BLENDED AUTOMATION: INTEGRATING ALGORITHMS ON THE FLOOR OF THE NEW YORK STOCK EXCHANGE

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Abstract

The recent automation of the American stock market has replaced floor intermediaries with trading algorithms, calling into question the sociological claim that markets are structured by networks of intermediaries. Our study examines the social nature of markets in automated settings with an inductive, qualitative study of the automation of the NYSE during the period 2003-12. It proposes the concept of *blended automation* to denote an automation design that preserves the social structure of a market. Our analysis of the Flash Crash of 2010 suggests that such design offers greater resilience to economic shocks. Our study contributes to the literature on technology in organizations by characterizing a novel automation design that reconciles technology with social relations, and contributes to economic sociology by outlining how automated markets can remain socially structured, pointing to role of politics, ideology and design in market automation.

BLENDED AUTOMATION: INTEGRATING ALGORITHMS ON THE FLOOR OF THE NEW YORK STOCK EXCHANGE

The current trend towards automation in stock markets, including the rise of high frequency trading and financial algorithms, has fundamentally transformed how equities are traded in the United States (MacKenzie and Pardo-Guerra 2014). This change poses a difficult challenge to economic sociologists, who have long regarded intermediation as a key social feature of markets (Burt 1992, Baker 1984, Abolafia 1996). As Baker (1984: 778) famously put it, financial markets are "socially structured" by networks of intermediaries on the trading floor. But as these markets are automated and algorithms displace floor intermediaries, it becomes necessary to reexamine the ways in which financial markets are socially structured. The gap in our understanding created by automation became apparent in the Flash Crash of May 6, 2010, the fastest and second-largest percentage-point price decrease in the history of the Dow Jones. The severity of the Flash Crash, attributed by the Securities and Exchange Commission (SEC) to the misuse of trading algorithms (CFTC/ SEC 2010a), suggests that automation has led to structural changes to the market and risks that are insufficiently understood. We thus ask, how has automation reshaped the social structure of the American equities market?

In addressing this question we draw on the seminal work of economic sociologists on market intermediaries (Simmel 1902/ 1950, Burt 1992, Khurana 2002, Obstfeld 2005) as well as more recent ethnographic studies of financial floor intermediaries (Baker 1984, Abolafia 1996, Zaloom 2003, Barrett and Scott 2004). In our reading, these two literatures have established that floor intermediaries provide three core functions: matching buyers and sellers, enforcing norms, and providing sensemaking. By performing these activities, floor intermediaries help investors confront Knightian uncertainty and forestall opportunism (Baker 1984), contributing to create fair and orderly markets (Abolafia 1996). Sociologists offer a less clear answer for a second key question: how will such intermediary activities change with automation? Recent research in the social studies of finance has begun to examine this (Knorr Cetina and Bruegger 2002, Zaloom 2003, Muniesa 2004, Pardo-Guerra 2010). But as we

detail below, their empirical findings are mixed, suggesting that the coexistence of humans and algorithms in trading remains poorly understood.

Understanding automation, we argue, calls for expanding our analytical purview beyond finance and economic sociology and into the literature on technology in organizations (Barley 1986, Orlikowski 1992, 2000, Orlikowski and Scott 2008, Leonardi and Barley 2010). Because technology, this literature argues, simultaneously enables and constraints practices, the introduction of new technology can trigger the emergence of practices associated with new roles, leading to changes in social order. In this regard a key debate concerns the impact of technology on existing social relations. Proponents of the "complementarity thesis" argue that technology introduction can reinforce social ties and preserve the social order (Bensaou 1997, Grover, Teng, and Fiedler 2002, Kraut, Steinfeld, Chan, Butler and Hoag 1999) but others have countered that automation hampers interaction between intermediaries and market participants, leading to arms-length relations, disembeddedness and loss of human capital (Schultze and Orlikowski 2004, Malone et al. 1987). Complementarity thus provides a lens to explore the effects of automation; other relevant perspectives include Zuboff's (1988) view of automation as the textualization of organizational activity, and the ongoing debate between the practice-based (Orlikowski 2000; Boudreau and Robey, 2005; Feldman and Orlikowski, 2011) and alignment perspectives (Leonardi and Barley 2010) over the nature of agency in technological emergence.

Our study examines the effects of market automation by turning to the New York Stock Exchange (henceforth NYSE or "the Exchange"). Founded in 1792, the Exchange is known for its iconic trading floor and a "specialist system" whereby the execution of transactions is organized by floor intermediaries such as specialists and floor brokers. The floor of the Exchange remained vibrant through the early 2000s, well after rival exchanges in London and Paris closed theirs. But in 2006 the Exchange faced a regulatory mandate to automate by the SEC and in response the management of the NYSE sought to introduce automation while preserving its trading floor. Its first attempt to do so was largely unsuccessful, leading to a sharp drop in market share, but a second attempt in 2008 resulted in

a stable market share and allowed for the economic survival of the floor intermediaries. We conducted a longitudinal qualitative study of the NYSE to examine the process and design by which the NYSE's incorporated automation while keeping its floor intermediaries.

Based on our analysis we propose the concept of "blended automation" to denote an automation design that preserves key aspects of a market's original social structure, along with the positive properties associated with it. Blended automation is premised on two design principles: duplication (e.g., having both a data center and a trading floor), and exceptionality (confining manual trading to crises and the market open and close). It operates through a mechanism of adjustment to environmental complexity, and it emerges from contestation between various groups, a rebalancing of power, and knowledge sharing.

Our analysis of the Flash Crash of 2010 lends support to the concept of blended automation. The Crash not only entailed unprecedented volatility but also led to inexplicable prices, whereby companies like Procter & Gamble and Accenture traded as low as a penny or as high as $100,000. Such was the extent of the price dislocation that the SEC decided to "break" or cancel all trades outside a 20 percent band above and below the prevailing price twenty minutes before the Crash, declaring thousands of trades "clearly erroneous." We use these broken trades to compare the relative performance of floor-based automated exchanges like the NYSE versus floor-less exchanges like NASDAQ, and others. We find that while these floorless rivals had to undo more than 15,000 trades after the crash, the trading floor of the NYSE did not have to break a single one (Kissane 2010, CFTC/ SEC 2010b). Our analysis also confirmed that the outperformance was due to the floor intermediary's ability to engage in sensemaking and norm enforcement.

Our study offers several contributions to the literature. First, blended automation extends the complementarity thesis in the technology literature (Bensaou 1997, Grover et al. 2002, Kraut et al 1999), providing two design principles that reconcile automation with frequent and meaningful face to face interaction. Second, blended automation enriches Zuboff's (1988) analysis by exploring how the problems induced by automation can be prevented by preserving part of the original human actors and roles. Third, our study adds to

the alignment perspective advanced by Leonardi and Barley (2010) by illustrating the political dimension of market automation.

Second, our study contributes to economic sociology by speaking to the effects of market automation on the social nature of markets. It show that automation need not mean the elimination of the floor intermediary, and that instead a blended automation design is compatible with floor intermediaries and their roles. Such design preserves the positive properties traditionally identified with the intermediary by Baker (1984) and Abolafia (1996) such as resilience to external shocks like the Flash Crash.

AUTOMATING THE FLOOR INTERMEDIARY

How does automation reshape markets? Financial automation typically entails the replacement of floor intermediaries with so-called "matching engines" that rely on algorithms to pair off buy and sell orders (MacKenzie and Pardo-Guerra 2014). Proponents of automation see algorithms as fairer and more efficient than floor-based exchanges, as they eliminate costly and conflicted floor intermediaries. For instance, a recent study by Hendershott, Jones, and Menkveld (2011) found that the introduction of automation reduced transaction costs as measured by the bid-ask spread. But following the Flash Crash of 2010, a growing number of critics have focused on the activities of dark pools (Patterson 2012) and high-frequency trading (Lewis 2014), portraying financial automation as more unequal, crash prone and opaque than floor-based trading (Saluzzi and Arnuk 2012). In advancing the debate, our study seeks to move past empirical comparisons of transaction costs before and after automation, turning instead to the structural changes induced by automation.

Understanding such changes calls for a firm grasp of the original role of the floor intermediary, as well as the various activities it performed. Indeed, such was the importance of intermediaries that some exchanges like the NYSE were characterized as having a "specialist system". According to Saar (2010: 1425), a specialist market is "a hybrid market structure that includes an auction component (e.g., a floor auction or a limit order book) together with one or more designated market makers ('specialists') who trade as dealers for their own account. The designated market makers have some responsibility for the market."

Saar thus points to three aspects of a specialist market: social roles (specialist and broker); a practice or routine (the call auction); and a material setup, primarily the trading floor. Automation, in other words, has to be understood as an intervention on a social system.

In grasping the workings of such system, we draw on a rich sociological literature on market intermediaries that harks back to the notion of third-party mediation formulated by Simmel (1902/ 1950). Simmel's third party profits from exploiting the disunion of the other two, as elaborated in Burt's (1992) concept of brokerage. Alternatively, this third party can profit from moderating the forces that divide the group, as formalized by Baker (1984), Khurana (2002), and Obstfeld (2005). This structuralist approach has been complemented by ethnographies that explored the institutional, material and embodied aspects of trading floors (Abolafia 1996, Zaloom 2003, Pitluck 2011). Taken together, these studies suggest that floor intermediaries are central to make markets viable, especially when economic activity is threatened by opportunism and uncertainty (Baker 1984). Floor intermediaries provide matching (Khurana 2002, Abolafia 1996), sensemaking (Zaloom 2003, Pitluck 2011) and norm enforcement (Baker 1984, Abolafia 1996). We consider these below.

Matching. One key contribution of intermediaries is to facilitate exchange by matching the transacting parties. The theoretical mechanisms are particularly clear in Khurana's (2002) study of a different form of intermediary, executive recruitment firms (i.e., headhunters). Such firms facilitate the match between buyer and seller by mobilizing their contacts, thus expanding the array of potential trading partners. Such matching activity extends to the task of mitigating the uncertainties entailed in the transaction often by pacing the rhythm at which the parties interact by dictating a schedule and offering resources to help the transaction take place. Ethnographies of trading floors have identified how brokers and market makers accomplish these functions. Abolafia (1996), for instance, underscored the role of NYSE specialists in matching buyers and sellers, and in buffering imbalances in demand and supply.

Sensemaking. A second contribution of the floor intermediary is to provide sensemaking. Given the volatility of stock prices (Baker 1984) and the need to interpret

ambiguous news (Abolafia 1996) market actors need to give meaning to orders and prices. The literature documents two ways in which this happens. First, by participating in call auctions at the post, market makers and floor brokers provide each other with social cues that reveal their motives or interpretations: As Zaloom (2003: 263) documents, an order conveyed with a fearful voice elicits a different response than one with confidence. Second, floor intermediaries frame market developments by drawing on their knowledge of historical prices and the trading book (Abolafia 1996), an activity known as providing "market color." As microstructure economists have established, such framing is important to forestall the risk of adverse selection: because a customer agreeing to trade at a given price may be doing so because he or she knows something that the other side does not, posing a risk for the latter (Glosten and Milgrom 1985). Such adverse-selection (or "lemons") problem can discourage transactions, drying up liquidity. But as the ethnographic work of Pitluck (2011) demonstrated, floor intermediaries can address this problem by framing, typically through the partial disclosure of the identity of the seller. Partial identification gives meaning to the seller's actions, eliminating the buyer's suspicions of adverse selection while protecting the seller's identity.

Norm enforcement. The literature has discussed a third activity performed by floor intermediaries, namely, enforcing norms and limiting opportunism. For instance, Baker (1984) showed how market makers enforce norms such as not selling while prices are falling. They do so by "freezing out" opportunistic colleagues from trading (Baker 1984: 782). Norm enforcement has also been identified as one of the specialist's functions at the NYSE (Abolafia 1996). Over the years, Abolafia found, the Exchange instituted formal controls over its specialists, including "affirmative" and "negative" obligations of legal nature, an embryonic computerized auction (discussed below), and an internal bureaucracy that awarded new listings to compliant specialists. These formal means of control were reinforced by an informal culture of "rule veneration" (Abolafia 1996) whereby the Exchange's rulebook was repeatedly cited, known and followed by actors on the floor.

***Intermediary opportunism*.** While floor intermediaries reduce opportunism, they can also abuse their own position and exhibit the same opportunism they were meant to limit in the first place. This is consistent with the general tendency of the intermediary, discussed by Burt (1992), to exploit his or her structural advantage. In the context of trading floors, the risk of opportunism is echoed in Abolafia's (1996: 105) analysis of the NYSE prior to the reforms of the 1960s: "in the 1920s," he explains, "specialists aided and abetted 'bear raids' and manipulated their stocks" (see also Brooks 1969, Sobel 1975). Thus, while floor intermediaries aim at limiting opportunism they can also generate their own form of abuse.

Taken together, existing studies in economic sociology illuminate the multiple functions of floor intermediaries but have not considered how automation might transform these functions. A more recent literature in the social studies of finance has begun to address this question (Zaloom 2007, Barrett and Scott 2004, Muniesa 2004, Pardo-Guerra 2010, MacKenzie and Pardo-Guerra 2014), but its empirical findings are nevertheless mixed. For instance, while Knorr Cetina and Bruegger (2002) argue that the shift to electronic trading need not hamper the intermediaries' ability to relate and enforce norms, Zaloom (2007) and Pardo-Guerra (2010) contend that technology makes manual trading less effective. Knorr Cetina and Preda (2007) go even further, arguing that technology has replaced social networks as the organizing device of the capital markets. In light of this unresolved debate, we turn to the literature on information technology in organizations for its analysis of automation in general.

Automation and the floor intermediary

Scholars of technology in organizations have long debated the effects of new technology on social relations. The key intellectual building blocks were arguably laid out by Malone et al. (1987), who identified an "electronic brokerage effect" whereby the electronic representation of potential commercial partners reduces search costs and make intermediaries such as brokers unnecessary. The brokerage effect provides an initial framework to explore the effect of financial automation on social structure.

Complementarity. A number of authors have drawn on the above to empirically document the complementarity between social relations and information technology. Bensaou (1997) found that the introduction of information technology in car manufacturers reduced physical, spatial and temporal limitations to effective cooperation with suppliers, as it increased the manufacturers' ability to process the informational needs that arose from outsourcing. Grover et al. (2002) found that information technology reduced task uncertainty by automating and integrating organizational transactions, lowering opportunism and freeing up space for more personal communication and thus contributing to closer social bonds (see also Kraut et al. 1999, Holland and Lockett 1997). The findings of these scholars are consistent with those of sociologists of finance such as Knorr Cetina and Bruegger (2002), who found that negotiation with counterparties through a terminal screen is as effective as over the telephone (see also Muniesa 2004).

Displacement. By contrast, detractors of the complementarity thesis contend that technology weakens and displaces social relations. Schultze and Orlikowski's (2004) study of web-based service automation highlights how a company's use of a self-serve technology made it more difficult for its sales representatives to maintain social relations with their customers as it undermined their ability to provide consulting services, reduced the frequency of their interaction, and prompted sales reps to spend social capital to promote customers' technology adoption (Schultze and Orlikowski 2004). Their findings are consistent with those of sociologists of finance who saw incompatibility between automation and social relations. Zaloom (2007) found that the use of handheld devices on the trading floor silenced the social cues encoded in the floor brokers' voices, reducing their ability to engage in sensemaking. Knorr Cetina and Preda (2007) argued that the introduction of electronic displays led to a shift in the "organizing device" of the market, from the social networks of the traders to the electronic representation on the trading terminal, leading to what they called a "scopic market." Following the complementarity versus displacement debate we ask: how did automation impact face-to-face interactions on the floor of the NYSE?

Contingency. Subsequent studies added to the complementarity debate by emphasizing the contingent effects of technology on organizations. The introduction of technology, Robey and Boudreau (1999) argued, can weaken as well as reinforce the status quo, and needs to be understood as the outcome of multiple forces pushing in different directions. Zuboff (1988) added that technology's ability to change the social order depends on the state of knowledge, authority and technology in the organization: automation, she showed, differs from other forms of technology introduction in that it amounts to the comprehensive "textualization" of organizational activity. The resulting electronic text can only prompt fundamental change (a process she denotes as "informate") when users are able to expand the scope of their jobs to include symbolic manipulation, and such expansion is not frustrated by their managers' self-interest. Orlikowski (2000) and Boudreau and Robey (2005) report consistent findings. The case of the NYSE poses the reverse problem to that examined by this literature: instead of change, the challenge of technology-induced permanence. We ask, how did the relative power, knowledge and authority of the various actors at the NYSE enable an automation design that preserved features of the original structure?

Agency. A related debate entails the nature of agency within technological emergence. Following Orlikowski's (2000) articulation of a practice-based lens, scholars have emphasized the enacted, situated and improvised nature of technological structuring. In the context of the NYSE, this approach calls for exploring how different floor brokers and specialists automated their day-to-day activities. In contrast, Leonardi and Barley (2010) have cautioned against an excessive focus on micro level interactions and enactment, arguing instead for an emphasis on power, contestation and macro level institutions. Their approach would call for the study of the interest groups involved in the automation of the NYSE. That is: which key actors took part in decisions over the automation at the NYSE? Which beliefs and ideologies were at play, and how were the controversies between them resolved?

RESEARCH METHODS

Research Site

To address the above, we conducted an inductive, qualitative study of the automation of the NYSE during the period 2003-12. While our research design is primarily ethnographic, it departs in various ways from the canonical single-site, single-period study. It relies on a core set of ethnographic observations on the floor of the NYSE during 2008-10 but complements these with other data points. These include observations of the floor in 2003, oral history interviews of actors at the NYSE during 2008-10, interviews outside the NYSE in the field of securities trading during the same time period, the outcome of the Flash Crash of 2010, and follow-up interviews at the Exchange in 2011-13. We discuss these below.

Data sources

Fieldwork and interviews at the NYSE, 2008-10. Our primary data entails ethnographic observations and interviews at the NYSE during 2008-2010. By the beginning of this period, the regulatory mandate to automate order matching had already been enacted and the Exchange was well down the path of automation. Between 2008 and 2010 we made 29 visits to the NYSE, interviewed 19 officials, including its Chairman, top management team and several floor governors. We also conducted detailed observations of the floor booths of two brokers, and the post of a specialist firm. In these, we interviewed the designated market makers and floor brokers responsible for these booths, as well as the clerks that worked with them. In addition we also observed two regular market openings, one market closing, and one mid-day special situation during the record-volume stock-rebalancing auction of Citibank (see Tables 1 and 2).

Observations in 2003. We first visited the Exchange in June 2003. We observed the work of a specialist, a floor broker, a research official and a compliance officer, witnessed a ringing of the bell ceremony, and conducted observations on the trading floor and at the Luncheon Club. These provided us with a window into a world that would subsequently disappear, and gave us grounds to compare the Exchange before and after automation.

Follow-up after 2010. Our data extends beyond 2010. Between 2011 and 2013 we conducted ten follow-up interviews in person at the NYSE, as well as two telephone interviews. These allowed us to gauge the response of the Exchange to the Flash Crash. More importantly, by returning to the same group of actors at the NYSE over a period of 8 years, we gained a longitudinal perspective that allowed us to capture the different dimensions of the change undergone by the Exchange (Benner and Tushman 2002, Katila and Ahuja 2002).

Interviews outside the NYSE. We complemented our ethnographic data with interviews of industry participants and scholars of market microstructure during 2008-12. This contextualization was important in light of the regulatory impetus that forced the Exchange to automate: interviewing actors outside the NYSE gave us both sides of the debate over market microstructure, rather than just the Exchange's (Fligstein 2010). As Table 1 shows, the interviews with NYSE outsiders included the President and Chief Executive Officer of the International Stock Exchange, the Chairman and one specialist at the American Stock Exchange, as well as two officials at the NASDAQ, one at BATS, one at Goldman Sachs, one of the founder of Instinet, one at an automated trading firm, and one at a brokerage firm. Beyond practitioners, our interviewees included the Chief Economist at the SEC during the period when automation was mandated, as well as his successor. Finally, we interviewed three industry consultants and two academic specialists in market microstructure. This rich set of sources gave us insight into the controversy over the regulation of stock exchanges that shaped the automation of the NYSE.

-- Insert Tables 1 and 2 here --

Analysis

We employed several analytical strategies to build theory from the case. Following Agar (1986) we started by identifying breakdowns in our initial conception of the phenomenon, and reconceptualized our thinking around them. Our primary breakdown was clear: given the well-documented benefits of social interaction whilst trading (Beunza and Stark 2004), why was the Exchange giving up on its floor? The resolution of this puzzle sensitized us to the political nature of financial automation. We also relied on grounded

theory (Glaser and Strauss 1967): for instance, comparing the practices at the NYSE before automation in 2003 with those after the second automation phase in 2008-10 allowed us to gauge the extent to which the original intermediary functions were preserved, and the key mechanisms.

Finally we make use of the Flash Crash of 2010 to ascertain the effectiveness of floor intermediaries in an automated exchange. The Flash Crash impacted stocks that were traded in all four American equities exchanges in 2010 (NYSE, NASDAQ, BATS, and DirectEdge), but not all exchanges were equally hit. By studying the relative incidence of these broken trades we gained insight into the relative effectiveness of floorless versus floor-based automated exchanges. Second, by reconstructing the actions of the floor intermediaries through interviews immediately after the Flash Crash we were able to ascertain the mechanisms behind the superior performance of a floor-based automated exchange like the NYSE.

AUTOMATING THE NEW YORK STOCK EXCHANGE

2003: The NYSE before automation

It did not take long for us to witness the social nature of the NYSE. We first entered the floor of the Exchange at 9:25 am on the morning of May 23, 2003, invited by an Exchange official. Looking up from the floor, we saw its Chairman standing on a podium and surrounded by a mixed troupe constituted by high-ranking military officers and Miss America dressed in full Beauty Queen costume -- including bathing suit, crown and band. As the countdown to the ringing of the bell began, the brokers on the floor began clapping. At exactly 9:30 am the bell clanged, and a raft of camera flashes immortalized the moment. After the bell, a loudspeaker invited everyone to join in as Miss America sang the national anthem to commemorate Memorial Day.

With the exception of the anthem, such elaborate market openings were (and to this date still are) performed daily at the NYSE. This ceremony was revamped in 1995 in response to a technology-themed advertisement campaign by the NASDAQ. By inviting celebrities to ring the bell and giving television stations access to the floor of the Exchange, its Chairman

created an event that could be broadcast live, in stark contrast to NASDAQ's impersonal electronics. The strategy proved successful and by 2003 the Exchange had 55 international television networks broadcasting live from its floor (Gasparino 2007). Social interaction, we understood on our very first visit to the Exchange, was not just a means to conduct transactions but part of its brand and identity.

The floor of the NYSE, we quickly learnt, rested on a social division of labor between specialists and floor brokers, known as the "specialist system." In it, so-called specialists acted as both principals and agents on "designated" stocks. That is, instead of relying on competing market makers to provide the best price, the NYSE assigned stocks to individual market makers who were for that reason known as specialists. As principals, specialists were expected to "make a market," that is act as counterpart to buyers and sellers; as agents, specialists were expected to hold call auctions to price the shares. The second group of actors within the specialist system of the NYSE entailed the floor brokers, who handled clients' orders. This division of labor between specialists and brokers extended to the physical location of these two groups: specialists stood at their trading post in the center of the floor, and brokers took clients' orders from vertical telephone booths in the periphery of the floor, placing those orders by walking to the specialists' post. Specialists wore sober suits, while clerks and brokers dressed in colorful jackets. Seen from above, the Exchange looked like many other markets: a chaotic combination of a few individuals standing still, surrounded by others walking between them.

How did such system facilitate trading? We pursued this question with ethnographic observations and interviews. We started at the post of a specialist company, where pseudonymous Ryan served as specialist on a panel of several international companies. Ryan gave us the first clues into the nature of the specialist's job, confirming the importance of the three mechanisms discussed above: matching, sensemaking and norm enforcement.

Matching. Ryan matched buyers and sellers by conducting call auctions at his post at designated times, with a clerk behind him typing the prices he dictated on a computer terminal known as the Display Book. In doing so, Ryan established the price at which demand

and supply equilibrated, an activity that the Exchange denoted "price discovery." These were *call* auctions in that they batched all the orders before setting a price, "pouring orders like water on a swimming pool," as another specialist explained to us. The call auction thus processed the orders of all brokers at the same time, preventing the proverbial rush to the fire exit and ensuring that small orders get the same price as large ones. For this reason, floor participants typically saw themselves in conflict with Wall Street banks, which could not use their greater size to gain a price advantage.

As we soon found out, there was a key personal component to conducting call auctions. A former specialist explained to us how a call auction had elements of crowd control:

> Let's say you are a seller for 200,000; you are a seller for 200,000; you are a seller for 200,000. I'm a specialist, I come in and say 'Calm down, all right, just everybody calm down, what do you have to do? [moving his head left] What do you have to do? [moving right] What do you have to do?' Ok the market right now is $20 bid for 100 shares and a million shares offered at $21' you show it on the screen. 'Ok what do you want to do? You want to sell 100 shares now at the dollar? Ok now you sold 100 shares, now the market is $19 for 100 shares, do you want to sell another 100 shares?' 'Ok let's calm down, let's see if we can find some buyers, let's see what happens at various prices, let's talk this thing out, let's do business'.

The quotation suggests that price discovery is a form of economic intervention, smoothing prices by managing the anxieties of floor brokers who compete for attention. Such pacing of the rhythm resulted in "slowing the transacting, preserving the flow," as another specialist explained.

The role of time, we realized, was particularly important in trading because liquidity is a temporal variable. Liquidity denotes the availability of counterparts during a given time interval. Batching orders, as the specialists did in their call auctions, extended the length of time used for matching and increased the likelihood of finding a counterparty. In this sense, the task of the specialists was similar to the work of the headhunters analyzed by Khurana (2002): by managing the speed of the interaction between buyer and seller, both headhunters and specialists ensured that the rhythm of activity was not destructive to the successful completion of the transaction. As we discuss below, in their efforts at pacing the specialists

went as far as to routinely freeze an automated auction system used by the Exchange for small orders, which run in parallel to the call auctions.

The specialists' role also included market making, that is, dealing in stock for their own proprietary account to limit volatility. Specialists, Ryan explained, were "like shock absorbers," compensating the pressures of supply and demand to make prices more stable. This contributed to fulfill one of their "affirmative obligations" included in their formal job description, namely to keep a "fair and orderly market." To do this Ryan relied on the information he had about the upcoming orders in the book. The temptation to use this information to sell ahead of a client's order (to "front-run" the customer) was partly limited by the existence of "negative obligations."

Sensemaking. Our observations also pointed to the importance of sensemaking. This took place in several forms. First and as Zaloom (2003) discussed, the act of buying and selling generated social cues: floor participants bought, sold, joked, walked around, shouted information at each other, etc, producing cues for others in the process of doing their job. Second, over time specialists had become adept at framing ongoing events. The arrival of CNBC and other television stations to the floor meant that specialists were interviewed daily, leading them to develop a skill in producing sound bites for the camera that explained the evolution of prices. Third, we also observed the partial disclosure of the orders in the book to help potential buyers address the problem of adverse selection.

We first saw partial disclosure when a broker called Stefano (pseudonymous) walked up to Ryan's post. "Stefano and I," he said, touching Stefano's shoulder in appreciation, "worked together fifteen years ago." The visit was not a courtesy call however: "still here snooping?" asked another broker when Stefano arrived. Stefano, it turned out, had a large buy order. Instead of simply handing it over to Ryan, he told him about it first. "I think it's a little heavy," Ryan replied, suggesting that there were many other buy orders at that time and that Stefano might want to come back later. This partial disclosure of the book enabled Stefano to better time his order. The practice, known as "giving looks," allowed specialists to elicit orders without compromising the positions of the existing ones. We observed this yet again as

we followed another floor broker from one specialist post to another. When he approached a specialist with a question, the answer was revealing but somewhat diffuse: "stock's hanging in there, lots of machine buying, Morgan's a seller, Merrill has an interest."

In subsequent interviews with industry consultants we learnt just how elaborate and important giving looks was. Looks were crucial for matching large blocks of shares, where the problem of adverse selection is most acute. In large blocks, investors avoid disclosing the size of their position for fear of showing their hand and influencing the price. But as we learnt from a microstructure consultant, some disclosure is inevitable to find a counterparty: given the adversarial nature of transacting, one side cannot interest the other without disclosing something about the size and nature of the block. As this consultant wrote in a trade journal, even a minimal disclosure exposes the actor to opportunism: "it is impossible to draw a black and white distinction between seeking liquidity and violating confidentiality (…) The market maker cannot accelerate liquidity arrival without revealing trading interest" (Wagner 2004: 5). Matching large orders, in other words, is fraught with risk, and calls for a high level of trust among trading partners. The NYSE specialist was a figure that could be trusted to tap into the latent demand for blocks of shares held by institutional investors through partial disclosure (Wunsch 2011). We see partial disclosure as a form of sensemaking in that it was not only about providing information about orders, but about helping investors interpret those orders in a way that was not disruptive. In sum, sensemaking at the NYSE took place through giving looks on the part of the specialists, and was particularly important for large blocks of shares.

Norm enforcement. We gained insight into the Exchange's norm enforcement mechanisms from Ryan over breakfast at the NYSE's Luncheon Club. Conflicts, he explained, were managed on the floor through a combined mechanism of formal rules and informal norms. The formal ones included the figure of the Floor Governor, appointed by the Exchange. The Exchange also controlled a formal system to allocate new listings that rewarded the specialists who followed the norms. Ryan provided us with various examples of

how self-interest was kept in check even in the absence of competition among specialists for the same stock. Referring to one particular instance, he said:

> The Governor said to me, 'Ryan, that was a good trade.' I lost money on twelve consecutive orders, and then made money on the last one. But all got the same price.

In other words, specialists were characterized by restraint as much as by eagerness to profit – an argument made by Abolafia (1996).

While formal rules were a key means of norm enforcement, informal norms were equally important. As we followed one of the floor brokers mentioned above from one post to the next we also noticed how he addressed, backslapped and saluted with nicknames the people he met on his way. Everyone on the floor was Johnny, Jimmy or Bobby; there were no Johns, James or Roberts. Indeed, actors exhibited a remarkable ability to make a quick joke that acknowledged the presence of the other without being formulaic. Interactions were humorous, fast, witty and casual. Such penchant for banter is consistent with Baker's findings (1984) on the importance of network cohesiveness in forestalling opportunism and bringing about an orderly market.

In sum, our observations at the NYSE in 2003 suggest that floor intermediaries at the Exchange were fulfilling the three functions discussed by the sociological literature: by holding call auctions, giving looks, matching blocks, respecting obligations, and living up to informal norms, the specialists and brokers effectively performed matching, sensemaking and norm enforcement. At the time, the NYSE ruled the American equities market with a market share above eighty percent, and nothing suggested that this state of affairs would change. But as we explain below, the following four years brought dramatic upheaval to the NYSE.

2004-08: Algorithms vs. floor intermediaries

Starting in 2003, a number of changes in regulation and technology combined to weaken the NYSE specialist and create an algorithm-based approach to trading that put an end to the dominance of the NYSE. These were part a long-running and sometimes acrimonious struggle between floor-based exchanges like the NYSE and the proponents of electronic trading, including the SEC, Wall Street banks and technological entrepreneurs. In

this section we detail this struggle, and explore how it played out in a sequence of legal and regulatory events that culminated in the obligatory automation of the NYSE.

The struggle over the specialist system, we discovered from our interviews, entailed two competing conceptions of the market. Floor participants at the NYSE espoused a conception of markets as socially mediated, not unlike that of economic sociologists (Baker 1984, Abolafia 1996, Zaloom 2003, Pitluck 2011). According to floor participants, stock exchanges were an organizing device to ensure a fair and orderly market; and stock prices were the outcome of a social process (the call auction) that was shaped by the collaboration between specialists and floor brokers, as well as their internal organization (the specialist system).

In contrast, the SEC and other detractors of the specialist system held a conception of trading as information processing, of exchanges as a form of database, and of social relations on the trading floor as suspect and problematic. According to Muniesa (2007), this view can be traced back to the economic vision first formulated by Black (1971). The renowned economist pioneered the computerization of libraries and hospitals as a consultant for Arthur D. Little (Mehrling 2011), went on to advocate the automation of the NYSE. At the heart of Black's (1971) proposal laid a vision of trading as information processing, and of exchanges as self-organized books of orders, namely, as databases. For instance, Black did not see a need for specialists to limit price volatility because in an efficient market stock prices are supposed to follow a random walk. Four decades later, these ideas served as inspiration for the SEC and can be found in the thinking of Lawrence Harris, Chief Economist of the SEC at the time when key regulation was put in place. In Harris' view, "trading is essentially an information problem when sellers are looking for buyers … were it not for some difficulties concerning order exposure, this would just be a database problem" (Harris interview).

The controversy between the proponents and detractors of the specialist system played out in three different episodes that contributed to the emergence of algorithmic trading. We consider them below.

Grasso's resignation. The first such episode was the forced resignation of the Chairman of the Exchange, Richard Grasso, over his compensation in July 2003. At the time, the board of the NYSE granted Grasso a combined retirement and compensation package of $190 million. This prompted widespread media outcry and led to his resignation. The resignation, however, did not draw a line under the crisis and in May 2004 the SEC and New York State's then-Attorney General Eliot Spitzer submitted a civil lawsuit accusing Grasso and other board members of manipulating the NYSE board. In October 2006 the New York Supreme Court ordered Grasso to repay the NYSE part of the compensation package. However, this ruling was reversed in 2008 following an appeal.

The Grasso affair points to the political dimension of the struggle over the specialist system. In our interviews we consistently found divided opinions, demarcated alongside professional lines: regulators and finance academics took the resignation to be a sign of cronyism at the NYSE, while floor participants at the Exchange took it to be illustrative of the SEC's animosity towards the NYSE, and symptomatic of the efforts by Wall Street banks to do away with the NYSE floor intermediaries (who ensured that both large and small orders got the same price) and gain control of the market. The resignation by Grasso left the other proponents of the floor without a key political ally, paving the way to automation.

The specialists' lawsuit. The second episode in the controversy took place shortly after Grasso's resignation. In 2003, the SEC sued a number of NYSE specialists for neglecting their obligations, accusing them of inter-positioning (unnecessarily placing of an order at a price between current bids and offers), front running (trading ahead of a client's order), as well as of freezing the Display Book. Following an internal investigation, in October 2003 the NYSE imposed a fine of $150 million on five of the seven specialist firms for "habitual abuse" of their market roles (Colesanti 2008). The specialist firms took on a reputational loss and agreed to pay $240 million to settle with the Exchange, but the SEC persisted with the case separately. In 2006, however, a judge reversed the conviction of leading specialists in the SEC court case (Colesanti 2008).

The specialist lawsuit illustrates the technical nature of the controversy. One of the three key charges against the specialists was that they habitually stopped, or "froze," the Display Book they used for the automated matching of small orders (i.e., of less than 1000 shares). When asked about the freezing, however, the specialists gave us a different perspective: this was not done to take advantage of the electronic customers, but to stop the price movements and be able to complete the call auction. It was impossible, they added, to have a call auction while prices kept moving, for the point of such auction design is to elicit all orders *before* adjusting the price. The problems around the small-order matching engine are thus a prime example of the technical difficulty in reconciling manual and automated practices. As we shall see below, the mandated automation of the NYSE in 2007 introduced similar problems.

The lawsuits against Grasso and the specialists prompted change in the NYSE's top management. In 2003 the Board of the NYSE appointed a new interim Chairman, John Reed, who was a noted proponent of technology and known for pioneering the use of automated teller machines as CEO of Citibank. At the Exchange, Reed introduced a new governance structure and led a permanent CEO search, culminating in 2004 with the appointment of another technology proponent, John Thain from Goldman Sachs (Gasparino 2007).

Regulation National Market System. The third episode in the controversy was the enactment of regulation that imposed automation on the NYSE. In 2005 the US Congress enacted Regulation National Market System (so-called "Regulation NMS"), using automation to advance a form of managed competition among exchanges that the SEC had promoted since the late 1960s. The approved system, known as the National Market System, connected the various American exchanges via order routers, directing incoming orders to the exchange with the best price. The NYSE was initially excluded from the requirement to connect to the system owing to the slower speed of its manual call auction. But Chief Economist Lawrence Harris persuaded the SEC to oppose NYSE's exception on the grounds that it gave specialists an unfair advantage. Regulation NMS thus required the disclosure of prices and immediate tradability of assets in all the exchanges of the National System, including the NYSE. This

would force the Exchange to respond to any incoming order within a second, starting in 2007. Because the humans on the floor could take up to 30 seconds to hold a call auction, the NYSE found itself in urgent need to accommodate automated trading.

Algorithms. Regulation NMS came in the wake of several technological developments that made the new regulation effective. These developments went back to the founding of the first algorithmic share-trading venue in 1996, Island Inc, by an online trading entrepreneur (MacKenzie and Pardo-Guerra 2014). Island algorithmically matched and executed the orders sent by clients internally, and came to be known as an "electronic communication network" (ECN). The company delegated the pricing of stocks to an algorithm, doing away with the market maker's prerogative to set prices. This was done through a matching engine that paired orders using explicit rules like "price-time priority," making it impossible for any seller to arbitrarily favor one buyer over another (MacKenzie 2012). The number of ECNs soon grew to include several companies.

The dominance of ECNs increased further with the rise of new and inexpensive automated exchanges like BATS Exchange and Direct Edge in the 2000s. These relied on ECN technology, and were run as consortia for the benefit of their owners/ customers, which included Wall Street banks like Goldman Sachs or JP Morgan. Partly for this reason, the new exchanges offered low prices at the expense of profitability, and quickly took market share away from the NYSE. Another reason for their success was the controversial payment of rebates to participants who posted limit orders in them (Saluzzi and Arnuk 2012).

Automation was further developed by the rise of so-called dark pools, that is, electronic trading venues that specialized in confidentially matching buy and sell orders. Because customer orders in a dark pool were matched internally and prices were only displayed after a trade had been executed, these venues allowed fund managers to trade large blocks of shares without creating price movements against them (Patterson 2012). In contrast to ECNs, which were premised on making trading more transparent than the NYSE, dark pools competed with the NYSE in partial form of disclosure, offering a valuable complement to ECNs. Dark pools quickly became a lucrative business, and banks like such as Goldman

Sachs or Credit Suisse developed large operations that attracted large blocks of shares that ECNs could not easily match. But dark pools proved controversial because they do not produce live prices that can inform investors, potentially hindering the informational function of public capital markets (Saluzzi and Arnuk 2012).

The trend towards automation was also reinforced by the development of technology for algorithmic order execution at large institutional funds such as Fidelity. These systems "sliced," or broke up, large orders into small parts to minimize price impact, automating the work that a sales trader would normally do. Best known among them was the so-called VWAP, or "Volume-Weighted Average Price" algorithms. These sought to replicate the human ability to "work" a large order without impacting the price. Execution algorithms facilitated the use of ECNs by providing investors with a mechanism to handle large orders, eroding the dominance of the NYSE's matching capacity. As we shall see below, execution algorithms also played a central role in the Flash Crash of 2010.

Finally, automation was advanced by the rise of so-called "high frequency trading" firms. These firms made algorithms a central part of their trading *strategy* (as opposed to just part of their execution), and typically involved electronic market making, that is, they provided liquidity by posting limit orders that others execute against, thereby replacing the traditional stabilizing role played by NYSE specialists (MacKenzie, Beunza, Millo and Pardo-Guerra 2011). They were not, however, subject to any of the obligations that the specialists were: for instance, they did not have to participate to ensure that prices moved smoothly. High frequency trading was conducted by large hedge funds such as Chicago-based Citadel, as well as by specialist firms like Chicago-based GETCO (Global Electronic Trading Co.), Kansas City-based Tradebot, and Amsterdam-based Optiver. High frequency traders subsequently became noted for their contribution to the Flash Crash of 2010. More recently, Lewis (2014) has argued that some HFT companies profited by creating an unequal market in which they were able to see orders before others.

Taken together, the combination of new regulation (Regulation NMS), automated exchanges (ECNs), confidential trading venues (dark pools), algorithmic ways to replicate

sales traders (algorithmic execution), and automated trading strategies (high frequency traders) created an alternative pathway for stocks to be traded. Traditionally, an investor wanting to buy shares in say IBM would call her brokerage firm and this broker would relay the order to its floor broker, who would walk to the specialist post at the NYSE and place the order or work it slowly if it was large. By 2007, an investor (even one holding a large block of shares) had a range of algorithmic alternatives, none of which included the NYSE.

The politics of market automation. In sum, the first half of the decade of the 2000s was marked by struggle between two rival conceptions of markets (Fligstein 1993). This not only entailed competing visions for stock exchanges, but also the technologies that made those visions possible. But most importantly, the struggle was shaped by regulatory coercion that imposed the SEC's vision: the NYSE, our informants made clear, did not automate because of the availability of fast and inexpensive matching algorithms as a technologically deterministic view might hold, but did so out of legal imperative. This observation underscores the political nature of technology emergence (Leonardi and Barley 2010) whereby the day-to-day practices of the actors can be radically altered by actors that differ from those engaged in such daily practice. Indeed, the case goes beyond organizations in that automation was shaped by societal-level dynamics, as it was prompted by the SEC's decision. In that regard it suggests that automation and technology are a key avenue whereby the markets are political (Fligstein 1996).

2006-10 The automation of the NYSE

The passage of Regulation NMS in 2005 forced the Exchange to automate its order matching procedures over the course of 2006, adopting algorithms to respond to incoming orders in less than a second. In doing so, its Chief Executive John Thain opted for a unique strategy: instead of replacing the specialist system with an algorithmic order matching engine as the London Stock Exchange and Paris Bourse had done, he decided to develop and maintain *both* a matching engine and a trading floor, taking the first step towards what we denote "blended automation." We first attributed Thain's approach to the interests of self-serving specialists, but as we continued our longitudinal fieldwork we noted that this was not

a fully satisfactory explanation: by the time the decision to keep the floor was taken by Thain in October 2006, the Exchange had already stripped the specialists of much of their power. Indeed, floor participants viewed Thain with skepticism and even staged a protest in March 2006 by booing on the floor at market close (Luccheti, 2007). In this section we detail Thain's approach to automation, and explore the challenges it posed.

Starting in 2005, John Thain initiated a long march towards automation by weakening the power of specialists in various ways. He started with demutualization, buying the seats of the Exchange's members and gaining control of the board. With a greater handle on the Exchange's board, Thain diversified the Exchange's business away from floor trading and to electronic trading by acquiring an electronic communication network known as Archipelago Exchange. Thain also steered the NYSE away from low-margin US equities by merging with Euronext, a European exchange conglomerate. The combined effect of these moves shrank the economic importance of the floor to ten percent of the Exchange's overall revenue, reducing the political power as well as the economic significance of the specialists.

In this context Thain undertook the first round of automation at the NYSE, the so-called "Hybrid" system. Hybrid attempted a difficult compromise between automated and manual trading: a juxtaposition of two approaches that did, for reasons explained below, not fully cohere. The Exchange introduced order matching through an algorithm by disabling the artificial limit that constrained its previous automated system to trades smaller than 1,000 stocks. At the same time, Thain preserved the presence of the specialist at the post to give customers a choice between automatic and manual auctions. Thus, unlike the second round of automation examined below, Hybrid had algorithms and specialists operating in parallel.

Liquidity Replenishment Points. Amidst the limitations of Hybrid noted above, the system also included a pioneering feature to prevent problems with algorithmic trading that would prove successful at a later stage. Hybrid could slow the pace of trading by switching into manual trading. The feature, known as Liquidity Replenishment Points (LRPs), shifted the auction from automatic to manual when prices moved beyond a fixed threshold. This feature aimed at dampening volatility under crises by conducting a call auction at the

specialist post. Hybrid thus preserved the specialists' ability to match orders, but only during crisis. Yet despite the LRPs, Hybrid remained ineffective for the reasons noted below.

Market open and close. Hybrid retained manual auctions for the market open (before 9.30 am) and for the market close at 4:00 pm. This was possible because the legal requirement by Regulation NMS to respond to orders within a second only applied to the open market hours, that is from 9.30 am to 4:00 pm. Manual auctions allowed the specialists to begin trading a stock at the price they thought it was going to reach during the first minutes of trading, rather than that where the last buy and sell orders crossed. The point, specialists explained, was to reduce uncertainty, i.e., to prevent jumps in the prices that might upset investors. The open and close auctions also helped specialists because they could see who was bidding at various prices, and use that information to match orders. It also gave them a critical source of revenue (as high as 70 percent of their total income) and helped them preserve a routine of daily interaction that helped specialists confront interruptions of automated trading during crises, just as the military retain preparedness for war by training during peacetime.

Underperformance. It soon became clear that Hybrid was not working as expected. A basic problem was that its speed was not competitive with rival exchanges: NYSE's servers and routers took 360 milliseconds to process an order, while the competitors were in the ten-millisecond range and in some cases even less (MacKenzie and Pardo-Guerra 2014). A more fundamental problem was the incompatibility between algorithms and specialists: while algorithms matched orders in a continuous auction, specialists engaged in call auctions that made it impossible for them to interact with a continuous electronic order flow. As a former specialist explained, "the bid that you think you are matching has already been hit and it's offered there [somewhere else]". As another specialist put it, "the order walks away from you."

As a result of Hybrid the participation rates of the specialists and floor brokers, which measure the degree to which they were active in trading, fell from close to twenty percent in 2006 to nearly half that amount in 2007 (Table 4). One specialist firm even handed back its license rather than attempting to sell it, arguing that it was worth nothing. At some point, an

Exchange official recounts, “it became clear that while the operation [automation] was a success, the patient [the intermediary] was really dying.”

We observed the effects of Hybrid in person when we returned to the NYSE in February 2008. We started with a guided visit to the floor with the same official we interviewed in 2003. This time, however, the floor looked markedly emptier. “Things have been very, very difficult,” the official explained. Hybrid, the official told us, had failed to live up to its promise. The NYSE had lost the bulk of its market share, dropping from a peak of 83 percent in 2003 to 27 percent in 2009, and the specialist firms had laid off clerks and specialists to the point that three of the five trading rooms of the NYSE had closed (See Table 3).

---- Table 3 and 4 here ----

The extent of the dissatisfaction became clear to us when we met with Ryan again, the specialist we followed in 2003. We found him at the post of a different specialist firm, tall and impeccably dressed as usual. He started the conversation by volunteering his frame on daily macroeconomic events, as he was used to. “I don’t see the market coming back until financials are doing better.” But despite the semblance of business as usual, Ryan was concerned. As he spoke, we noticed a peculiar artifact resting on the top of one of his monitors: a small statue of a bull with a folded cylinder of paper protruding from behind it. The bull was labeled “Hybrid” and the cylinder read “ECNs.” When we asked about it, the clerk in Ryan’s post gave us an embarrassed look. “No, it’s ok,” Ryan said to him. And, to us: “that’s what we think is happening with the market right now. We’re getting screwed by the ECNs.” One of the specialists went on to describe problems that other NYSE officials had already highlighted: a proliferation of ECNs and dark pools had led to a system that he perceived as unfair. “Stocks are now very volatile, very thin margins. Before, it used to be everyone on an equal footing. Now, the people who have the bigger computer and the more money are winning. It’s a poor system.”

2007-10 A second attempt at automation: the Next Generation Model.

In December 2007 a change in the top management of the Exchange created an opening for reforming Hybrid, save its disappearing specialists, and remedy the NYSE's shrinking market share. Following the departure of John Thain for Merrill Lynch the Exchange appointed Thain's second-in-command Duncan Niederauer as Chief Executive. The new CEO started by investing more than $500 million in automation, building a state-of-the-art data center in Mahwah, New Jersey. This facility was to house a new matching engine for the NYSE and allow high frequency traders to co-locate their servers and gain a time advantage over other investors and allowing the Exchange benefit from their business. But while continuing to invest in technology, Niederauer also reformed the floor.

In his policy towards the trading floor, Niederauer introduced changes to Hybrid that would culminate in an entirely new system known as the Next Generation Model. Niederauer started by assembling a design team that brought back to the Exchange ex-floor participants, and then-current participants who had introduced new technology on the floor. Their liminal status –neither complete insiders nor outsiders-- gave them both knowledge of the floor and an independent perspective. Niederauer also created two positions, Specialist Liaison and Floor Broker Liaison, to ensure that the needs of those two communities were taken into account in the redesign of the system. Niederauer thus brought a governance framework that partly placed the design of automation in the hands of the floor intermediaries and not just in those of the Exchange managers.

This team went on to debate how to redesign Hybrid. In these debates, our key observation was the concerted attention that floor participants devoted to the specialist role. The management team at the Exchange was comprised of reflexive observers of the specialist system, and it redesigned the Exchange so as to preserve its role structure. The new automation design was launched in November 2008, and included changes at the level of the specialists and the brokers aimed at preserving these roles.

The new specialists. Whereas specialists in Hybrid were expected to hold manual auctions at the same time as the matching engine paired orders algorithmically, the Next

Generation Model limited manual auctions to a few time periods per day: the market open, close, special situations, and crises. During regular trading hours, specialists were refashioned as automated market participants. To this end the Exchange provided them with desktop computers on their posts, programmed with algorithms to interact directly with the Exchange's algorithmic matching engine. In return the specialists agreed to give up their ability to have an advance look at the order book. The combination of these two changes pushed specialists away from their original price-setting role towards the more peripheral role of automated market participant. As such, they were expected to simultaneously buy and sell to profit from the spread as they always did, but do so using algorithms. The Exchange also altered the payout structure of the specialists, introducing subsidies to help specialists survive economically. Given the changes, the name "specialist" was changed to "designated market maker" (DMM).

We observed the new specialists in action at one of the posts in 2009. We found the specialist standing outside his post, as specialists typically did. But instead of talking to passing floor brokers as we had seen Ryan do in 2003 (not a single broker came by during the hour we observed) the new specialist focused on six screens in front of him; he was using the new algorithms to participate in the market. His trading strategy, he explained, reproduced the approach he had used in the manual environment but now the algorithm did the information processing. "Before," he said, he would see "sell, sell, and suddenly sell, buy, sell, sell, buy, and [he would] go 'this is it, this is it,'" pointing to his belly to signal a gut feeling. Now, his algorithm replicated the approach, initiating a buy order whenever the price of a stock moved more than three dollars away from the average price. In another sign of continuity, the specialists' quoting obligations were retained, although reduced.

Manual trading. In addition to automated trading, the Next Generation Model carried over from Hybrid the use of manual auctions at certain points in time. These auctions took place in situations of unusual volatility; in these, the Liquidity Replenishment Points were activated just as they were in the Hybrid model. Manual auctions also took place during the market open and close, before 9.30 am and after 4:00 pm. Thus while specialists were

expected to hold manual auctions at all times in Hybrid (even as automated auctions were taking place), the Next Generation Model introduced a system similar to pilots and the autopilot, whereby manual operations only took place in exceptional times.

In sum, the specialist role was partially altered in the shift from Hybrid to the Next Generation Model, but it was changed in a way that selectively preserved its core functions. As semi-automated proprietary traders, the new specialists engaged in matching, though now in the form of electronic market making; and in norm enforcement, by retaining a reduced version of their quoting obligations. The sensemaking aspect of the job disappeared during regular trading hours as the floor brokers no longer walked to the post to talk to the specialist, but was retained in manual auctions.

The new floor brokers. As with the specialists, the Next Generation Model partially changed the role of the floor broker, but did so in order to preserve it. Instead of buying and selling from the specialist as they had done before, brokers were to buy and sell directly from the algorithmic matching engine. To that end, the NYSE allowed brokers to transform their rudimentary handheld terminals (a tablet-like portable computer) to support execution algorithms. In this way brokers went from using the handheld terminal for trade annotation to using it for trade execution.

We explored this change in practice by observing how a floor broker used his NYSE-designed handheld (known as eBroker). "By standing here, he said, in reference to his booth "I am technically in every one of the crowds." Instead of walking frantically from one specialist post to another, the broker just tapped on the screen to place orders. Furthermore, the handheld reproduced some of the sensemaking possibilities of a trading crowd at the post. In one of the windows, the broker could see a list of tags with the badges of the other floor brokers who were buyers or sellers in a given stock – those who had a potential interest. He explained, "you can just tap a button, you can look at a stock and find out who the players were in it and then you can actually tap the line where the broker's badge is and you'll get like a messaging window." the broker demonstrated this by opening up a window, writing a question mark and sending it to a colleague. After a few seconds, the colleague replied with

another handwritten note, saying "just stray. sorry," meaning that he did not have any specific information, and apologized for not being able to provide insight. Thus, by reproducing the possibilities for quick communication of frames, the handheld helped floor brokers restore the sensemaking possibilities of the trading post, allowing them to reduce ambiguity and equivocality.

Nevertheless, the handheld was not a substitute for a crowd of live brokers at the post. While a crowd creates unintended communication trajectories (Hutchins 1995), offering social cues without the need for anyone to elicit them, the handheld requires brokers to purposefully communicate with each other. Indeed, the lack of crowds at the specialist post was a cause of concern for the floor broker. The management team at the NYSE concurred: as one official explained, while brokers were effectively communicating among themselves within the broker booths, brokers were not talking to specialists during routine trading and thus not helping each other make sense of price movements. As he explained, "at the booths it's a busy beehive, but cross pollination is not happening." Automation, in other words, had glued floor brokers and the new specialists to their respective computer screens during regular trading hours, limiting communication.

Outcome. Taken together, the outcome of the Next Generation Model was the elimination of some original functions of specialists and floor brokers, as well as the preservation of their key functions. The changes were mostly centered on automated trading, while in manual trading both roles were essentially preserved. But critically, the distinction between automated and manual modes did not hamper the NYSE's performance, because the Exchange could switch from manual to algorithmic trading in crises, allowing the floor intermediaries to engage in sensemaking and norm enforcement in those moments they were needed. The Next Generation Model also helped preserve the floor intermediaries by contributing to increase the income of specialists and floor brokers. According to NYSE officials, the new specialists more than tripled their participation rate between 2007 and 2009 to thirteen percent, and the new brokers experienced a similar increase to six percent (See

tables 4 and 5). Finally, the Next Generation Model stemmed the decline in NYSE's market share, but was not able to reverse it.

The NYSE and the Flash Crash

Did the New Generation Model work as intended? The incidence of the Flash Crash of 2010 on the NYSE provides suggestive evidence that it did. In the following paragraphs we summarize the dominant account of the Flash Crash, give evidence for the superior performance of the NYSE through the Crash and explain such performance in terms of the floor intermediaries' actions.

The Flash Crash can be summed up as the combined effect of a human error and a technological feedback loop. According to the governmental report (CFTC/ SEC 2010b), the Flash Crash was initially triggered by the rapid selloff on the part of a Kansas-based "Sell Algorithm." A trader at the fund (human error) placed an unusually large order in the trading algorithm: 75,000 E-Mini S&P 500 futures contracts, bound to have a large impact on prices. During a second stage of the Crash (feedback loop), the impact of that sell order was compounded by a feedback loop. As the aforementioned report contends, part of the selling volume stemming from the Kansas fund (with a net long position of 3,300 E-mini contracts) was absorbed by high frequency trading funds, but as their volume of transactions rose to an unusually high 140,000 contracts, the Sell Algorithm reacted by increasing its sales, flooding the market. In turn, high frequency trading funds reacted to the flooding by withdrawing from the market (as their risk limits were reached), thus contributing to the decrease in price. At the root of the feedback loop was a decision rule encoded in the Sell Algorithm that proved fatal: the algo was programmed to use trading volume as a proxy for liquidity, whereas on that day trading volume did not represent liquidity. As the report argues: "in times of significant volatility, high trading volume is not necessarily a reliable indicator of market liquidity" (CFTC/ SEC 2010b:3).

A voluminous literature has followed the Flash Crash and dissected its implications for high frequency trading and trading algorithms (The Government Office for Science 2012). But for the purposes of this study the Flash Crash provides a useful yardstick to appraise the

performance of the various exchanges and their automation designs. In that regard, the performance of the NYSE appears to be vastly superior to that of floorless exchanges. Consider broken orders: such was the dislocation of prices during the Flash Crash that the SEC decided to "break" or officially cancel all trades beyond a 20 percent band of the prevailing price twenty minutes before the crash. This led to extensive breaking of trades in all exchanges except in the NYSE. As stated by Jane Kissane, legal counsel of the NYSE, in a letter to the SEC (Kissane, 2010: 4):

> In the aftermath of May 6, other exchanges … engaged in a much criticized process of cancelling approximately 15,000 trades as 'clearly erroneous.' In contrast, not a single NYSE trade (excluding NYSE Arca, its electronic version) was required to be cancelled.

In other words, the NYSE's performance was exceptional. Indeed, this was corroborated by the official report on the Flash Crash (CFTC/ SEC 2010b). As Table 5 shows, all the floorless equities exchanges experienced a substantial incidence of broken trades, which the NYSE floor avoided. As we argue below, this performance is consistent with the functions that the sociological literature has outlined when discussing floor intermediaries.

--- Insert Table 5 ---

Sensemaking. In explaining the performance of the NYSE during the Flash Crash, officials point to the Exchange's ability to switch from automated to manual auctions thanks to the Liquidity Replenishment Points, which were highly active during the crash. While on a normal trading day there are around 50 LRPs activated, on the day of the Flash Crash there were more than 70,000. In a much-discussed article in *Tabb Forum*, microstructure specialist Wunsch (2010) concurs:

> The partially manual LRPs allowed the Big Board to apply some measure of old-fashioned reasonability tests to price formation. As a consequence, no NYSE trades printed at zero or anywhere close to it. Unlike all the other stock exchanges, the NYSE did not have to break any trades.

As Wunsch notes, one reason for the NYSE's superior performance was its ability to sustain sensemaking. Intermediaries on the floor could draw on social cues and their prior experience to establish that the sudden drop in the Dow Jones was purely due to factors internal to the market, with no economic news that could justify it. As soon as the price of stocks like

Accenture and Procter and Gamble began falling sharply, floor brokers were running to the post of the designated market maker and conferring among themselves. "I was on the Procter post at that time," explained to us a trader, "the away orders were off, they came six dollars below the previous price. Ours [the NYSE's] was one dollar below." In accounting for the better price, he adds: "what the market makers had to remember was, what's happening everywhere else *is not real.*" That is, the prices given by the automated exchanges did not represent the value of the companies but rather internal market processes.

The actions of the floor intermediaries can be contrasted with those of the Kansas Sell Algorithm (SEC/ CFTC 2011). As automated systems do, the Kansas algorithm relied on a simplified representation of the market (Zuboff 1988) that used traded volume as a proxy for market liquidity. This was appropriate during normal market conditions, but as described above it was an inadequate proxy during the Flash Crash, and led the Sell Algorithm to flood the market. Thus, unlike human floor intermediaries, a matching algorithm runs the risk of malfunction due to misrepresentation given its inability to exercise judgment as to the appropriateness of the proxy variables used by it.

Norm enforcement. A related reason for the performance of the NYSE was the norm enforcement function performed by the floor intermediaries. As Wunsch (2010) emphasizes, once the problems started, high-frequency traders withdrew their participation:

> Their high frequency market makers, sensing trouble, disappeared. With little else in their books, the market orders pushed prices to where the stub quotes were, producing ridiculous trade prices. With no floor governors or other manual processes to spot the difference between real trades and market structure failure, the electronic NMS printed them all.

This argument was echoed by NYSE officials. For instance, the low price in one of the more erroneously traded stocks, Procter and Gamble, was $39 in other exchanges but $56 at the NYSE. The reason for the difference, according to an Exchange executive, was that unlike market makers at database exchanges, NYSE specialists had a positive obligation to commit capital. Back in 2008, he explained,

> One of the flaws of electronic markets is that in general people don't have obligations with respect to the market so they come and go as they please. So if they get nervous about a situation, a macroeconomic event, a political event, they go away.

In other words, the absence of obligations contributed to an episode of illiquidity.

Finally, a more detailed consideration of the impact of the Flash Crash also allows us to rule out alternative explanations for the NYSE's outperformance. First, the lack of cancellations at the NYSE was not due to disengagement: the NYSE's market share between 2:30 pm and 3 pm was 26 percent, as compared to 21 percent on prior days (Kissane 2010: 5). As a result of the NYSE's shift to manual model, the counsel adds, prices on the NYSE were far less volatile than prices on electronic exchanges. Second, NYSE Arca (the electronic division of the NYSE purchased in 2006, as opposed to the trading floor) experienced similar trade cancelations as the floor-less exchanges, which is further confirmation of the advantages conferred by the ability to shift to manual trading: the NYSE did not do better because of its location or brand (Arca had the same advantages), but because of its reliance on the intermediaries on the floor.

In sum, the trading floor of the NYSE performed far better than the floorless exchanges during the Flash Crash. It increased its overall participation, its new specialists honored their obligations, its prices were less volatile, and it did not cancel any trades. The reason for this performance is that its new specialists and floor brokers at the NYSE were able to engage in their matching, sensemaking and norm enforcement functions, helping other market participants confront radical uncertainty and limit the individual incentive to pull out under crisis. Our analysis of the Flash Crash thus points to the strengths of the floor intermediary, in line with the sociological notion that in the absence of intermediaries, markets may be beset by opportunism and uncertainty (Baker 1984).

DISCUSSION AND CONCLUSION

Blended automation

In theorizing the developments described so far, we propose the expression "blended automation" to denote an automation design that preserves the original social structure of a market, alongside with its positive properties. In that respect, blended automation contrasts with Zuboff's (1988) notion of "informate." While informating denotes an automation design

that transforms the social order, blended automation denotes a design that preserves the social order. As we contend below, blended automation is characterized by two design principles (duplication and excepitonality), a mechanism of adjustment to environmental complexity, and emerges from an organizational process of contestation, redistribution of power, and knowledge sharing.

Duplication. In characterizing blended automation, we build on our observation of duplicative practices at the NYSE such as a reliance on call auctions and continuous auctions. We also found duplicative technologies such as the use of an algorithmic matching engine and a manual trading floor. Furthermore, this duplication was present during both Hybrid and the New Generation Model, suggesting it was a key element to the NYSE's automation design. By duplication we mean the use of two configurations (call auctions at the post, continuous auctions at the data center) that accomplish seemingly redundant goals. As we argue below, preserving two configurations is in fact not redundant, as it allows the organization to optimally adjust to environmental complexity. Furthermore, duplication is not simply the replication of technologies in their original form, but a more comprehensive intervention that makes the two configurations cohere: for instance, incorporating algorithms into the brokers' handhelds allowed them to engage with the algorithmic matching engine during automated trading, as well as participate in call auctions at the post in times of crisis.

Exceptionality. In its shift to the New Generation Market, the Exchange eliminated concurrent manual trading during so-called trading hours (9.30 am to 4.00 pm), suggesting a principle of exceptionality. Exceptionality, or the principle that activity is primarily automated unless unusual circumstances occur, allows for humans and algorithms to coexist despite their different speeds. Whereas in Hybrid manual auctions and algorithmic matching were taking place in parallel, the sharp separation in time between the two in the Next Generation Model allowed for the coexistence of both. Exceptionality was also made possible by the Exchange's decision to continue allowing manual trading outside trading hours (before 9:30 am and after 4:00 pm). It was also facilitated by the decision to transform the specialists into algorithmic market makers during trading hours. The first of these decisions gave floor

intermediaries a way to preserve their call auction routine and skills. Both decisions gave specialists an additional source of income and activity that made their job sustainable.

Adjusting to environmental complexity. At the core of blended automation lies a mechanism of organizational adjustment to environmental complexity, that is, of fit between the system and the wider environment. As Zuboff (1988) established, automation typically entails a simplified representation of an organization's task that boils down the multiple activities of the skilled manual workers into smaller parts that can be performed mechanically. While simplified representations work satisfactorily in most circumstances, there are situations when market complexity or opportunism call for the skilled activities of the manual actors. Blended automation addresses this problem by preserving the skilled actors and their routines and infrastructure (duplication), allowing them to remain available to address exceptional situations (exceptionality). The combined effect of duplication and exceptionality can readily be observed in the case of airplanes and autopilots, which rely on a combination of duplication (autopilot and the pilot) and exceptionality (reliance on the pilot for takeoffs, landings and turbulence) akin to the Exchange. As with the NYSE, the autopilot runs on a simplified representation of the navigational environment that is useful for most situations, but falls short in cases of high environmental complexity; in those, the presence of the pilots allows for their skills to be brought into bear.

Process. The case of the NYSE also speaks to the process by which organizations arrive at blended automation. It suggests that blended automation requires a balance of power between proponents and detractors of automation, as well as knowledge-sharing between the skilled manual workers and automation designers. At the NYSE, power balance was produced by the combination of the crises of 2003 and 2007: the former undermined the grip that detractors of automation such as Grasso had on the Exchange, and the latter prompted Niederauer and his team to draw on the tacit knowledge held by floor intermediaries that initially opposed automation. These crises suggest, in line with Leonardi and Barley (2010), that blended automation is the outcome of a political process within the organization. Finally, the presence of knowledge sharing is symmetrical to Zuboff's (1988) analysis. In her case,

automation only prompts fundamental change when the manual workers have the necessary knowledgeable to expand their original job. Automation, our case suggests, can only preserve the original social order (and its ancillary advantages) when designers can access the skilled manual workers' knowledge.

Resilience. Our analysis suggests that blended automation makes for a more resilient market. Such resilience was created by a combination of humans and machines that allowed the Exchange to preserve sensemaking and norm enforcement in times of crisis. In that sense, blended automation is consistent with the literature on high reliability organizations (Perrow 1984, Weick and Roberts 1993, Roberts 1990). This literature has shown that in settings characterized by tight coupling and complexity, redundancy (i.e., duplication) increases an organizations ability to cope with shocks (Perrow 1984). In our case, such effect is particularly clear in the case of the Flash Crash, but the Crash was not an isolated case. For instance, the manual system was repeatedly activated following the bankruptcy of Lehman Brothers in the Fall of 2008, when stocks in financial companies experienced extreme volatility (Gangahar 2008). In sum, whereas automation might be expected to make markets less irrational and more resilient, our study suggests that a blended automation approach is in fact superior to a floorless exchange design.

Limitations. Despite the effectiveness of the NYSE's approach, there are limits to the Exchange's ability to continue with two distinct forms of trading. First, the skills of floor participants are only exercised during limited periods every day, and while this may be enough to preserve knowledge of the call auction routine it may not be enough to train future generations of brokers and specialists. Second, to the extent that specialist firms derive more and more income from automated than manual trading their investments in talent and innovation might switch away from their floor operation and focus instead on electronic trading. Finally, the NYSE's approach may be threatened if the SEC introduces individual-stock circuit breakers that eliminate the Exchange's ability to switch to manual call auctions. In sum, the remarkable ability of the NYSE to reconcile manual and algorithmic trading

cannot be assumed to last indefinitely without future refinements and improvements, and support from the regulators.

Contributions to the technology literature

The concept of blended automation contributes to the literature on technology in organizations by offering qualified support for the thesis that technology can be complementary to social relations (Bensaou 1997, Kraut et al. 1999, Grover et al. 2002). Previous formulations of this thesis were predicated on the advantages of eliminating routine interactions (Grover et al. 2002). But as Schultze and Orlikowski (2004) demonstrated, volume and quality of interactions go hand in hand. Our concept of blended automation, in contrast to Grover et al.'s (2002), is based on preserving the quality *and* quantity of social interactions by creating provisions for face-to-face encounters (exceptionality), as well as maintaining a critical mass of interactions that retain manual competences (duplication). Blended automation thus contributes to the complementarity literature by proposing a design that reconciles technology with face-to-face dealings. One remaining question for future research is whether blended automation is sustainable over the long term, or is simply a short-lived phenomenon that hinges on pre-automation skills, networks and norms.

Blended automation also contributes to the literature on automation by building on Zuboff's (1988) approach to automation as the textualization of organizational activity. As Zuboff noted, automation is problematic when the electronic text fails to represent the environment. Blended automation addresses this by retaining floor intermediaries for situations of exceptional complexity (the Flash Crash of 2010 is an example). Our study also builds on Zuboff's (1988) emphasis on power sharing as a condition for effective automation: as we observed, participation by floor members in automation design is a key part of blended automation. On the other hand, blended automation departs from Zuboff's (1988) notion of informate and its emphasis on the transformational possibilities of automation by pointing to the many benefits of preserving part of the original social order.

Finally, blended automation contributes to the alignment perspective and its focus on power and macrolevel dynamics (Leonardi and Barley 2010). Whereas recent research has

emphasized the situated and improvised nature of technology implementation (Orlikowski 2000, Orlikowski and Scott 2008, D'Adderio 2008, Feldman and Orlikowski 2011) our case underscores the key role of power and politics at the macro-organizational level, pointing to the importance of regulators and Exchange management in the design of automation. In doing so, our study joins Leonardi and Barley's (2010) approach by suggesting that automation is shaped by the interplay of powerful groups of actors with different interests and ideologies.

Contributions to economic sociology

Our study contributes to economic sociology by speaking to sociological studies of floor intermediaries (Baker 1984, Abolafia 1996) and exploring their applicability to automated settings. These studies emphasized the embedded and socially structured nature of equities markets, but automation has called such arguments into question. How then are automated markets social? Our study suggests that automation need not remove the floor intermediary, and that the extent of social mediation in an automated market is a function of its automation design. That is, whereas floor-based automation designs such as the NYSE's preserved the embedded and socially mediated nature of securities trading that Baker (1984) and Abolafia (1996) identified, floorless automation designs such as NASDAQ's did away with floor intermediaries altogether. Mediation, in other words, is thus no longer a *structural* feature of markets but a *design* characteristic and an outcome of a controversy. Furthermore, the superior performance of the NYSE during the Flash Crash supports Abolafia (1996) and Baker's (1984) contention that the floor intermediary helps investors confront uncertainty and forestall opportunism, extending the work to an automated setting.

Our study also contributes in three ways to the debate on market automation within the social studies of finance. First, it challenges the sociologists of finance who argued that automation weakens social structure in financial exchanges (Zaloom, 2007, Pardo-Guerra 2010), by showing that blended automation is complementary with existing social relations. Second, it supports Knorr Cetina and Bruegger's (2002) contention that interaction through a terminal screen can preserve existing social relations, extending their claim beyond automated communication (screens) to one of automated trading (algorithms). Third, blended automation

provides partial support to Knorr Cetina and Preda's (2007:116) claim that automated (i.e., "scopic") markets are defined by their technological rather than social features. As discussed above, in a context of automation the degree of social structuring is itself a technological design variable.

Finally, our study contributes to the "markets as politics" literature within economic sociology (Fligstein 1996, Krippner 2005, Quinn 2008) by highlighting how beliefs and ideologies shaped the automation of the American stock market during the 2000s. As our case shows, the automation of the NYSE was not the spontaneous result of new technology availability, but the outcome of a concerted political process. This process entailed a controversy between rival conceptions of the market (socially mediated versus information-processing) that was resolved in favor of the latter. Our analysis extends Fligstein's (1996) contention that politics shape markets through the actions of regulators by pointing to the role played by technology in such process. Future research may explore the extent to which Wall Street banks, dark pools, and high frequency trading firms influenced the regulator's mandate to automate (Saluzzi and Arnuk 2012).

In closing, our study underscores the distinct benefits of bridging the sociology of markets and the literature on technology in organizations. By bridging these theoretical domains our analysis brings to the fore the reciprocal influence of the economic on the technological. On the one hand, the economic influences the technological in that it was an ideological controversy over the nature of markets (social mediation versus information-processing) that shaped the technology used by the exchanges (floor-based versus floorless). On the other hand, our analysis also shows how the technological shapes the economic, for it was the technological features of exchanges (floor-based versus floorless) that shaped the economic properties of the market (resilient versus not). In sum, by bridging scholarly understandings of social structure and algorithms, our study hopes to do justice to the complexity entailed in market automation. We hope our approach inspires market scholars, designers, and regulators to ground future efforts at automation on a solid understanding of the social nature of economic activity.

REFERENCES

Abolafia, M. 1996. *Making Markets: Opportunism and Restraint on Wall Street*. Cambridge, MA: Harvard University Press.

Agar, M. 1986. *Speaking of Ethnography*. Sage, Beverly Hills, CA.

Baker, W. 1984. The social structure of a national securities market. *American Journal of Sociology* **89**, 4: 775-81.

Barley, S. 1986. Technology as an occasion for structuring: evidence from observations of CT scanners and the social order of radiology departments. *Administrative Science Quarterly*, **31**: 78-108.

Barrett, M. and Scott, S. 2004. Electronic trading and the process of globalization in traditional futures exchanges: a temporal perspective. *European Journal of Information Systems*, 13 (1). 65-79.

Benner, M. and M. Tushman. 2002. Process management and technological innovation: A longitudinal study of the photography and paint industries. *Administrative Science Quarterly* **47**: 676-707.

Bensaou, M. 1997. Interorganizational cooperation: The role of information technology, an empirical comparison of U.S. and Japanese supplier relations. *Inform. Systems Res.* 8(2) 107–124.

Black, F. 1971. Toward a fully automated stock exchange, part I. *Financial Analysts Journal*, 27 (4): 28.

Boudreau, M. and D. Robey. 2005. Enacting integrated information technology: A human agency perspective. *Organization science*, 16(1), 3-18.

Brooks, J. 1969. *Once in Golconda: A True Drama of Wall Street 1920–1938*. New York, Harper & Row.

Burt, R. S. 1992. *Structural Holes: The Social Structure of Competition*. Harvard University Press, Cambridge, MA.

Colesanti, J. 2008. Not Dead Yet: How New York's Finnerty decision salvaged the Stock Exchange specialist. *Journal of Civil Rights and Economic Development* **23**(1): 1-34.

Commodities and Futures Trading Commission and Securities and Exchange Commission. 2010a. Preliminary Findings Regarding the Market Events of May 6, 2010, Report of the staffs of the CFTC and SEC to the Joint Advisory Committee on Emerging Regulatory Issues, May 18.

_____ 2010b. Findings Regarding the Market Events of May 6, 2010, Report of the staffs of the CFTC and SEC to the Joint Advisory Committee on Emerging Regulatory Issues, September 30.

D'Adderio, L. 2008. The Performativity of Routines: Theorising the influence of artefacts and distributed agencies on routines dynamics. *Research Policy*, **37**(5): 769-789.

Feldman, M. and Orlikowski, W. 2011. Theorizing practice and practicing theory. *Organization Science*, 22(5), 1240-1253.

Fligstein, N. 1993. *The transformation of corporate control.* Harvard University Press.

_____. 1996. Markets as politics: A political-cultural approach to market institutions. *American Sociological Review*, 656-673.

____. 2010. Response to Kenneth Zimmerman. *Economic Sociology The European Electronic Newsletter* 11:53.

Gasparino, C. 2007. *King of the Club: Richard Grasso and the Survival of the New York Stock Exchange*, Collins Business, New York.

Gangahar, A. 2008. "Faith in trading floor returns." *Financial Times.* October 29.

Glaser, B., and A. Strauss. 1967. *The Discovery of Grounded Theory*. Aldine Publishing Company, New York.

Glosten, L., and Milgrom, P. 1985. Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. Journal of financial economics, 14(1), 71-100.

The Government Office for Science. 2012. Foresight: The Future of Computer Trading in Financial Markets. Final Project Report, London

Grover, V., Teng, J., and K. Fiedler. 2002. Investigating the role of information technology in building buyer-supplier relationships. *Journal of the Association for Information Systems*, 3(1), 7.

Holland, C. P., G. A. Lockett. 1997. Mixed mode network structures: The strategic use of electronic communication by organizations. *Organization Science* 8(5) 467–488.

Hendershott, T., & Moulton, P. 2011. Automation, speed, and stock market quality: The NYSE's hybrid. *Journal of Financial Markets*, 14(4), 568-604.

_____ C. M. Jones and A. Menkveld. 2011. Does algorithmic trading improve liquidity? *Journal of Finance* **66**: 1–33.

Hutchins, E. 1995. How a cockpit remembers its speeds. *Cognitive Science* **19**: 265-288.

Katila, R. and G. Ahuja. 2002. Something old, something new: A longitudinal study of search behavior and new product introduction, *Academy of management journal* **45**: 1183-1194.

Khurana, R. 2002. Market triads: a theoretical and empirical analysis of market intermediation. *International Journal of Theory of Social Behavior*. **32**: 239–262.

Kissane, J. 2010. File No. 265-26, Joint CFTC-SEC Advisory Committee on Emerging Regulatory Issues http://www.sec.gov/comments/265-26/265-26-26.pdf Accessed on December 2012.

Knorr Cetina, K. and U. Bruegger. 2002. Global microstructures: the virtual societies of financial markets. *American Journal of Sociology* **107**(4): 905-950.

_____ and A. Preda. 2007. The temporalization of financial markets: from network to flow. *Theory, Culture and Society* **24**: 116-138.

Khurana, R. 2002. Market triads: A theoretical and empirical analysis of market

intermediation. *Journal for the Theory of Social Behaviour*, 32(2), 239-262.

Kraut, R., Steinfeld, C., Chan, A., Butler, B. and Hoag, A. 1999, "Coordination and virtualization: the role of electronic networks and personal relationships", *Organization Science*, 10(6): 722-40.

Krippner, G. 2005. The financialization of the American economy. *Socio-Economic Review*, 3(2), 173-208.

Leonardi, P. and Barley, S. 2010. What's under construction here? Social action, materiality, and power in constructivist studies of technology and organizing. *The Academy of Management Annals*, 4(1), 1-51.

Lewis, M. 2014. *Flash boys: a Wall Street revolt.* WW Norton & Company.

Luccheti, Aaron. 2007. "Boos vs. Moos: NYSE Deal Gets One or the Other At Closing Bell, Traders Show Their Displeasure Over Euronext Merger." The Wall Street Journal, April 6. Accessed in June 2010 at http://online.wsj.com/articles/SB117582609448361819

MacKenzie, D. 2012. Mechanizing the Merc: The Chicago Mercantile Exchange and the rise of high-frequency trading.
http://www.sps.ed.ac.uk/__data/assets/pdf_file/0006/93867/Merc11.pdf
Accessed July 2012.

_____ and J.P. Pardo-Guerra. 2014. Insurgent capitalism: Island, bricolage and the re-making of finance. *Economy and Society*, 1-30.

Malone, T., Yates, J., and Benjamin, R. 1987. Electronic markets and electronic hierarchies. *Communications of the ACM*, 30(6), 484-497.

Mehrling, P. 2005. *Fischer Black and The Revolutionary Idea of Finance*. John Wiley and Sons, Hoboken, NJ.

Muniesa, F. 2004. Assemblage of a market mechanism. *Journal of the Center for Information Studies* **5**: 11-19.

_____. 2007. Market technologies and the pragmatics of prices. *Economy and Society*, **36**(3): 377-395.

Obstfeld, D. 2005. Social networks, the tertius iungens orientation, and involvement in innovation. Administrative science quarterly, 50(1), 100-130.

Orlikowski, W. 1992. The duality of technology: rethinking the concept of technology in organizations. *Organization Science*, **3**(3): 398-427.

_____ W. 2000. Using technology and constituting structures: A practice lens for studying technology in organizations. Organization Science 11(4) 404–428.

_____ and Scott S.V., 2008. Sociomateriality: Challenging the separation of technology, work and organization. *Academy of Management Annals*, 2 (1), 433-474.

Pardo-Guerra, J. P. 2010. Creating flows of interpersonal bits: the automation of the London Stock Exchange, 1955-1990. *Economy and Society*. **39**(1): 84-109

Perrow, C. 1984. Normal accidents: Living with high-risk technologies. NY: Basic Books.

Patterson, S. 2012. Dark pools: High-speed traders, AI Bandits, and the threat to the global financial system. Random House LLC.

Pitluck, A. 2011. Distributed Execution in Illiquid Times: An Alternative Explanation of Trading in Financial Markets." *Economy and Society*. **40**(1): 26-55.

Quinn, S. 2008. The Transformation of Morals in Markets: Death, Benefits, and the Exchange of Life Insurance Policies. *American Journal of Sociology*, 114(3), 738-780.

Saar, G. 2010. Specialist Markets, in *Encyclopedia of Quantitative Finance*, ed. Rama Cont, John Wiley & Sons, Chichester.

Saluzzi, J. and S. Arnuk. 2012. *Broken Markets: How High Frequency Trading and Predatory Practices on Wall Street Are Destroying Investor Confidence and Your Portfolio*. FT Press, Upper Saddle River, NJ.

Simmel, G. 1902 /1950. *The Sociology of Georg Simmel*. Free Press, Toronto, Ontario.

Sobel, R. 1975. *NYSE: A History of the New York Stock Exchange: 1935–1975*. Weybright and Talley, New York.

Schultze, U., and W. Orlikowski. 2004. A practice perspective on technology-mediated network relations: The use of Internet-based self-serve technologies. *Information Systems Research*, 15(1), 87-106.

Wagner, W. 2004. The Market-Maker in the Age of the ECN. *Journal of Investment Management* **2**(1): 4-15.

Weick, K. 1993. The collapse of sensemaking in organizations: The Mann Gulch disaster. *Administrative Science Quarterly*, **38**: 628-652.

_____ and Roberts, K. 1993. Collective mind in organizations: Heedful interrelating on flight decks. *Administrative science quarterly*, 357-381.

Wunsch, S. 2008. Challenges to the sell-side Pp. 292-300 in Wayne Wagner (ed.), *Meeting the Noble Challenges of Funding Pensions, Deficits, and Growth*. Wiley Finance, New York.

_____ 2010. *War on Wealth: The SEC, the National Market System and the Flash Crash*.

_____ 2011. "Straitjacket" *Tabb Forum*. Available on http://www.tabbforum.com/opinions/ Accessed on January 2011.

Zaloom, C. 2003. Ambiguous numbers: trading technologies and interpretation in financial markets. *American Ethnologist* **30**(2):258–72.

_____. 2006. *Out of the Pits: Traders and Technology from Chicago to London*. University of Chicago Press, Chicago, IL.

Zuboff, S. 1988. *In the age of the smart machine: The future of work and power.* Basic Books.

TABLES AND FIGURES

Table 1. Interviews conducted for the study

Interviewee	Date	Affiliation on first interview
Todd Abrahall	May 7, 2009 May 11, 2010	Vice President, NYSE Euronext
Rich Barry	August 25th, 2009	Vice President, NYSE Euronext
Herbert Beherens	May 25, 2009	Advisor, Brill Securities
Paul Bennet	May 08, 2008	Chief Economist, NYSE Euronext
Gordon Charlop	August 10, 2008 July 30th, 2009 * December 9, 2012	Managing Director, Rosenblatt Securities Inc.
Christopher Concannon	June 22, 2008	Executive Vice President, NASDAQ
Josepth Gawronski	August 13, 2012	President, Rosenblatt Securities Inc.
Peter Giacchi	August 26, 2009	Director, Bank of America
Lawrence Glosten	February 9, 2009	Professor of Finance, Columbia University
Mark Gurilacci	June 23, 2003	Managing Director, NYSE
Robert Hardy	June 23rd, 2003 February 25, 2008	Specialist, Fleet Financial
Lawrence Harris	December 12, 2009	Professor of Finance, University of Southern California
William Harts	June 15, 2009 August 10, 2012	President, Harts & Co.
Frank Hathaway	June 30, 2008	Chief Economist, NASDAQ
David Humphreville	May 5, 2009	President, The Specialist Association
James Hyde	December 1, 2008	Vice President, NYSE Euronext
Bryan Hyndman	August 14, 2008	Senior Vice-President, NASDAQ
Charles Jones	March 18, 2009	Professor of Finance, Columbia University
Gary Katz	January 12, 2009	President and CEO, International Stock Exchange
David Krell	January 26, 2009	Chairman, International Stock Exchange
Gregory Maynard	August 4, 2008	Officer, International Stock Exchange
James McGuire Sr	September 1, 2009	Specialist, Barclays Capital
Joseph Mecane	August 4, 2009	Executive Vice President, NYSE Euronext
Nina Mehta	May 15, 2009	Senior Editor, Traders Magazine
Duncan Niederauer	May 8, 2009	Chief Executive Officer, NYSE Euronext
Lawrence Leibowitz	June 25, 2008	Chief Operating Officer, NYSE Euronext
Thomas Luby	May 5, 2011	Chief Executive Officer, Clearingbid Inc.
Daniel O'Donnell	July 24, 2009 December 9, 2009 August 15, 2012	Managing Director, Bank of America
Stephen Oppenheimer	August 19, 2008	Director of Marketing, Aegisoft
Bradford Paley	August 25, 2009	Principal, Digital Image Design Incorporated
Ray Pallecchia	August 14, 2009 December 9, 2009 February 26, 2013	Vice President, NYSE Euronext
Lou Pastina	August 14, 2009 Februrary 22, 2012	Executive Vice President, NYSE Euronext
Gerard Petti	August 14, 2009	Designated Market Maker on NYSE floor, Getco

		LLC
Alice Rivlin	August 18th, 2010	Senior Fellow, Brookings Institution
Michael Rutigliano	July 7, 2009 December 10, 2009	Vice President-Broker Liaison, NYSE Euronext
Joseph Saluzzi,	December 20, 2011	Partner, Themis Trading LLC
Alyssa Schoenfeld	August 24, 2008	Managing Director, NYSE Euronext
Edward Schreier	August 13, 2008	Managing Director, Deutsche Bank AG
Andrew Schwartz	September 10, 2008	Senior Partner, AGS Specialists
George Sofianos	June 24, 2009	Vice President, Goldman Sachs
Chester Spatt	February 9, 2009	Professor of Finance, Carnegie Mellon University
Murray Teitlebaum	June 23rd, 2003,	Education Director, NYSE
Wayne Wagner	August 13, 2008 *	Former Chairman, Plexus Group
Randall Williams	July 24, 2009	Vice President, BATS Exchange
Benedict Willis	August 17, 2009 April 10, 2012 April 4, 2012	VDM Institutional Brokerage
Neal Wolkoff	January 21st, 2008 September 21st 2009	Chairman, American Stock Exchange
Stephen Wunsch	August 26, 2008 December 4, 2008 August 13, 2012	Corporate Initiatives, International Stock Exchange

Note: An asterisk indicates that the interviewers were both authors. All other interviews were conducted by the first author.

Table 2. Site visits to the NYSE (does not include visits and interviews outside the NYSE)

Date	NYSE department observed
2003	Observed call auctions at the specialist post (1 hour), a floor broker's booth (1 hour) and conducted three interviews (1 hour each)
2008	Observed call auctions at the specialist post (1 hour), floor call auction (1hour), market open (1 hour), the NYSE Amex trading floor (1 hour) and conducted 7 interviews lasting between 45 minutes and 1.5 hours each
2009	Observed a floor broker's booth (1 hour), a designated market maker post (1 hour), a stock rebalancing auction (1 hour) and conducted 13 interviews lasting between 45 minutes and 1.5 hours each
2010	Two interviews lasting 30 minutes and 1.5 hours respectively
2011	Two interviews lasting one hour each
2012	Observed a floor broker's booth (1 hour) and market open auction (1 hour), and conducted seven interviews lasting between 45 minutes and one hour
2013	One interview lasting one hour

Table 3. Market Share of the NYSE in US equities. Note: Data is for market share for all us equities turnover, Tape A. Source: Thompson Reuters

Year	Market share
2000	80.00%
2001	80.61%
2002	78.14%
2003	77.92%
2004	76.07%
2005	76.03%
2006	71.00%
2007	44.27%
2008	29.41%
2009	27.16%
2010	27.78%
2011	26.86%
2012	23.80%

Table 4. Relative importance of human (floor-based) versus algorithmic trading

Year	Floor trading percentage out of overall volume
1999	50%
2000	48%
2001	47%
2002	44%
2003	37%
2004	33%
2005	29%
2006	19%
2007 (January to June)	11%
2008	n.a.
2009	22%

Note: Human (floor based) trades are defined as the aggregate of specialist and floor broker participation. Algorithmic includes all trades matched by algorithms, including small-order automated trades before 2007. Source: NYSE, Hendershott and Moulton (2011).

Table 5. Number of Broken Trades by Exchange

Exchange	Number of Broken Trades
NYSE Market (excluding Arca)	0
Arca	4,903
NASDAQ	12,306
BATS	1,094
Direct Edge	1,816

Source: CFTC/ SEC (2010a: 32)