appendix 2.

The study assembled a database of practitioners for the purpose of the interviews. This was designed to capture different perspectives across the marketplace by targeting firms in various places of the value chain. We approached over 60 market participants, and we had a positive response rate of 21 per cent, leading to 14 completed interviews. The majority of our interviewees are linked to institutions with a clear presence in the UK financial system and include funds, banks and multi-lateral trading facilities (MTFs). The study also includes some interviewees in the United States and continental Europe. Because the study extended to the views about the future, we decided to include some industry members that are not directly involved in trading or employed in a trading firm, but who are nevertheless widely regarded as thought leaders. We also included a senior practitioner that is *not* involved in computer-based trading. The identities of the interviewees have been kept anonymous, but a list of the positions held by the interviewees and selected characteristics of their firms is included in Appendix 1.

Our interviewees provide a wealth of data: although the interviews were organized around a set of pre-defined themes, its semi-structured form allowed us to ask respondents to expand on particular responses. This fine-grained approach allowed us to take advantage of the reliability of open-ended interviews while maintaining a structured approach to data collection and analytical comparison.

[3] The practice turn has its roots in the sociology of Bourdieu (1977) and Schatzki, Knorr Cetina and Von Savigny (2001) among others.

Interviews lasted on average between one hour and an hour and half. The shortest interview took 46 minutes, while the longest interview involved an in-depth conversation over 151 minutes. Interviews were recorded and transcribed. Transcripts were then analysed by the members of the research team, and patterns in the interviews and clusters of concepts were identified. Coding and analysis was carried out in parallel and iteratively using the specialized software Nvivo 8.0. After agreeing on an initial set of codes for the analysis of the interviews (structured around infrastructure, innovation, social networks, crisis, benefits, risks and fairness), the interviews were simultaneously coded by the three members of the team. Discussions then took place about the reliability and validity of the initial coding structure; further coding and re-coding was conducted until 'stable' themes and conceptual clusters had been identified. The team thus clustered the initial themes into a core six: technology, practices, innovation, social networks, risks and perceived futures. Discussions then took place on determining an explanatory framework for each of the themes.

3. Findings

Our findings are structured around six areas: technology, innovation, practices, social networks, risks and the future of computer-based trading.

3.1. Technology

Many interviewees regard the adoption of computer technologies as a fundamental change, and compared the changes induced by computer-based trading to those observed with the rise of manufacturing in the Industrial Revolution.

An intriguing comment from Interviewee 13 is that the automation process entailed in computer-based trading is not specific to finance. It is, instead, part of a broader trend towards the automation of supply chains and decision-making. In the coming months, he argued, we would see similar developments in other industries, and it was key for the national competitiveness of the United Kingdom to retain this practice and promote leadership in it.

Interviewee 14 offered an alternative framing: he referred to computer-based trading as a part of a broader change in market microstructure that originated in various changes in regulation in the US equities markets. This broad trend is disintermediation, and the resulting narrowing of spreads and reduction of commissions.

3.1.1 Computer-based trading is a disruptive innovation

One key feature of this innovation is its disruptive character, that is, it reduces the value of the existing competencies of incumbent market participants. Interviewee 2, for instance, contrasted current technological developments with innovations in television technologies:

> It's about the destructive power of technology, where it's impossible for Sony to innovate when they are the leader of big box TV and you do flat screen TV's. They think, 'no, no, no, we own the market share, etc.' and lag behind and need to spend 20 billion dollars to catch up. The same thing is happening here and the same thing happened to Motorola, which went bankrupt.

In other words, the interviewee argues that automated trading is equivalent to the shift from traditional cathode-ray tube television sets to the flat screen systems. There, incumbents saw their market dominance challenged and were forced to make considerable investments at higher costs than entrants.

Entrants with flexible business models can and often do challenge the position of incumbents. Incumbents such as established brokers, traditional fund managers and regulated exchanges are thus faced with a form of increased competition that challenges their existing stocks of knowledge about the market and their patterns of organizational learning. As Interviewee 2 noted:

> If you look at how long it takes [incumbents] to connect to a venue, it is months. If you ask them how much it costs to connect to a venue, it is millions of dollars. If you look at what it takes us, and what it costs, three days and we're connected to a venue. We are 200, 300 times more efficient than some of the incumbents (Interview 2).

Interviewee 2 refers to an important difference across institutions: while both entrants and incumbents have access to the same set of sophisticated technologies and general technical expertise, they differ in their attitudes to the market and their organizational responses to competitive challenges.

Our interviewees also stressed features that make certain technologies more competitive in the current environment. These include such aspects as the 'cleverness' of models (Interview 5), the 'speed and flexibility' of systems (Interview 2), and the 'reliability' of services (Interview 3). We explore these in other sections below.

3.1.2 Computer-based trading has led to a two-tier industry structure

The disruptive character of recent innovations induced a re-organization of the industry. This has created two tiers of technological capabilities, knowledge of the market and ability to influence the shape of the marketplace. The first tier is characterized by firms that are able to deploy sizeable investments in infrastructure. By aggregating order flow, some of these firms not only achieve economies of scale in their operations but, as importantly, 'exert a lot more leverage than the other trading participants on the exchanges' (Interview 4). The second tier comprises smaller firms and investors that have smaller order flows and are less capable of exerting leverage on regulators and trading venues.

This two-tiered structure is the result of two factors. First, as mentioned by Interviewee 4, technology has led to a more competitive market:

> Technology's cheaper so anybody can get into this business. And the spreads are tighter so [making money] is really on a lot more volume. You know, the more volume you put through the higher probability that you will make money and the more you can internalize and the more you can save with regards to trading costs (Interview 4).

Lower technology costs, then, has meant lower barriers of entry according to some informants.

The second characteristic is that despite the overall lower costs of technologies there remain different 'price brackets' of investments in infrastructure. Thus, while tier-one firms can invest in such things as a '£40 million connection between London and New York' (Interview 5), tier-two firms cannot and rely on different business strategies, such as co-location and the development of 'better' trading models. (Clearly, this observation contrasts with the view that the falling cost of technology has reduced entry barriers.)

The evidence on this two-tiered structure was consistent across the interviews. For instance, it was clear in discussions of so-called *slippage*. Slippage is a practitioner term that refers to the

difference between the estimated transaction cost associated with an order, and the actual cost of the trade. Although a widespread term, some second-tier firms do not have precise knowledge of their slippage rates, as demonstrated by the account provided by Interviewee 5:

> I asked the head of trading at [name of a fund], what's the slippage rate you get? 'Zero'. Zero? And she said 'one bps?' Asking me whether that is reasonable. She had no idea. And what does zero bps mean? What does two bps mean? Most fund managers have no idea about that type of thing (Interview 5).

In other words, the interviewee argued that some fund managers who are engaged in automated trading have a remarkably limited knowledge of the technical aspects of it. We see this as an outcome of the two-tiered structure.

Another manifestation of this duality in expertise is the practice of using *third-party algorithms*. One senior market participant who works for what we would call a tier one firm noted:

> The second tier brokers that cannot keep up with the technological arms race have become one of our fastest growing client segments. So, as we are developing our own algorithms, we now have a certification process by which we can offer our algorithms certified to third-party brokers so they can go and retain the ownership of their clients. So, we don't interfere with their client relationships. They can say, 'we have comfort using [name of firm's] algorithms' (Interview 1).

Thus, second-tier firms are relying on the automation capabilities of first-tier companies. Another case of a first-tier firm selling to a second-tier one is the selling of a *white-label dark pool*, that is, providing a dark pool under a brand that is different from that of the company that runs it.[4]

These practices, which are usual in other industries such as retailing and Internet technology, can also be seen as potentially dangerous, in that they entail a non-expert user employing a body of codified knowledge for which they might lack the necessary tacit knowledge. After all, the SEC-CFTC report on the Flash Crash points to the order placed by a non-expert fund as the key cause for the chain of events that unleashed the crisis.

Although exchanges are one archetypal incumbent in the world of automated trading, we also found that exchanges have remained central in an environment of automated markets. Exchanges have identified new sources of income. For instance,

> Exchanges have started charging for data, because they recognize there's a big community of HFTs out there who are data-hungry. They have also used their data centres as a fantastic source of income because they know that they have a captive audience (Interview 3).

Selling data and co-location has thus given exchanges a new life. As we shall see below, exchanges are also important in that they are at the centre of informal conversations about the technical state of connectivity in the market. And these are crucial to computer-based traders.

[4] On a related note, the interviewees explained that they do not make use of dark pools for computer-based trading.

3.2.Innovation

The second overall theme of our findings relates to innovation. Innovation was brought up by the interviewees not only in connection with the adoption of new hardware and software, but more broadly. This included the introduction of new regulatory frameworks, contractual instruments, standards of accounting, systems inter-operability, organizational protocols, and business strategies.

3.2.1 Speed and technology confer a smaller advantage than in recent years

A theme that emerged consistently in our data is the observation that computer-based trading became an extremely competitive activity in recent years. The perception of intense competition was independent of the size and nature of the firms analyzed. For instance, Interviewee 1 noted:

> We are now in a very significant technological arms race. Only a few players can afford to keep pace (Interview1).

Conversely, Interviewee 6, head of a latency-sensitive fund, observed:

> The days where you could make money directly out of connectivity are pretty much all gone. Now everything is collocated or approximately based. There is very little edge in making money. There are guys that focus purely on speed and they make some money, but it is by no means like the 2007 days (Interview 6).

Interviewees seemed to agree on the timeline for this increased competition. For the participants, the intensity of competition increased notably in the period 2006/2008. During and after this period, technology-driven latency-sensitive business models decreased in profitability, to the extent that activities such as high-frequency trading became marginal contributors to the income of some firms. The events leading to lower profits were described particularly well by Interviewee 5:

> There are many reasons why there is a decay in profitability. One is more people come into the thing. Say, the late ‘90s, there weren’t that many people, really. The other thing is the volatility in that period was gradually going down. If nothing moves, there’s no opportunity there. So, that’s another reason for decay, not only for high-frequency, even statistical arbitrage and other strategies, were decaying in performance. And then, obviously, that combined with all the crowding. With more people coming in, they don’t all trade the same stuff. Because in the easy days, with less competition, you made money with a reasonably good model. Now models have to be a lot more sophisticated, and the profit margins in general are smaller, and so this is where the race started kicking in (Interview 5).

Interviewee 6 confirmed these views. For this fund manager, increased market efficiency was responsible for the higher level of competition observed in recent years. According to him:

> Markets are definitely a lot more efficient. And, it is even more efficient now than it was in 2006. So, like the ultrahigh frequency side, we’ll try high frequency trading at our firm. But it is not a significant profit centre by any means (Interviewee 6).

Some interviewees suggest that the lower profitability of latency-sensitive business models is leading to ‘either shut-downs or acquisitions by other players’ (Interview 6). This is apparent in

the case of smaller, less-capitalized firms that follow market neutral strategies (e.g., high-frequency traders). With lower profits, some of these firms can no longer make the 'half a million pounds [per month] to cover their costs' (Interviewee 6), and are either absorbed by larger, better capitalized organizations or altogether stop their operations. Interviewee 3 concurred, stating that 'the majority of HFTs trading in the marketplace over the last five years have not been successful' (Interview 3).

It thus seems that, contrary to what is alleged in current public debates, high-frequency strategies are not only pursued for their profitability but also for the data and practical knowledge. Interviewee 6 provides, again, a candid explanation of this rationale:

> The amount of resources that we have to put in [ultra-high-frequency trading] is not commensurate with the P&L that we derive from it. I mean, it makes money, net-net, but it is by no means what you would consider a successful venture. However, the reason we do it is because the data that we collect from the ultrahigh frequency guys, we believe it's valuable for our long-return trading.

3.2.2 Features of the innovation process

The combination of industry competition and an equally intense technology race has resulted in distinct mode of innovation, characterized by two processes. First, market participants tend to prefer technologies that have proven reliable through their extended adoption. Hardware, for instance, is 'pretty standardized […] the technology is pretty much accessible to everyone' (Interview 6). Similarly, as Interviewee 4 put it:

> Trying new technologies on an established trading system that is generating revenue is pretty foolhardy. And there are certain things where we are fairly primitive, you know, in some ways because it works. Don't fix it. Don't mess with it unless you really have to (Interview 4).

Thus, one feature of innovation is reliability rather than speed.

Indeed, even in the latency-sensitive domain of high-frequency trading, investments in technologies that offer additional speed or computing capacity are not regarded as crucial when compared to tried and tested systems. As Interviewee 3, head of a connectivity service provider mentioned:

> If you are one of 100 different HFT's and you know that the other 99 guys have got their trading machines in the same data centres as you, you can relax a bit because, 'okay. I might get ten meters closer to the matching engine,' but it becomes *de minimus* the differences that you're going to be able to achieve (Interview 3).

Again, here we see that technological specifications are not the key current dimension of advantage. Once a high frequency trader is close enough to an exchange to be in the same data centre as its matching engine, it is impossible to be closer (that is, faster) than those rivals in the same data centre.

Second, most innovations are produced as re-combinations of existing technologies, techniques and procedures. Innovations in algorithms, for instance, are built from an established – if largely conventional – technological baseline but mix knowledge of markets, technologies and regulation. As Interviewee 3 explained, in the face of high levels of competition in technology 'it's

the case of saying, “Okay. Well what about the processes that I’m using, you know, what are we doing?”’ (Interview 3).

3.2.3 Speed vs. cleverness

Another type of innovation involves the development of more sophisticated models. Given the high costs and risky competitive dynamics of technology, firms that are unable or unwilling to invest in state-of-the-art infrastructures focus on the development of algorithms. This was expressed succinctly by Interviewee 5, who mentioned:

> My firm can have a slightly less competitive speed, but if I go up in cleverness of the model, I can still be profitable. We tend to work on the cleverness, rather than trying to get expensive dedicated networks (Interview 5).

The importance of model-development was confirmed by Interviewee 6, who noted that research ‘is something that we have to invest in continuously and we keep refining it continuously’ (Interview 6).

3.2.4 Innovations combine resources across domains

Model building is a form of innovation that requires combining expertise across domains: it requires knowledge of the market, hardware, software, exchange rules, architectures of connectivity and regulations (Interview 7). In this sense, the traditional roles of trader, researcher and technologist no longer describe the work conducted within many financial organizations. As Interviewee 8 explained, the importance of models led his firm to blur the line between technology and research:

> Our researchers ended up doing a lot of coding. A lot of our best coders are quite good researchers. Probably, in terms of investment management, there’s probably 40/60, 40 percent technology to 50/50 (Interview 8).

Model development exists alongside other forms of innovation that result from working across domains. Interviewees highlighted the fact that opportunities also emerge by exploiting novel regulations or altering organizational practices in creative ways. Interviewee 1, for instance, offered the introduction of commission sharing arrangements as example that, in his view, is related to recent regulatory changes in the European equities market, known as unbundling:

> The way this model works is, the asset manager sits down with the executing broker of choice and says, ‘Right, I will send you all of my workflow to execute. As I send you my commission for the order flow, we agree upfront to split that into two pieces.’ So, in one step, this model gives the freedom to choose the broker or brokers for best execution and the power to still reward value added ideas and get rid of that conflict (Interview 1).

An innovation can therefore originate in a non-technological domain, and firms may combine such disruptive changes with their established technologies and techniques.

The interviews suggest that in computer-based trading, innovation is more often than not a product of changes in the way organizations behave and shifts in the regulatory regimes of financial markets; technological developments, while important, are not the sole drivers of the industry.

3.2.5 Computer-based trading is characterized by 'siloed knowledge'

The critical role of knowledge in computer-based trading is reflected in the fact that sensitive innovations and processes are often siloed.[5] Each silo may correspond to an individual trader or a small team that has direct knowledge of a handful of strategies and algorithms. Complete knowledge of the models of firms is thereby fragmented across several departments and individuals. This is reflected in Interview 4, which explains how a particular firm deals with the production of new trading models:

> We have the quant that did the research code the strategy. And that's why each quant owns the predictors signal-based models that he works on, but not all the other ones. And when you don't have all the pieces of the puzzle, basically, you're not going to be able to replicate it anywhere else. I mean you know conceptually how we run our operation, but the truth is not available to them. You know, everybody has a piece of the equation, but there are only one or two people that have transparency in all of them (Interview 4).

Similar views were expressed by Interviewee 5. As he mentioned, hiring policies are adjusted to prevent leakage of intellectual property.

Much of the understanding of the structure of the financial system is tacit rather than explicit; knowledge of how the market is organized and works is fragmented throughout individuals and across organizations. Fuelled by competition and secrecy, such fragmentation of the knowledge of the architecture of the market may also lead to an increased difficulty in identifying systems that are tightly coupled and sources of systemic risk. This phenomenon is what we define elsewhere as 'fragmented innovation.'[6]

3.2.6 Bottlenecks in innovation

Interviewees also considered that technology innovation is shaped by the existence of bottlenecks. Interestingly, these are not related to the limits of technological capabilities but rather to institutional and human constraints on research and product development.

First, technology development is largely conditioned by the development pipelines of major vendors, responsible for the provision of standardized software, 'trading boxes', processors, servers and networks (Interviews 1, 4, 5, 6, 8). As Interviewee 1 (UK based) observed,

> There is a significant concentration and a handful of independent vendors. But the unintended consequence is a bottleneck point. Anytime you want to product innovate, you become subservient to the product rollout timetable of the vendor. In a way, that was one of the insights that we had in cash equities which lead us to doing it all ourselves (Interview 1).

This sentiment is reflected clearly in other interviews: with the exception of service providers, all of the interviewees highlighted the fact that they produce and/or customize most of their systems, partly to avoid the cumbersome pipelines of vendors.

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[5] Tufano (2003) provides a brief discussion of the problem of intellectual property, secrecy and financial innovation.

[6] See Beunza, MacKenzie, Millo and Pardo-Guerra (2011).

Second, a different bottleneck emerges when innovation efforts are internalized. This happens also when customization of off-the-shelf systems is conducted in the firm (Interview 4, UK based). In particular, testing and debugging is a time consuming process that slows the rate at which new systems and products can be introduced to the marketplace. Interviewee 5, for instance, recalled the rationale and problems of such internalization:

> Anything that is not sensitive, I will buy because I don't want to maintain it. But anything that is useful in trading that is sensitive, it will have to be handwritten. I hate doing it because writing high precision requires so much testing. Because you can't have something going wrong when you work so many thousands of orders. And you can't trust somebody else to do it, unless you find somebody as paranoid as you who can actually be that precise (Interview 5)

The problems of internalization and testing were further corroborated by Interviewee 1. As the interviewee mentioned:

> We found that as the markets electronified, became faster, and latency became more sensitive, the third parties may not have been able to keep pace with the developments. We found we were able to be more nimble ourselves. The single biggest bottleneck is not so much monetary resources, but human being calendar constraints in terms of Quality Assurance testing (Interview 1).

A third bottleneck (particularly in the UK) is the lack of qualified technologists. As analyzed, the development of both systems and models occurs in a highly siloed environment. Since the knowledge possessed by individual developers is critical to the operation of firms, their expertise is guarded. This is reflected in the comments of UK-based Interviewee 5:

> If you have a technologist leave, and that person has access to everybody's code, we don't want a person with all this knowledge walk away. That's one thing. And two, there aren't that many. If you find a handful of programmers, there's only one that may actually cut it. So, there are not that many of those people. So they are a lot more costly than an average programmer, even two, three times (Interview 5).

A technological bottleneck thus emerges at the level recruitment and retention: highly qualified technologists are difficult to come by and, when found, are retained whenever possible.

Interestingly, some of our more technologically sophisticated informants did not see these factors as bottlenecks. Testing and technological talent, according to Interviewee 2, are not constraints but the new *assets* in an automated environment. Interviewee 10 agreed:

> The skill set you need if you are a floor trader is about presence and also being a relatively quick in calculating. But the skill that you need to provide liquidity on a screen is quantitative skills and technology.

Computer-based trading, the argument goes, has turned upside down the personal skills and organizational capabilities that are at a premium. There are new assets. Testing is not a chore, but a source of competitive advantage. It leads to more reliable systems. Connecting to new venues is not a pre-requisite to actual trading, but part and parcel of effective trading in an environment of fragmented liquidity, changing venues and a shifting landscape.

3.3. Practices

The interviewees discussed the practices that characterize computer-based trading. These refer, among others, to changes in the ways human judgement is utilized, the prominent role of models, and more generally the changing nature of the decision-making process.

3.3.1 The changing role of the human in computer-based trading

Interviewees emphasized the changing role of humans in the decision-making process that surround trading. Human traders control the parameters of the system and negotiate the form of the models with quantitative researchers and programmers (Interview 7). In other words, there is a shift towards a higher-level control of automated systems. Interviewee 4 described these traders as turning into 'anti-traders':

> Our systems, are, generally, fully automated. So, we call the traders anti-traders because on a particular day if the market's not exactly doing what it's supposed to be doing or you have an outage or something goes down, then the trader's job is to, basically, wind down the position until we figure out what's going on (Interview 4).

Thus, the use of automation has turned upside down the traditional role of what a trader used to be. From doing to monitoring, and from trading to stopping the algorithm.

Interviewee 10 added to this. To him, the key thing of what a computer-based trader does is to adjust the parameters of the algorithm.

> Traders are there to tweak the settings because what this business is about is being able to give optimal pricing. And the inputs and how you, what weights you give to each of these inputs, that is the secret sauce and that is the secret sauce that a trader will constantly try to tweak. Do we give more weight to this input, more weight to that input? But this is the basic model for every single firm (Interview 10).

In connection with this, Interviewee 12 argued that this shift is leading to de-skilling, whereby traders gradually lose the instincts and tacit knowledge developed in floor-based trading. Arguably, such forms of expertise may no longer be necessary in an environment dominated by automated trading.

3.3.2 Computer-based trading is enabled by models, but also constrained by it

Practices in computer-based trading are shaped by the use of models. Modelling, however, can take several forms, from emphasis on arbitraging differences across markets, to identifying statistical/ behavioural patterns in historical data, to models that take into account the execution costs of a particular trading strategy. Interviewee 4 provided an example of how modelling practices have several aspects. The models in his firm are based on predictors or trading signals:

> The predictor is telling us to buy 10,000 share of the stock. So, the order strategies are going to figure out what is the optimum way to minimize opportunity costs and maximize my execution (Interview 4).

The model thus takes into account both statistical signals and execution costs, thereby combining different forms of knowledge into a single trading strategy. Other firms, however,

approached modelling from a different perspective, focused on such things as fundamental analyses (Interviewee 6) or 'vanilla' quantitative trading models (Interview 5, 8).

This practical focus on models has several consequences. The first relates to the inherent limitations of models. Interviewee 6 noted the following:

> It's not really possible to build one model that does everything. What you do is you build one model for this effect, and you build one model for this other effect, and then maybe you build a bridge between the two. But nobody builds one model that does everything (Interview 6).

Thus, models are limited: not everything can be modelled; a model has a finite reach and is valid only under a certain, well-specified set of conditions.

Second, models that utilize historical data are fine-tuned to the time-series on which they were tested (Interview 6). Events in the market that exceed historical parameters make the model inadequate. Here, sharp price movements are particularly noteworthy causes for the inapplicability of models. Our interviewees suggest that many strategies used by computer-based traders rely on statistical models whose behaviour derives from a large record of 'normal' price movements. Increased markets volatility may lead then to withdrawal from the market. This was explained by Interviewee 5:

> It doesn't have to be a Flash Crash. It could even be a three percent move based on some actually fundamental reason. It could be a news event. The model doesn't know the news event and it sees the market move, say, two, three percent. It knows that its confidence goes down in forecasting, it just liquidates. When you don't know, you stay out (Interviewee 5).

It is also important to clarify that it is not only volatility but lack of liquidity and delays in data that undermine the models. Furthermore, in some cases a bounded measure of volatility is key part of the trading strategy. Interviewee 4 describes, for instance, that 'in the business that we're in, volatility is actually a very good thing; the more volatility, the more volume, the better for us' (Interview 4).

Models also constrain the choices of assets and contracts. According to Interviewee 3:

> Stock indices 'seem to be a favourite' of the computer-based trading community. They avoid the 'risk of corporate actions that might suddenly move the market in individual shares in an illogical way that wouldn't meet the patent recognition that your program was designed to view' (Interview 3).

This reliance on indexes is consistent with a critique of computer-based trading levelled by Interviewee 12. According to him, traditional agency brokers have laid off their desks, so the expertise and tacit knowledge about trading specific sectors has been lost. Computer-based traders provide liquidity for the 200 most-traded stocks, but not for the other ones. And the alternative source, the brokers, has disappeared.

Finally, the reliance of model-based trading on data transmission introduces another technological constraint, as the interviewee 5 explains: 'if you have delays in market data, your models are not going to be trading on reliable information. Then you have to shut that down' (Interview 5).

3.3.4 Tight coupling

A related trait of computer-based trading is the critical importance of the infrastructure used in trading. We noted this when asking interviews what part of their systems was critical. The most common response was puzzlement, as *all* of them were critical.

> It is a network that is strongly interconnected and it's actually like, any point that fails takes the whole system down. So, if the matching engine goes down, the whole thing goes down. If the gateways go down, the whole thing goes down. And, if the routers for the exchange go down, all of them go down. So, in that sense, there are many points of failure that could go down (Interview 5).

In other words, every link in the chain needs to be in place. All of the components of the infrastructure need to be work for the trading to take place. In principle (but see the section on risks below) the system leaves little room for problems, because of it's high degree of interdependence, or tight coupling.

The need for reliability has led some of the funds that we interview to invest in very specialized and secure assets. Consider the security measures adopted by Interview 8's fund:

> Interviewee 8: Our backend infrastructure, we have two data centers, one of them is an ex-military facility. When you go in, you get weighed. When you leave, you get weighed. You don't check anything in or out.
>
> Interviewer: You cannot drink when you're inside?
>
> Interviewee 8: No
>
> In other words, tight coupling has led to huge investment in the security of the various pieces in the infrastructure.

3.3.5 Competitive advantage originates from multiple sources

Our interviews suggest that computer-based trading is composed of a diverse number of strategies along a wide spectrum. In addition to the well-known distinction between trade origination and execution, interviewees referred to both model-intensive and latency-sensitive business strategies. For example, Interviewee 2 explained how the strategy of their firm was based on economies of scale:

> Our business is about compressing the cost space and making sure that we're going to be so efficient that doing a trade where we earn one cent is good enough, but we do billions of trades. So, when you look at the size of our firm—for example, we have a client business in the U.S. that trades five times more than LSE on a principal basis. We have a matching engine, which is five times the capacity of the LSE. We have 22 people in that business. So, the cost of running that business is two percent of LSE. The profit of doing that business is, the revenue, you know, the margin we need to be for that business to be sustainable is cents, you know, two cents per transaction. While LSE, if they don't make two pounds per trade, they're out of business (Interview 2).

This business strategy can be contrasted with those that invest on the so-called 'cleverness' of models (Interviews 4, 5, 6).

Another interviewee observed, for instance, that his firm's overall trading strategy was 'different from any other high frequency trading [firm's]' (Interview 6). His firm engaged in what he represented as 'the fundamental investors of high frequency', developing models that 'look at more fundamental themes in our trading strategy. So, we as traders, look at the market and go, "OK. What are traditionally good trades to do?"' (Interview 6).

The focus on factors different from low-latency when designing and implementing the business model is also related to the geographical location of the fund. As interviewee 9 explains, location can dictate strategies that do not compete on speed:

> If we're sitting in London, trading the CME, which is one of our big markets in London across effectively what is a public network because at that stage we will have had to almost Internet connectivity into the CME; into a broker that's going into a CME, going through their infrastructure by probably a relatively slow network link and their infrastructure is going to the CME and coming back again, water flow is going to be running very slowly (Interview 9).

Business strategies also include other factors. The interviewees discussed, among others, approaches of capital raising (interview 8), aggregating order flow and market data (Interview 4), controlling inventories (Interview 7), and managing risk (Interview 3). Interviewee 8 noted, for instance, that the strength of his firm was not uniquely in the models but in 'the asset raising [since we have shareholders] we are able to raise assets effectively across the world' (Interview 8). In short, competitive advantage comes from many different sources.

3.4.Social networks

Another theme in our questionnaires concerned the use of social ties and networks. We asked the interviewees about the structures of connections they formed and maintained, and their influence on decision-making. We learnt that social networks are often used as a contingency in cases of failure in the electronic networks, and for sensitive information such as recruiting. The answers given by the interviewees suggest that these ties can be classified into two types, shallow and deep, and that different ties are used for different purposes.

3.4.1 Participants rely on 'shallow ties' to evaluate the routine state of the market

Interviewees stressed the importance of maintaining ties and communicating with other market participants. The interviews indicate that communications that take place through these ties complement decision-making processes by providing a general view of the state of the market. In particular, these ties are utilized for accessing types of information that are not readily visible in the order book and that are not to be found in 'the wire.' These include, for instance, market sentiment, explanations of market behaviours, and other similarly general evaluations. Sociologists typically refer to these ties as 'shallow', as there is a low level of trust invested and expected from the parties to the ties.

3.4.2 Deep ties are used for exchanging sensitive information

Market participants also rely on ties based on longstanding friendships, common group membership or, as one interviewee mentioned 'relationships of significant depth' (Interview 6). The mention of these deep ties was consistent throughout the interviews: other interviewees often indicated having a small group of 'very trusted' friends in the industry that served as confidants on business-sensitive issues. Interviewee 8 noted, for instance, that he had 'a small number of really trusted people that we share some of our business ideas with' (Interview 8).

The information that travelled through these ties included, for instance, evaluations of their firm's competitive position in the market. Speaking about how he knew he was competitive, Interviewee 5 argued:

> In New York, we are as good as anybody else, even Citadel or Morgan Stanley. Because I have friends there and I know exactly what they are getting (Interview 6).

Deep ties are also used for evaluating the merits of job candidates, as explained by interviewee 8. Friends, he said, are those with whom he discusses problems of recruitment such as 'whether I'm realistic and try to hire someone for a certain price band, or from a certain firm' (Interview 8).

The complex structure and role of these ties was further confirmed by Interviewee 6. For him:

> Market participants are all dependent on each other for sharing the information and that's why probably it works. So, that is the social network in a human way. You don't have to see those people often. I saw this friend of mine in New York in June, when I was there. That has given me enough information that I need for at least another three or four months. And he has got enough from me in terms of what's happening here, or what we are doing, or any trend. So we are competitors, but still there are some things that we can share (Interview 6).

Our interviewees, however, do not indicate collusion or price coordination in the industry. Instead, they suggest the existence of norms of reciprocity in information exchange through deep ties:

> My friend is not going to tell me anything if there's no gain for him. So, there is a mutual dependence on sharing information. We're not shooting ourselves in the foot, but enough to kind of bargain and trade information. My four relationships are strong. This is why you can share a little bit without thinking that you are giving away too much. Because the decency factor will keep things in balance and we want the others to be successful in what they do. I might even advise them, or they might even advise. One of the guys actually told me about some data that I should even look at. But he wouldn't go around to say exactly how he's using it. But he said, be careful with those things. That will save me a few months of pain (Interview 6).

Deep ties, then, do not seem to be used to exchange detailed information about trading strategies or to agree on particular actions in the marketplace.

A related area where network ties matter is in situations of crisis. Participants again turn to a few trusted friends. Consider Interviewee 8:

> On a daily basis, outside my own company, I'm in touch with lots of friends at banks, and also colleagues at banks. I don't make the mistake of assuming all the people I deal with are my friends. I couldn't care less about the direction of trading. I want to know about participation. Are people still trading? What are volumes like? Because we don't want to be too big or too small in the market. Are people taking risks? Are your prop desks busy, or are they sitting on their hands waiting, trying to get a feel for markets' (Interview 8).

As we can see here, participation is the key variable. This is consistent with a world where the key decision that the 'anti-trader' makes is whether to keep the algorithm in the market, or to it pull out.

3.4.3 There is 'social lineage' among market participants

The social networks in computer-based trading also extend through time, following the career paths of market participants. Deep ties, for instance, are often forged with former industry colleagues, and remain strong sources of insights throughout time. Interviewee 5, for instance, noted:

> My business partnership is with another person who I've been with for the last 12 years. We have been friends. We used to be traders together back at [name of bank]. And, basically, I look after the proprietary trading side of the business (Interview 5).

Such persistence of ties, which sociologists refer to as 'social lineage', is important because of its role in deciding, for example, what knowledge is used in making critical decisions. An example of how social lineages affect business strategy is provided by the use of consultants in the industry. Consultants, the interviewees indicate, were selected through their membership of a particular lineage, as noted by Interviewee 8:

> Generally, they're introduced by various senior management within the firm, so we might have individuals who have worked at some reputable investment banks before, you know, on their businesses. People used to work with them years ago (Interview 8).

In other words, by limiting the employment of high-level consultants to those with deep ties with senior management, computer-based trading firms place social networks at the center of their knowledge and capabilities.

We speculate that social lineage may be a source of risk, as it creates homogeneity in the knowledge sets held by market participants. This may contribute to cascades of similar reactions amongst market participants. Advice sought by market participants may mirror and reinforce their own behaviours, and lead to a more general process of self-reinforcement[7].

3.5.Risks

Our study also covered the issue of risks and potential crises by examining how interviewees accounted for their actions in Flash-Crash-like events. Three key findings emerged.

3.5.1 The Flash Crash is perceived to be a distinctly American crisis

Our interviewees believe that due to their different market structures, European markets are less likely to experience an event such as the Flash Crash of May 2010. Along with market fragmentation and the absence of trade-through rules (e.g., Interview 4), interviewees identified the widespread use of volatility-initiated auctions as a practice that is less prone to flash-crash-like events. This was illustrated by the comments of interviewee 6, who noted:

[7] For a simulation-based study of copycat strategies, see Benink, Gordillo, Pardo-Guerra and Stephens (2010).

> The Flash Crash is not something that can happen in Europe. It's because of the way the market is organized. The Americans are very, laissez-faire, kind of like, 'Look, all people should just trade however they want, however they want.' Europe has always been like, 'Yeah, OK. Trading is fine, but if things start going wrong, we will pull the plug immediately, right?' And, to reassess. For almost a decade now, we've had volatility auctions since basically 2002, 2003. So if something moves in excess of some threshold, up or down, it goes into auction and that just slows down the whole process and gives people a chance to reassess for several minutes what's actually going on.

3.5.2 Communication during the Flash Crash

The interviewees stressed the importance of informal communication during times of crisis. For instance, Interviewee 8 suggested that event like the Flash Crash is identified not only (or even primarily) by technological systems, but also through social signals such Bloomberg chats:

> I knew about the Flash Crash because a couple of traders shouted 'What is going on?' They'd just seen stocks drop. I think probably the friends that I would normally have called in the market weren't at their desk at the time because it was later in the evening. The first thing we will normally see on the desk here is we've got all these Bloomberg chat messages. If you see suddenly the Bloomberg chats light up, there's a lot of chatter from market people, 'what went on there?' 'what happened?' 'Don't know what that was.'

This form of social cue is helpful, according to the same interviewee. Without additional information supporting a change in the fundamental valuation of securities, in an event like the Flash Crash the interviewee would tend to underestimate the danger.

> [I would have tended to] look at it and go 'It's a fat finger. It's a glitch'. If there's no news announcement because people always search for news and say, 'US government just said something.' If there's no news on, I would normally just write it off as a fat finger, and assume it's going to bounce back'. Accessing additional information thus contributes to a better operation since it adds to the evaluation of the event (Interview 8).

Informal communication with others thus helps prevent the risk of overlooking a significant event. It structures attention and gives meaning to puzzling developments.

3.5.3 Communication during outages

Other interviewees stressed the importance of social communication during outages. Outages were perceived as particularly important in the benchmarked price system that exists in Europe:

> Alternative trading venues are benchmarked to the primary market. So, it's all driven by that. If the primary market stops trading, then they continue to trade, but if there's a huge price dislocation then it sort of gets to the point where people just step back and they're not going to trade in there and they won't trade around it (Interview 5).

While outages are undesirable, interviewees see them as unavoidable. One interviewee explains:

> It certainly happens -- you know, it's part of the operational cycle, typically, because as an electronic business we're dependent on a large number of particular counterparties that

> we interact with. We get a failure of one of them I would say several times a month, in some technical description (Interview 9).

Yet the possibility of communicating with the exchange and other participants is useful.

> Even with the best intentions in the world, we have to anticipate that systems—particularly when they're external systems—may have outages from time to time. That becomes part of the landscape. That needs to include our response to that. This is where communication becomes very key (Interview 1).

Communication is helpful in two different ways. First, having clear and transparent communication channels with exchanges and trading venues helps participants understand the situation. Interviewee 1, who oversees the operation of a multilateral trading facility, noted:

> We'll call the exchange directly. No problem. I mean, they know we're operating a referenced price system. We'll call them up and let them know what's happening. They often will know about the issue themselves because they're also monitoring. If they don't know, they might say, 'Oh, thanks for the heads up' (Interview 1).

Communication protocols, however, differ across trading venues. Some interviewees argued, for instance, that incumbents (i.e., primary market exchanges) were less customer-oriented than new entrants. As Interviewee 4 mentioned,

> Some exchanges will send you an email. They also have websites, basically, that show you the trading status of each of the matching engines or each of the segments. Some exchanges will just say 'look, if you think there's a problem look on my website. We're not going to even bother sending you a market notice. Go look on the website.' And sometimes they're not even correct. And sometimes when there's a problem, the trading status website crashes because everybody's coming onto it (Interview 4).

Second, interviewees emphasized that communication across firms allows for a more efficient recognition of connectivity problems that may affect the market. Again, Interviewee 1 provides an example:

> The other day we had an issue around data and we were calling our members just to also let them know. It's also very interesting because one of them says, 'Oh, I'm really glad you raised this issue because coincidentally, someone accidentally turned off one of our automatic protection mechanisms across all of our markets.' So, that's the culture of this communication dynamic, to ensure the markets are operating well. I think that's an important feature in the market, this kind of ecosystem we operate in (Interview 1).

As automation continues to gather pace, the relief mechanisms introduced to financial markets must take into account the development of cultures of communication that allow market participants to understand operational problems as they become visible in the horizon.

3.6. Perceived future of computer-based trading

In addition to discussing current practices, interviewees were asked about future challenges of computer-based trading, as far ahead as ten years from the present. The challenges that they identified are related to non-technological factors. They see the future of computer-based trading as dependent on the intricate interactions between regulation, novel markets and

refinements in operational systems. The trends of the future consist, in this sense, of increased harmonization, integration and interconnection in the global financial system.

First, consolidation of actors, achieving economies of scale by merging resources and reducing costs. This is expected to take place as a consequence of competition in the industry and the lower profitability of latency-sensitive business models (Interview 6). But as Interviewee 9 noted, competition may bring about disintermediation, both technologically and organizationally:

> Technology disintermediation has happened; the organizational disintermediation hasn't. And to some extent one of the macro challenges is, how did you get to that level of efficiency by removing a set of incumbents from the world? Now, if you've got trading functionality happening at a utility level, it's possible for investors to group together in that new way, because [you do not have to build] all of the infrastructure that you need for an investment bank anymore (Interview 9).

Thus, the existence of two different forms of disintermediation, technical and organizational, may lead to different rhythms between them and open up potential for problems.

Second, consolidating clearing and settlement. This is expected to take place through the expansion of choice-of-clearing models. As Interviewee 1 noted,

> The whole point about computerized trading is scale, but we also need to be able to scale the post-trade model. This European model, which allows us to trade Daimler in Germany or U.K. and settle in Germany, or multiple countries and settle in the respective home markets, we can scale to Asia.

A related scenario is the expansion to 24 hour trading. Interview 1 noted the following:

> We're also beginning to try and learn insights from markets like the foreign exchange market, which is also increasing electronified and futures. The key, big insights to draw from FX is, it trades 24 hours a day and settles in one place. Futures are moving to 24 hour trading. So, why shouldn't we also think about doing it for equities? (Interview 1).

Thus, integration is expected to take place both across countries and time zones.

A third trend is the development of new products that can be used throughout different time zones. This would happen by creating additional pricing points in the market that mirror underlying assets from the primary market. Such is the case of exchange-traded funds. But, as Interviewee 1 observed,

> If you're going to have a successful ETF that trades in different time zones, it makes sense to be able to launch a product in one country and to be able to sell it in another country. This is from the perspective of asset managers. The primary focus is to see a fund framework that allows the passporting of product from one country to another (Interview 1).

This scenario, which the interviewee refers to as ‘passporting,’ would require linking not only trading and clearing models, but also regulatory frameworks. That is, the type of innovations discussed above in this report.

A fourth trend is the increase in exchange-traded activity. This increase would be fuelled by regulatory pressures to move over-the-counter instruments onto public order books. Not all instruments can be transported onto order books, though. As Interviewee 1 observed, a great number of instruments lack the liquidity that would justify eliminating a dealer model

> When we speak to our colleagues in credit or fixed income and they tell us, ‘Oh look, you need to consider what we do today.’ There is still a traditional dealer market where the dealers are the buyers and sellers. If you look at the most liquid single name credit default swap, it might be GM and you’d be lucky if it trades 15 times a day. That’s true for today (Interviewee 1).

The interviewee noted, however, that there exists a subset OTC instruments that can, potentially, migrate to exchanges:

> People are saying, ‘Hmm, what if we could trade together equity puts and credit default swaps?’ Because people trade in that today, but it’s a bit of a manual process. But we know they must be related, because if the company goes down, the credit default swap goes up, but so does the equity put. So, you got liquidity. Then the new incremental liquidity which would come from the over-the-counter markets that comes to order books’ (Interview 1).

In short, by linking OTC instruments with exchange-traded instruments, public order books could gain extra liquidity.

We can think of this in terms of what sociologists of technology call a ‘socio-technical network’ (Latour 2005). The concept builds on the observation that in highly technological societies events are caused by the interaction of people and machines, and that treating the two as distinct overlooks their interdependence. In that sense, we see participants weaving that network together, that is, tying together machines and algorithms across geographical areas, organizations and regulatory systems. Four predicted trends are particularly noteworthy.

In weaving together this socio-technical network, we see a trade off between efficiency and stability. We anticipate that in tightening and further weaving the network, the system will manage to arbitrage away additional mispricings, thereby increasing efficiency. At the same time, however, it will build transmission mechanisms that might reproduce a financial shock in one region and asset to the rest of the system, opening up the door to a greater risk of systemic instability. In fact, we already see an element of this. According to Interviewee 6:

> There’s a higher correlation in the markets. In 1987 when the U.S. woke up they didn’t care what the hell was going on in Europe. Okay, well, those guys can do whatever they want. Asia was not a factor -- it was irrelevant. Today, all the markets are correlated so, if Greece defaults, they all care about it. So, they’re much more correlated and it’s a much more news-driven market. So, any little bit of news comes out, basically, the market goes crazy. People react to news a lot more, you know.

This emphasis on correlation and sensitivity to news is consistent with other comments that we heard from interviewees.

The debate about high-frequency trading

Almost all our informants alluded to the public debate on the risks of high-frequency trading. Some distanced themselves from this term, including some firms that we identified as high-frequency traders before the interview with them. Others drew nuanced distinctions, Interviewee 10 argued that his company had a high-frequency *technology*, but not a high frequency *strategy*. But this emphasis on terminology is not just a sign of rigour in language. Industry participants seem to have a sense of being under attack and misunderstood, following the Flash Crash. Many asked specifically about the purpose of our interview.

Our interviewees agree that there is a debate about the costs and benefits of the current market microstructure. Our single non-computer-based respondent (which we included in the study for contrast of opinions) provided a summary of the case against high-frequency trading (Interviewee 12), centered on the excessive reliance on rebates (at least in the US equities market) and on the lack of obligations of the computer-based traders.

By contrast, some of our computer-based interviewees see non-automated traders as slow, expensive and overly based on their business contacts. Some even suggest that part of the debate is caused by lack of understanding of computer based trading, or the inability to adapt to an automated world.

In other words, there is a debate. The controversy has turned into a debate about the definitions of high-frequency trading. The unfortunate consequence is the lack of a shared view on what computer-based trading entails. Indeed, our interviews suggest that the expression ‘high-frequency trading’ conceals a wide range of trading strategies. A better understanding of this diversity might allow the industry to make a better case for its positive effects on the market.

4. Concluding remarks

Our report sought to provide an insider’s perspective on computer-based trading. It asked traders about their practices and their views on the future. Its findings highlight the role of disruptive technological change, the need to have a broad view of innovation in computer-based trading (especially one that includes the organizational aspect), the changing role of human traders in a model-centered world, and the importance of informal communication through social networks, especially in crises and outages. The participants come across as resourceful and reflexive, and do not see a Flash Crash in Europe or the UK as a likely possibility. The future they see is one of greater efficiency, but also greater interconnectedness. In closing, we would like to remind the reader the limitations of our interview-based research study: by design, it can only spot common themes among the interviewees. That is, we had to rely on their own words rather than observing them directly. We also had to rely on a snapshot at one point in time rather than over time. Given these limitations, there are several aspects of computer-based trading that we believe deserve further study. These include a detailed study of how computer-based trading attains returns in practice, especially in relation to the controversy over high frequency trading; also, a study how inter-firm communications occur in moments of crisis; and finally, a study of how actors innovate by recombining resources across different domains, markets and asset classes. In any event, it is hoped that the practices outlined in this report will help policy-makers in their understanding of computer-based trading.

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Appendix 1: Description of respondents

Interviewee	Description
Interviewee 1	Background: Sciences and banking Role: Senior management of an MTF; Holding company: International Investment Bank (AUM > $500 billion); Reach: Global
Interviewee 2	Background: Consulting and banking Role: Senior management of execution services; Holding company: Asset Manager (AUM > $10 billion); Reach: UK, Europe and North America
Interviewee 3	Role: Senior management, clearing, risk management and connectivity provider. Reach: UK and Europe
Interviewee 4	Background: Banking Role: Senior management of electronic market-making firm. Reach: UK, Europe and North America
Interviewee 5	Background: Banking and computing Role: Senior management, quantitative trading fund (AUM < $200 million). Reach: UK, Europe and North America.
Interviewee 6	Background: Sciences and banking Role: Senior management, systematic trading fund (AUM < $100 million); Reach: Europe and North America.
Interviewee 7	Background: Computing and programming Role: Programmer, proprietary trading firm; Reach: Global
Interviewee 8	Background: Banking and management Role: Senior management, quantitative hedge fund; Reach: Global
Interviewee 9	Background: Computing and programming Role: Senior management, quantitative hedge fund; Reach: Global
Interviewee 10	Background: Computing and programming Role: Senior management, quantitative hedge fund; Reach: Global
Interviewee	Background: Computing and programming

Interviewee	Description
11	Role: Senior management, quantitative hedge fund; Reach: Global
Interviewee 12	Background: Banking and management Role: Senior management, non-computer based agency broker; Reach: US
Interviewee 13	Background: Banking and management Role: Independent consultant; expert in computer based trading; Reach: UK
Interviewee 14	Background: Journalism Role: Expert in market microstructure; senior role in brokerage firm. Reach: US

Appendix 2: Interview structure

Interviewee Description	
Background questions	How did your firm become involved in automated trading? What is the extent of your current involvement in automated trading?
Infrastructure	How many data sources do you use? How many venues do you operate in? How many internalizers, MTFs, dark and lit pools do you employ? How do you manage operations across these systems? What do you consider the critical points in this infrastructure?
Innovation	What is the most relevant area for investments in technology in your firm? Are your systems off-the-shelf or customized? What is the trend? How many in-house people work in technology in your firm relative to total headcount? Where are they based? What is the trend in technology recruitment in your firm? Do you use external consultants for introducing out new systems? Do you have formal strategies for dealing with changes in trading technologies? If so, who decide and who implement these strategies?
Social networks	Are you in touch with other market participants on a regular basis? Do you contact them to get advice? Do you give them advice? What type of knowledge do you share with these individuals?
Risk/ Crises	Have you experienced a flash-crash-like event in the past two years? If so, could you take us through the event? What did you do? What did you learn from the event?
Future	What are the challenges and opportunities that you face in the next 3, 5 and 10 years?

Foresight
1 Victoria Street
London SW1H 0ET
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