Tools of the Trade: The Socio-Technology of Arbitrage in a Wall Street Trading Room

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Abstract

Our task in this paper is to analyze the organization of trading in the era of quantitative finance. To do so, we conduct an ethnography of arbitrage, the trading strategy that best exemplifies finance in the wake of the quantitative revolution. In contrast to value and momentum investing, we argue, arbitrage involves an art of association - the construction of equivalence (comparability) of properties across different assets. In place of essential or relational characteristics, the peculiar valuation that takes place in arbitrage is based on an operation that makes something the measure of something else - associating securities to each other. The process of recognizing opportunities and the practices of making novel associations are shaped by the specific socio-spatial and socio-technical configurations of the trading room. Calculation is distributed across persons and instruments as the trading room organizes interaction among diverse principles of valuation.

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Introduction

What counts? This question expresses most succinctly the challenge facing securities traders in the era of quantitative finance. As for other industries where actors are immersed in a virtual flood of information, the challenge for traders is not faster, higher, stronger – as if the problem of the volume of data could be solved by gathering yet more – but selecting what counts and making sense of the selection. The more information is available to many simultaneously, the more advantage shifts to those with superior means of interpretation. How is a trading room organized for making sense of what is to be taken into account?

What counts? This question also expresses most succinctly a challenge for economic sociology. What is valuable, and by what metrics of value and what performance criteria? In its contemporary form, economic sociology arguably began when Talcott Parsons made a pact with economics. You, the economists, study value; we sociologists study values. You study the economy; we study the social relations in which economies are embedded. This paper is part of a research agenda that breaks with that pact by turning to problems of valuation and calculation (Boltanski and Thevenot 1991; White 1981, 2001; Thevenot 2001; Stark 2000; Girard and Stark 2002; Callon and Muniesa 2002; Callon et al. 2002). Just as post-Mertonian studies of science moved from studying the institutions in which scientists were embedded to analyze the actual practices of scientists in the laboratory, so a post-Parsonsian economic sociology must move from studying the institutions in which economic activity is embedded to analyze the actual calculative practices of actors at work.

Our analysis starts with the fundamental theme that network analysis shares with other schools of economic sociology – the conception that markets are social (Granovetter 1985; Fligstein, 1990; Uzzi 1997). But we extend and deepen that perspective by arguing that social network analysis should not be limited to studying ties among persons. Because the social consists of humans and their non-humans (artifacts), in place of studying "society" we must construct a science of associations - an analysis that examines not only links among persons but also among persons and instruments (Callon 1998; Latour 1988, 1991; and Hutchins 1995). What counts? Tools count. Instrumentation must be brought into the accounts of economic sociologists. Calculation, as we shall see, is not simply embedded in social relations. Calculative practices are distributed across persons and instruments.

Studying Quantitative Finance

To analyze the organization of trading in the era of quantitative finance we conduct an ethnography of arbitrge, studying how traders recognize opportunities in the trading room of a major international investment bank. We focus on arbitrage because it is the trading strategy that best represents the distinctive combination of connectivity, knowledge, and computing that we regard as the defining feature of the quantitative revolution in finance. With the creation of the NASDAQ in 1971, Wall Street had an electronic market long before any other industry. With the development of Bloomberg data terminals in 1980, traders in investment banks were connected to each other in an all-inclusive computer network long before other professionals. With the development of formulae for pricing derivatives such as the Black-Scholes formula in 1973, traders gained powerful mathematical tools. And with the dramatic growth in computing power traders were able to combine these equations with powerful computational engines. This mix of formulae, data to plug into them, computers to calculate them, and electronic networks to connect them was explosive, leading to a decisive shift to "quantitative finance" (Lewis 1999; Dunbar 2000).

To date, the leading analytic strategy by sociologists studying modern finance has been to focus on one or another of the key components of the quantitative revolution. Exemplary, in this light, is the recent paper by Knorr Cetina and Bruegger (2002) which analyzes one of the key trends of the quantitative revolution, the rise of electronic markets, arguing that electronic trading has altered the relationship between market participants and physical space. Their work is pathbreaking for the insight that the numbers on the screens of the electronic traders do not *represent* a market that is elsewhere; instead, the market is "*appresented*" (p. 4). Like a conversation taking place through instant messaging (but unlike, say, a movie or TV show), electronic markets constitute an on-screen reality that lacks an off-screen counterpart. This has important implications for the practice of quantitative finance. Just as the eyes of traders in a commodities pit are glued to the gestures of other traders, so Knorr Cetina and Bruegger found that the eyes of their currency traders are glued to the screen – because in both cases that is where the market is. Electronic markets, they assert, have brought the marketplace to the trader's screen, prompting the traders to shift from a "face-to-face world" to a "face-to-screen world" and bringing about the "diminishing relevance of the physical setting" (p. 23).

While Knorr Cetina and Bruegger focus on the rise of connectivity in finance, MacKenzie and Millo (2001) focus on another leg of the quantitative revolution, the rise of mathematical formulae and their consequences for trading (see also MacKenzie 2002).[1] The mathematical formulae of modern finance, they argue, do not *represent markets* so much as constitute part of a network (also made up of people, computers, ideas, etc.) that *performs the market* in the sense developed by Callon (1998). As an example of such a "performative" that does not just mirror a reality but is constitutive of it, they point to the role of the Black-Scholes formula in predicting and later setting option prices on the Chicago Board Options Exchange.

The two studies are nicely complementary: Knorr Cetina and Bruegger examine the network connectivity of electronic trading, but ignore formulae entirely; MacKenzie and Millo address

[1] For a large-sample approach to the organization of trading rooms, see Zaheer and Mosakowski (1997).

the role of formulae but ignore the connectivity of electronic trading. But if we are to understand the organization of trading in the era of modern finance, we must examine all three pillars of the quantitative revolution: network connectivity, mathematical formulae, and computing. It is precisely this combination that gives the study of modern arbitrage – as the trading strategy that most powerfully (and, to date, most profitably) exploits the mathematics and the machines of modern market instruments – such analytic leverage.

In taking the limitations of these studies as our point of departure, the opportunity we seize, however, is not just to examine as an ensemble the pieces they had begun to analyze separately. Amidst the circulating information of Knorr Cetina and the diffusing equations of MacKenzie, we find little about the core problem facing any trader – how to recognize an opportunity? We will argue that traders do so by making of their trading room a laboratory, by conducting experiments, by deploying an array of instruments to test the market. In the practices through which value is calculated, equivalencies are constructed, and opportunities are realized, tools count. Calculation is distributed across the human and non-human agents and instruments enacting the trade. But, if calculation involves both the mathematics and the machines of quantitative finance, as we shall see, even when it is automated, it is far from mechanical: at this level of performance, calculation involves judgment. Moreover, calculation is not detached: whereas the trader is emotionally distant from any particular trade, to be able to take a position, the trader must be strongly attached to an evaluative principle and its affiliated instruments.[2] In the field of arbitrage, to be opportunistic you must be principled, that is, you must commit to an evaluative metric.

Second, our focus on the the problem of identifying value leads us to take into account the dynamics identified by Knorr Cetina, MacKenzie, and their co-authors but to draw radically different analytic conclusions. For Knorr Cetina and Bruegger (2002), the displacement of physical locale in favor of the "global microstructures" on the screen is explained by the ever-increasing rapidity of the circulation of information. We, too, initially approached our research setting as a world of globally instantaneous information. By studying sophisticated derivative traders, able to produce formulae that quantify unknown magnitudes, we hoped to demarcate a world of pure information that could stand as a benchmark against which we could differentiate other calculative settings. And, yes, we encountered a world abundant in information, delivered with dazzling, dizzying speed. But after months of fieldwork, we realized that, as increasingly more information is almost instantaneously available to nearly every market actor, the more strategic advantage shifts from economies of information to socio-cognitive process of interpretation (Weick 1979; Brown and Duguid 2000; Grabher 2002b). Precisely because all the relevant alters have the same information as ego, this particular trading room makes profits (considerably higher than industry-average profits) not by access to better or timelier information but by fostering interpretive communities in the trading room.

Similarly, learning from MacKenzie and Millo (forthcoming) about how the diffusion of formulae shapes markets, we go on to ask the next question. If everyone is using the same

[2] Zaloom (2004) correctly emphasizes that, to speculate, a trader must be disciplined. In addition to this psychological, almost bodily, disciplining, however, we shall see that the arbitrage trader's ability to take a risky position depends as well on yet another discipline – grounding in a body of knowledge.

formulae, how can you profit? The more that formulae diffuse to perform the market, the more one's profits depend on an original performance. That is, the premium shifts to innovation. As with information (which you must have, but which in itself will not give advantage) so with formulae: the more widely diffused, the more you must innovate.

What then facilitates interpretation and fosters innovation? The answer came only when we stopped regarding the trading room simply as a "setting" and began to regard the spatial configurations of this particular locale as an additional dimension alongside the combination of equations, connectivity, and computing. In analyzing the *modus operandi* of modern finance, we came to see that its *locus operandi* could not be ignored. That is, whereas Knorr Cetina and Bruegger dismiss physical locale in favor of interactions *in cyberspace*, we found that trading practices are intimately tied to the deployment of traders and instruments *in the room*.

Arbitrage trading can be seen as an economy of information and speed. So is flying a fighter aircraft in warfare. Without the requisite information and the requisite speed neither trader nor pilot could do the job. But maneuvering in the uncertain environment of markets, like maneuvering in the fog of battle, requires situated awareness[3]. As we shall see, the configuration of the trading room, as a specific locale, provides the socio-spatial resources for this sense making. A trading room is an engine for generating equivalencies. Such associations are made *in situ,* that is, they entail the use of financial formulae that result from associations among people working in the same physical place.

The cognitive challenge facing our arbitrage traders – a challenge central to the process of innovation – is the problem of recognition. On one hand, they must, of course, be adept at *pattern recognition* (e.g., matching data to models, etc). But if they only recognize patterns familiar within their existing categories, they would not be innovative (Clippinger 1999). Innovation requires another cognitive process that we can think of as *re-cognition* (making unanticipated associations, reconceptualizing the situation, breaking out of lock-in). It involves a distinctive type of search – not like those searches that yield the coordinates of a known target or retrieve a phone number, product code, or document locator for a pre-identified entity or category – but the search where you don't know what you're looking for but will recognize it when you find it.

The organization of the trading room, as we shall see, is equipped (quite literally) to meet this twin challenge of exploiting knowledge (pattern recognition) while simultaneously exploring for new knowledge (practices of re-cognition).[4] Each desk (e.g., merger arbitrage, index arbitrage, etc.) is organized around a distinctive evaluative principle and its corresponding cognitive frames, metrics, "optics," and other specialized instrumentation for pattern recognition. That is, the trading room is the site of diverse, indeed rivalrous, principles of valuation. And it is the interaction across this heterogeneity that generates innovation.

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[3] For an application of interpretive theories of organization to the military, see Weick and Roberts (1993).

[4] We are re-interpreting March's (1991) exploitation/exploration problem of organizational learning through the lens of the problem of recognition. See also Stark 2001; Girard and Stark 2002.

To explore the socio-cognitive, socio-technical practices of arbitrage, we conducted ethnographic field research in the Wall Street trading room of a major international investment bank. Pseudonymous International Securities is a global bank with headquarters outside the United States. It has a large office in New York, located in a financial complex in Lower Manhattan that includes the offices of Merrill Lynch and other major investment banks. With permission from the manager of the trading room we had access to observe trading and interview traders. We found an environment extremely congenial to academic inquiry. In our conversations with arbitrageurs, who are the intellecual elite of Wall Street, it was not unusual for us to hear timely references to economic history, French cinema of the 1960s, books on network analysis, and even the philosophy of Richard Rorty or Martin Heidegger. More importantly, the traders relished reflecting on the nature of their work, and were correspondingly generous with their time. Our observations extended to sixty half-day visits across more than two years. During that time, we conducted detailed observations at three of the room's ten trading desks, sitting in the tight space between traders, following trades as they unfolded and sharing lunch and jokes with the traders. We complemented this direct observation with in-depth interviews. In the final year of our investigation, we were more formally integrated into the trading room – provided with a place at a desk, a computer, and a telephone. The time span of our research embraced the periods before and after the September 11th attack on the World Trade Center (for accounts of the trading room's response and recovery, see Beunza and Stark 2003 and 2004).

In the following section we make the case that arbitrage constitutes a distinctive trading strategy that operates by making associations among securities. In contrast to value and momentum investing, we argue, arbitrage involves an art of association - the construction of equivalence (comparability) of properties across different assets. In place of essential or relational characteristics, the peculiar valuation that takes place in arbitrage is based on an operation that makes something the measure of something else - associating securities to each other. Subsequent sections analyze how the trading room is organized to recognize opportunities. We first observe how the spatial organization of the room facilitates general sociability among traders. Second, we examine how these traders are grouped into specialized desks, each deploying distinctive financial instruments and evaluative metrics for pattern recognition. Next, we examine the trading room as an ensemble of multiple desks, exploring how this ecology of diverse evaluative principles facilitates practices of re-cognition; and finally, we examine the room as an assemblage of instrumentation, exploring how the socio-cognitive and the socio-technical are intertwined.

Arbitrage, or Quantitative Finance in the Search for Qualities

Arbitrage is defined in finance textbooks as "locking in a profit by simultaneously entering into transactions in two or more markets" (Hull, 1996, p. 4). If, for instance, the prices of gold in New York and London differed by more than the transportation costs, an arbitrageur could realize an easy profit by buying in the market where gold is cheap and selling it in the market where it is expensive. As such, classical arbitrage lacks sociological as well as economic interest: it relates markets that are the same in every dimension except for an obvious one such, as in this case, the geographical. Reducing arbitrage to an unproblematic operation that links the obvious (gold in London, gold in New York), as textbook treatments do, is doubly misleading,

for modern arbitrage is neither obvious nor unproblematic. It provides profit opportunities by associating the unexpected, and it entails real exposure to substantial losses.

Arbitrage is a distinctive form of entrepreneurial activity that exploits not only gaps across markets but also the overlaps among multiple evaluative principles. Arbitrageurs profit not by having developed a superior way of deriving value but by exploiting opportunities exposed when different evaluative devices yield discrepant pricings at myriad points throughout the economy.

As a first step to understanding modern arbitrage, consider the two traditional trading strategies, *value* and *momentum* investing, that arbitrage has come to challenge. Value investing is the traditional "buy low, sell high" approach in which investors look for opportunities by identifying companies whose "intrinsic" value differs from its current market value. They do so by studying a company's annual reports, financial results, products, and executives; they then compare the intrinsic value that emerges from this analysis with the market price of the company (Graham and Dodd, 1934). Value investors are essentialists: they believe that property has a true, intrinsic, essential value independent from other investors' assessments, and that they can attain a superior grasp of that value through careful perusal of the information about a company. Value investors map the many aspects of a company by translating them into abstract variables – e.g., return, growth, risk – and collapsing them into a single number ("value") with the use of formulae such as discounted cash flow. They proceed with the belief that mispricings will be eventually corrected – that is, that enough investors will eventually "catch up" with the intrinsic value and drive the price towards it, producing a profit for those who saw it first.

In contrast to value investors, momentum traders (also called chartists, see Smith 2001) turn away from scrutinizing companies towards monitoring the activities of other actors on the market (Malkiel, 1973). Like value investors, their goal is to find a profit opportunity. However, momentum traders are not interested in discovering the intrinsic value of a stock. Instead of focusing on features of the asset itself, they turn their attention to whether other market actors are bidding the value of a security up or down. Alert to trends, they believe in the existence of "momentum," a self-sustaining social process amenable to discovery by studying patterns in the time series of the stock – its chart. In contrast with value investing, a momentum strategy can involve buying when the price is extremely high, as long as the patterns in the chart suggest that it is getting higher. Preoccupied with vectors and directionality, momentum traders plot trajectories. Like the fashion-conscious or like nightlife socialites scouting the trendiest clubs, they derive their strength from obsessively asking, "where is everyone going?" in hopes of anticipating the hotspots and leaving just when things get crowded.

As with value and momentum investors, arbitrageurs also need to find an opportunity, an instance of disagreement with the market's pricing of a security. They find it by making associations. Instead of claiming a superior ability to process and aggregate information about intrinsic assets (as value investors do) or better information on what other investors are doing (as momentum traders do), the arbitrage trader tests ideas about the correspondence between two securities. Confronted by a stock with a market price, the arbitrageur seeks some other security – or bond, or synthetic security such as an index composed of a group of stocks, etc. – that can be related to it, and prices one in terms of the other. The two securities have to be similar enough so that their prices change in related ways, but different enough so that other traders have not perceived the correspondence before. As we shall see, the posited relationship can be highly

abstract. The tenuous or uncertain strength of the posited similarity or co-variation reduces the number of traders that can play a trade, hence increasing its potential profitability.

Arbitrage, then, is a distinct trading strategy. Whereas value investment is essentialist and momentum trading is extrinsic, arbitrage is associational. Whereas the value investor pegs value on intrinsic worth, and the momentum trader tracks the value assessments assigned by other investors, arbitrage traders locate value by making associations between particular properties or qualities of one security and those of other previously unrelated or tenuously related securities.

Arbitrage hinges on the possibility of interpreting securities in multiple ways. By associating one security to another, the trader highlights different properties (qualities) of the property he is dealing with.[5] In contrast to value investors who distill the bundled attributes of a company to a single number, arbitrageurs reject exposure to a whole company. But in contrast to corporate raiders, who buy companies for the purpose of breaking them up to sell as separate properties, the work of arbitrage traders is yet more radically deconstructionist. The unbundling they attempt is to isolate, in the first instance, categorical attributes. For example, they do not see Boeing Co. as a monolithic asset or property, but as having several properties (traits, qualities) such as being a technology stock, an aviation stock, a consumer-travel stock, an American stock, a stock that is included in a given index, and so on. Even more abstractionist, they attempt to isolate such qualities as the volatility of a security, or its liquidity, its convertibility, its indexability, and so on.

Thus, whereas corporate raiders break up parts of a company, modern arbitrageurs carve up abstract qualities of a security. In our field research, we find our arbitrageurs actively shaping trades. Dealing with the multiple qualities of securities as narrow specialists, they position themselves with respect to one or two of these qualities, but never all. Their strategy is to use the tools of financial engineering to shape a trade so that exposure[6] is limited only to those equivalency principles in which the trader has confidence. Derivatives such as swaps,[7] options,[8] and other financial instruments play an important role in the process of separating the desired qualities from the purchased security. Traders use them to slice and dice their exposure, wielding them in effect like a surgeon's tools – scalpels, scissors, proteases – to give the patient (the

[5] At the outset of our investigation, quantitative finance seemed an improbable setting to find actors preoccupied with qualities. On the qualification of goods in other settings and for theoretical discussions of economies of qualities, see Eymard-Duvernay (1994); Thevenot (1996); Favereau (2001); White (2001); and Callon et al (2002).

[6] The exposure created by a trade is given by the impact that a change in some variable (such as the price of an asset) can have on the wealth of the trader. Following the quantitative revolution in finance, traders think about their own work in terms of *exposure*, not in terms of *transactions*. Hence, for example, they do not use the expression "buy IBM", but say "to be long on IBM" which means that a trader stands to profit when the price of IBM rises. Similarly, they do not say "sell", but "be short on". The reason for this change in terminology is that, through the use of derivatives, traders can attain a given exposure in different ways.

[7] A swap is an agreement to exchange rights or obligations.

[8] A stock option is a derivative security that gives its holder the right to buy or sell a stock at a certain price within a given time in the future.

trader's exposure) the desired contours.

Paradoxically, much of the associative work of arbitrage is therefore for the purpose of "disentangling" (see Callon 1998 for a related usage) – selecting out of the trade those qualities to which the arbitrageur is not committed. The strategy is just as much not betting on what you don't know as betting on what you do know. In merger arbitrage, for example, this strategy of highly specialized risk exposure requires that traders associate the markets for stocks of the two merging companies and dissociate from the stocks everything that does not involve the merger. Consider a situation in which two firms have announced their intention to merge. One of the firms, say the acquirer, is a biotech firm and belongs to an index, such as the Dow Jones (DJ) biotech index. If a merger arbitrage specialist wanted to shape a trade such that the "biotechness" of the acquirer would not be an aspect of his/her positioned exposure, the arbitrageur would long the index. That is, to dissociate this quality from the trader's exposure, the arbitrageur associates the trade with a synthetic security ("the index") that stands for the "biotechness." Less categorical, more complex qualities require more complex instruments.

When, as in some forms of merger arbitrage, the process of dissociating is taken to the extreme, we could say that merger arbitrageurs trade in securities in order to bet on events. By hedging against all qualities of the stock other than the merger itself, the merger arbitrageur, in effect, is betting about the likelihood of a discrete event. You cannot go to a betting window to wager that two companies will merge (or not) on January 3rd. But with enough sophisticated instruments, you can shape your exposure to something very close to such a position.

Arbitrageurs, do not narrow their exposure for lack of courage. Despite all the trimmings, hedging, and cutting, this is not a trading strategy for the faint-hearted. Arbitrage is about tailoring the trader's exposure to the market, biting what they can chew, betting on what they know best, and avoiding risking their money on what they don't know. Traders expose themselves profusely – precisely because their exposure is custom-tailored to the relevant deal. Their sharp focus and specialized instruments gives them a clearer view of the deals they examine than the rest of the market. Thus, the more the traders hedge, the more boldly they can position themselves.

Arbitrageurs can reduce or eliminate exposure along many dimensions but they cannot make a profit on a trade unless they are exposed on at least one. In fact, they cut entanglements along some dimensions precisely to focus exposure where they are most confidently attached. As Callon (Callon and Muniesa 2002, Callon et al. 2002) argues, calculation and attachment are not mutually exclusive. To be sure, the trader's attachment is distanced and disciplined; but however emotionally detached, and however fleeting, to hold a position is to hold a conviction.

How do unexpected and tenuous associations become recognized as opportunities? In the following sections we enter the trading room to see how cognition is distributed and diversity is organized. Before examining the instruments that mediate the markets, we look first at the deployment of the traders themselves within the room. After examining the spatialized sociability of the trading room, we examine the *equipment* – the teams and the tools – of arbitrage.

The trading room as a space of sociability to make associations

The architecture and the ambiance of the trading room would be unfamiliar to someone who retired from trading several decades ago. To appreciate the changes, consider the following description of a typical Wall Street trading room in the 1980s:

> No sooner did you pass the fake fireplace than you heard an ungodly roar, like the roar of a mob... the bond trading room of Pierce & Pierce. It was a vast space, perhaps sixty by eighty feet, but with the same eight-foot ceiling bearing down on your head. It was an oppressive space with a ferocious glare, writhing silhouettes… the arms and torsos of young men… moving in an agitated manner and sweating early in the morning and shouting, which created the roar (Wolfe, 1987, p. 58).

This boiler-room imagery is absent from the Wall Street trading room of International Securities, the global investment bank where we have been conducting ethnographic research. Entering the trading room is like entering the lobby of a luxury hotel. Instead of a low ceiling, the observer finds high ceilings and a huge open space occupying almost the entire 20th floor of a skyscraper in Lower Manhattan filled with rows of desks, computers, and traders. Instead of a roar, the observer hears a hushed buzz among the traders immersed in the flickering numbers on hundreds of flat-panel screens. Instead of an oppressive space, the observer finds generous corridors, elegant watercolors on the walls, and a dramatic view of Manhattan. Instead of agitated employees, the observer finds relaxed traders in business-casual wear leisurely circulating about the trading room, coffee in hand. Instead of writhing arms and torsos, we see equations and formulae scribbled hurriedly on a large white board located prominently near the center of the trading room. And instead of a fake fireplace, the room is populated by non-human "intelligent agents," the computer programs executing automated trades, referred to by the traders themselves as "robots."

In the traditional corporate office, space is used to emphasize status differences as the hierarchy of concentric rings effectively isolates the highest-ranking employees. At International Securities, by contrast, space is used to create an atmosphere conducive to association. The open plan, not unlike the layout of a newsroom or a new media design studio, contains no cubicles or partitions. There is even a strict "low-monitor" policy enforced by Bob, the manager of the room, that prevents traders from stacking their Bloomberg monitors two- or three-high. "We try," he says, "to keep the PCs at a low level so that they can see the rest of the room."

Moreover, the social composition of the room promotes association among disparate communities of practice: the room not only accommodates traders and their assistants, but a diversity of employees, including salesmen, analysts, operation officers, and computer programmers. Flouting an industry-wide trend of relegating these latter employees to a back-office, International Securities has kept programmers and operations officers in its money-making core. They not only stay in the trading room but are given desks as large as the traders', and their area of the room has the same privileged feel as the rest. The objective, Bob states, is to prevent differences in professional status from undermining interaction among these groups. If placed in a different building, says Bob, "they might as well be in a different planet."

At 160 people, the trading room is small by current Wall Street standards. But this small number and the open plan layout were deliberately chosen to allow the type of low-key interaction that encourages experimentation and intellectual risk-taking. Bob says, "Managers, they'll tell you, 'communication, communication,' but you wonder." To make the contrast, he pointed us to the trading room of another international bank located in Connecticut:

> It's the size of three aircraft carriers. And the reason for it is that it is a source of pride to the manager. It is difficult to see how traders can communicate shouting at each other across two aircraft carriers. At [name of bank], what you'll find is chaos that looks grand.

Instead, at the trading room of International Securities,

> The key is [to avoid] social awkwardness. Two traders are talking to each other. A third needs a piece of information. He has to interrupt. 'Can I interrupt? Can I interrupt?' The key there is the social cost of the interruption. Part of my job is to keep those costs down.

Promoting sociability among traders is not an easy task. Whereas Tom Wolfe's "Masters of the Universe" were gregarious to the point of bullying, in the age of mathematical finance, arbitrageurs are intellectually over-confident, but socially inept:

> A trader is like an engineer type. Difficult when they think they're right. Abrasive. And not very social. Not socially adept. I can easily find you ten traders in the room who would be miserable at a cocktail party.

If such individualism is not addressed, it can result in fragmented territoriality in the trading room. For example, a trader recalls his experience in another bank years ago where he began his career,

> For years, there were areas of the trading floor I would never venture onto. People I never, absolutely never, talked to. There was no reason why I should go there, since we traded completely different things. Being there felt strange. There were these cold looks.

International Securities avoids this territoriality in the trading room by moving traders around. "I rotate people as much as I can," Bob says, "because sitting near each other is the best rule of thumb to predict that they will talk to each other." However, Bob is careful not to displace them too disruptively. He describes his approach as "not really shifting, more like drifting," and he continues:

> Once two traders have been sitting together, even if they don't like each other, they'll cooperate, like roommates. So, everyone gets moved every six months on average. But not everyone at a time. It's like those puzzles with one empty space in which you move only one piece at a time.

This emphasis on cooperative interaction underscores that the cognitive tasks of the arbitrage

trader are not those of some isolated contemplative, pondering mathematical equations and connected only to a screen-world. Cognition at International Securities is a distributed cognition. The formulas of new trading patterns are formulated in association with other traders. Truly innovative ideas, as one senior trader observed, are slowly developed through successions of discreet one-to-one conversations,

> First you talk to others. You tell someone else, 'I've got this great idea,' and if he tells you 'I read it yesterday in Barron's,' you drop it. If you get a positive take, then you work it around.

An idea is given form by trying it out, testing it on others, talking about it with the "math guys," who, significantly, are not kept apart (as in some other trading rooms), and discussing its technical intricacies with the programmers (also immediately present). Because they have been stirred up by the subtle churning of the room, traders can test the ideas on those with whom they were once "like roommates" but who might now be sitting in different parts of the room. Appropriately, the end of this process of formulation (and the beginning of the next stage of material instrumentation, see below) is known as a "victory lap" – a movement around the room in and through which the idea was generated. Place facilitates sociability to make associations.

And where is Bob, the trading room manager? He sits in the middle of the room despite the fact that he has a very well-appointed office in one corner, complete with designer furniture, a small conference table, and a home cinema-sized Bloomberg screen to watch the markets that can be controlled from a wireless mouse and keyboard. But he prefers to sit in a regular trader's desk in the middle of the room.

> I have that office over there – you just saw it. But I like this place better [referring to his desk]. Here, I am more connected. No one would come to tell me stories if they had to come into my office. Also, here I get a feel for how the market is doing. I have to know this, because the atmosphere definitely influences the way these guys trade.

In this way, the trading room at International Securities overturns the traditional concentric circles of status. Rather than enjoying less accessibility, the trading room manager is the most accessible. He is most easily reached; and he is best positioned to observe, indeed to sense, what is happening in the room.

What is happening is more than exchange of information. To be sure, traders must have access to the most timely and complete array of information; but this is not enough. In addition to being a nexus of data flows, the trading room is a room of bodies. Taking its collective "pulse" is a means to take the pulse of the markets. Whereas Knorr Cetina and Bruegger find their foreign currency traders "viscerally plugged into the screen reality of the global sphere" (2002:15), our arbitrage traders are reflective about how they are acutely attuned to the social reality of the local sphere:

> The phone and on-line communication are inefficient. It takes longer for people to tell each other what they want. You miss body language. Body language and facial expressions are really important. You're not conscious of body language

> and so it's another channel of communication, and it's one that's not deliberate. So it's a good source for what's happening. I don't try to get too conscious of how I'm reading body language and facial expressions. I just let it work its way to where it's useful.

Bob's observations (and those of many other traders with whom we spoke) highlight that cognition in the trading room is not simply distributed. It is also a situated calculation. A trader needs tools – the financial instruments of derivatives and the material instruments to execute a trade. But in addition to these calculative instruments, the trader also needs a "sense of the market." Knowing how to use the tools combines with knowing how to read the situation. This situated awareness is achieved by drawing on the multiple sensors (both human and instrumental) present within the room.

The trading room thus shows a particular instance of Castells' paradox: As more information flows through networked connectivity, the more important become the kinds of interactions grounded in a physical locale. New information technologies, Castells (2000) argues, create the possibility for social interaction without physical contiguity. The downside is that such interactions can become repetitive and programmed in advance. Given this change, Castells argues that as distanced, purposeful, machine-like interactions multiply, the value of less-directed, spontaneous, and unexpected interactions that take place with physical contiguity will become greater (see also Thrift 1994; Brown and Duguid 2000; Grabher 2002). Thus, for example, as surgical techniques develop together with telecommunications technology, the surgeons who are intervening remotely on patients in distant locations are disproportionately clustering in two or three neighborhoods of Manhattan where they can socialize with each other and learn about new techniques, etc.[9]

From the perspective of arbitrage as association, trading rooms can be seen as the "space of place" where novel associations emerge. One exemplary passage from our fieldnotes finds a senior trader formulating an arbitrageur's version of Castells' paradox:

> It's hard to say what percentage of time people spend on the phone vs. talking to others in the room. But I can tell you the more electronic the market goes, the more time people spend communicating with others inside the room.

The Trading Room as an Ecology of Evaluative Principles

Pattern Recognition at the Desk

From looking at the trading room as a simple society of individuals, we now turn to examine the teams that compose the trading room as a more complex organization of diversity. This organization of diversity begins by demarcating specialized functions. The basic organizational unit, "team," has a specific equipment, "desk." The term "desk" not only denotes the actual

[9] Castells' observations are consistent with findings in much of the Computer-Supported Cooperative Work literature on automated control rooms (see, for example, Heath et. al 1995).

piece of furniture where traders sit, but also the actual team of traders – as in "Tim from the equity loan desk." Such identification of the animate with the inanimate is due to the fact that a team is never scattered across different desks. In this localization, the different traders in the room are divided into teams according to the financial instrument they use to create equivalencies in arbitrage: the merger arbitrage team trades stocks in companies in the process of consolidating, the options arbitrage team trades in "puts" and "calls,"[10] the derivatives that lend the desk its name, and so on. The desk is an intensely social place. The extreme proximity of the workstations enables traders to talk to each other without lifting their eyes from the screen or interrupting their work. Lunch is at the desk, even if the sandwich comes from a high-end specialty deli. Jokes are at the desk, a never-ending undercurrent of camaraderie that resurfaces as soon as the market gives a respite.

Each desk has developed its own way of looking at the market, based on the principle of equivalence that it uses to calculate value and the financial instrument that enacts its particular style of arbitrage trade. For example, traders at the merger arbitrage desk value companies that are being acquired in terms of the price of the acquiring firm and specialize in asking, "how solid is company X's commitment to merge. For merger arbitrage traders, the companies in the S&P 500 index are little more than a set of potential acquirers and acquisition targets. In contrast, traders at the index arbitrage desk exploit discrepancies between the price of index securities (e.g., futures on the S&P 500 index) and the actual average price of the companies that constitute such indexes. Given the minuscule and rapidly vanishing nature of the misalignments among these two, they need to trade in high-volume and at a high-speed. Traders at the convertible bond arbitrage desk look at stocks as bonds, and specialize in information about stocks that would typically interest bondholders such as their liquidity and likelihood of default. The traders at the customer sales desk, meanwhile, take and propose orders to customers outside the confines of the room. Although not specialized in a distinct financial instrument, this most sociable team in the room provides a window on the anxiety level of their customers and thus of the market at large by the sound of their voices on the phone and the banging of headsets against their desks in frustration.

A desk generates its own form of pattern recognition. For example, merger arbitrage traders, keen on finding out the degree of commitment of two merging companies, look for patterns of companies' progressive approximation in stock prices. They probe commitment to a merger by plotting the "spread" (difference in price) between acquiring and target companies over time. As with marriages between persons, mergers between companies are scattered with regular rituals of engagement intended to persuade others of the seriousness of their intent. As time passes, arbitrage traders look for a pattern of gradual decay in the spread as corporate bride and groom come together. A similar correspondence of tools and concepts can be found at other desks.

Such joint focus on visual and economic patterns creates, at each desk, a distinctive community of practice around an evaluative principle with its own tacit knowledge. Traders at a desk develop a common sense of purpose, a real need to know what each other knows, a highly specialized language, and idiosyncratic ways of signaling to each other. This sense of joint membership translates into friendly rivalry toward other desks. A customer sales trader, for example, took us aside to denounce statistical arbitrage as "like playing video games. If you

[10] A put is a financial option that gives its holder the right to sell. A call gives the right to buy.

figure out what the other guy's program is, you can destroy him. That's why we don't do program trades," he explained, referring to his own desk. Conversely, one of the statistical arbitrage traders, told us, in veiled dismissal of manual trading, that the more he looked at his data (as opposed to letting his robot trade) the more biased he becomes.

Within each desk, there is a marked consistency between the trading strategy, mathematical formulae, and tools for pattern recognition that traders use. Merger arbitrage traders, as Table 1 shows, plot spreads on their screens but do not use convertible bond valuation models; neither do they employ Black-Scholes equations nor draw on principles of mean-reversion. Convertible arbitrage traders, by contrast, use bond valuation models but do not obsess about whether the spread between two merging companies is widening or narrowing. Customer sales traders are more keen on executing their clients' orders on the day they receive them than on following for months the evolution of the spread between two merging stocks.

Insert Table 1 about here.

The complex trades that are characteristic of our trading room, however, seldom involve a single desk/team in isolation from others. It is to these collaborations that we turn.

Connect to cut, co-locate to dissociate

The desk, in our view, is a unit organized around a dominant evaluative principle and its arrayed financial instruments (devices for measuring, testing, probing, cutting). This principle is its coin; if you like, its specie. But the trading room is composed of multiple species. It is an ecology of evaluative principles. Complex trades take advantage of the interaction among these species. To be able to commit to what counts, to be true to your principle of evaluation, each desk must take into account the principles and tools of other desks. Recall that shaping a trade involves disassociating some qualities in order to give salience to the ones to which your desk is attached. To identify the relevant categories along which exposure will be limited, shaping a trade therefore involves active association among desks. Co-location, the proximity of desks, facilitates the connections needed to do the cutting. Figure 2 presents the spatial positioning of the various desks in the trading room at International Securities.

Insert Figure 2 about here.

Whereas in most textbook examples of arbitrage the equivalence-creating property is easy to isolate, in practice, it is difficult to fully disassociate. Because of these difficulties, even after deliberate slicing and dicing, traders can still end up dangerously exposed along dimensions of the company that differ from the principles of the desired focused exposure. We found that traders take into account unintended exposure in their calculations in the same way as they achieve association: through co-location. Physical proximity in the room allows traders to survey the financial instruments around them and assess which additional variables they should take into account in their calculations.

For example, the stock loan desk can help the merger arbitrageurs on matters of liquidity. Merger arbitrage traders lend and borrow stock as if they could reverse the operation at any moment of time. However, if the company is small and not often traded, its stock may be difficult to borrow, and traders may find themselves unable to hedge. In this case, according to Max, senior trader at the merger arbitrage desk, "The stock loan desk helps us by telling us how difficult it is to borrow a certain stock." Similarly, index arbitrageurs can help merger arbitrageurs trade companies with several classes of shares. Listed companies often have two types of shares, so-called "A-" and "K-class" stock. The two carry different voting rights, but only one of the two types allows traders to hedge their exposure. The existence of these two types facilitates the work of merger arbitrageurs, who can execute trades with the more liquid of the two classes and then transform the stock into the class necessary for the hedge. But such transformation can be prohibitively expensive if one of the two classes is illiquid. To find out, merger arbitrageurs turn to the index arbitrage team, which exploits price differences between the two types.

In other cases, one of the parties may have a convert provision (that is, its bonds can be converted into stocks if there is a merger) to protect the bondholder, leaving merger arbitrage with questions about how this might affect the deal. In this case, it is the convertible bond arbitrage desk that helps merger arbitrage traders clarify the ways in which a convertibility provision should be taken into account. "The market in converts is not organized," says Max, in the sense that there is no single screen representation of the prices of convertible bonds. For this reason,

> We don't know how the prices are fluctuating, but it would be useful to know it because the price movements in converts impacts mergers. Being near the converts desk gives us useful information.

In any case, according to Max, "even when you don't learn anything, you learn there's nothing major to worry about." This is invaluable because, as he says, "what matters is having a degree of confidence."

By putting in close proximity teams that trade in the different financial instruments involved in a deal, the bank is thereby able to associate different markets into a single trade. As a senior trader observed,

> While the routine work is done within teams, most of the value we add comes from the exchange of information between teams. This is necessary in events that are unique and non-routine, transactions that cross markets, and when information is time-sensitive.

Thus, whereas a given desk is organized around a relatively homogeneous principle of evaluation, a given trade is not. Because it involves hedging exposure across different properties along different principles of evaluation, any given trade can involve heterogeneous principles and heterogeneous actors across desks. If a desk involves simple teamwork, a (complex) trade involves collaboration. This collaboration can be as formalized as a meeting (extraordinarily rare at International Securities) that brings together actors from the different desks. Or it might be as primitive as an un-directed expletive from the stock loan desk which, overheard, is read as a signal by the merger arbitrage desk that there might be problems with a given deal.

Practices of Re-cognition

How do the creativity, vitality, and serendipity stemming from the trading room yield new interpretations? By interpretation we refer to processes of categorization, as when traders answer the question, "what is this a case of?" but also processes of re-categorization such as making a case for. Both work by association – of people to people, but also of people to things, things to things, things to ideas, etc.

We saw such processes of re-cognition at work in the following case of an announced merger between two financial firms. The trade was created by the "special situations desk," its name denoting its stated aim of cutting through the existing categories of financial instruments and derivatives. Through close contact with the merger arbitrage desk and the equity loan desk, the special situations desk was able to construct a new arbitrage trade, an "election trade," that recombined in an innovative way two previously existing strategies, merger arbitrage and equity loan.

The facts of the merger were as follows: on January 25th, 2001, Investors Group announced its intention to acquire MacKenzie Financial. The announcement immediately set off a rush of trades from merger arbitrage desks in trading rooms all over Wall Street. Following established practice, the acquiring company, Investors Group, offered the stockholders of the target company to buy their shares. It offered them a choice of cash or stock in Investors Group as means of payment. The offer favored the cash option. Despite this, Josh, head of the special situations desk, and his traders, reasoned that a few investors would never be able to take the cash. For example, board members and upper management of the target company are paid stocks in order to have an incentive to maximize profit. As a consequence, "it would look wrong if they sold them" John said. In other words, their reasoning included "symbolic" value, as opposed to a purely financial profit-maximizing calculus.

The presence of symbolic investors created, in effect, two different payoffs – cash and stock. The symbolic investors only had access to the smaller payoff. As with any other situation of markets with diverging local valuations, this could open up an opportunity for arbitrage. But how to connect the two payoffs?

In developing an idea for arbitraging between the two options on election day, the special situations desk benefited crucially from social interaction across the desks. The special situations traders sit in between the stock loan and merger arbitrage desks. Their closeness to the stock loan desk, which specialized in lending and borrowing stocks to other banks, suggested to the special situations traders the possibility of lending and borrowing stocks on election day. They also benefited from being near the merger arbitrage desk, as it helped them understand how to construct an equivalency between cash and stock. According to Josh., head of the special situations desk,

> [The idea was generated by] looking at the existing business out there and looking at it in a new way. Are there different ways of looking at merger arb? … We imagined ourselves sitting in the stock loan desk, and then in the merger arbitrage desk. We asked, is there a way to arbitrage the two choices, to put one choice in terms of another?

The traders found one. Symbolic investors did not want to be seen exchanging their stock for cash, but nothing prevented another actor such as International Securities from doing so directly. What if the special situation traders were to borrow the shares of the symbolic investors at the market price, exchange them for cash on election day (i.e., get the more favorable terms option), buy back stock with that cash and return it to symbolic investors? That way, the latter would be able to bridge the divide that separated them from the cash option.

Once the special situation traders constructed the bridge that separated the two choices in the election trade, they still faced a problem. The possibilities for a new equivalency imagined by Josh and his traders were still tenuous and untried. But it was this very uncertainty – and the fact that no one had acted upon them before – that made them potentially so profitable. The uncertainty resided in the small print of the offer made by the acquiring company, Investors Group: how many total investors would elect cash over stock on election day?

The answer to that question would determine the profitability of the trade: the loan and buy-back strategy developed by the special situations traders would not work if few investors chose cash over stocks. IG, the acquiring company, intended to devote a limited amount of cash to the election offer. If most investors elected cash, IG would prorate its available cash (i.e., distribute it equally) and complete the payment to stockholders with shares, even to those stockholders who elected the "cash" option. This was the preferred scenario for the special situation traders, for then they would receive some shares back and be able to use them to return the shares they had previously borrowed from the "symbolic" investors. But if, in an alternative scenario, most investors elected stock, the special situations desk would find itself with losses. In that scenario, IG would not run out of cash on election day, investors who elected cash such as the special situations traders would obtain cash (not stocks), and the traders would find themselves without stock in IG to return to the original investors who lent it to them. Josh and his traders would then be forced to buy the stock of IG on the market at a prohibitively high price.

The profitability of the trade, then, hinged on a simple question: would most investors elect cash over stock? Uncertainty about what investors would do on election day posed a problem for the traders. Answering the question, "what will others do?" entailed a highly complex search problem, as stock ownership is typically fragmented over diverse actors in various locations applying different logics. Given the impossibility of monitoring all the actors in the market, what could the special situation traders do?

As a first step, Josh used his Bloomberg terminal to list the names of the twenty major shareholders in the target company, MacKenzie Financial. Then he discussed the list with his team to determine their likely action. As he recalls,

> What we did is, we [would] meet together and try to determine what they're going to do. Are they rational, in the sense that they maximize the money they get?

For some shareholders, the answer was straightforward: they were large and well-known companies with predictable strategies. For example, Josh would note:

> See... the major owner is Fidelity, with 13%. They will take cash, since they have a fiduciary obligation to maximize the returns to their shareholders.

But this approach ran into difficulties in trying to anticipate the moves of the more sophisticated companies. The strategies of the hedge funds engaged in merger arbitrage were particularly complex. Would they take cash or stock? Leaning over, without even leaving his seat or standing up, Josh posed the question to the local merger arbitrage traders:

> "Cash or stock?" I shouted the question to the merger arbitrage team here who were working [a different angle] on the same deal right across from me. "Cash! We're taking cash," they answered.

From their answer, the special situations traders concluded that hedge funds across the market would tend to elect cash. They turned out to be right.

The election trade illustrates the ways in which co-location helps traders innovate and take advantage of the existence of multiple rationalities among market actors. In some ways, the election trade can be seen as a re-combination of the strategies developed by the desks around special situations. Proximity to the stock loan desk allowed them to see an election day as a stock loan operation, and proximity to risk arbitrage allowed them to read institutional shareholders as profit maximizers, likely to take cash over stock.

The trade also shows that connectivity and electronic markets play a role that is complementary to place. With easy and automatic access to timely data on prices and transactions, the special situations traders were able to see two payoffs that could be connected in the election trade. The Bloomberg terminals subsequently allowed them to find out the identity of major shareholders. Finally, co-location in the trading room gave them confidence to make a tenuous and uncertain equivalency.

The Trading Room as a Laboratory

In the previous section we showed how calculation is not individual and asocial, but instead is distributed across various desks in the trading room. In this section we argue that calculation is distributed across socio-technical networks of tangible tools that include computer programs, screens, dials, robots, telephones, mirrors, cable connections, etc.

Although financial instruments (derivatives such as futures, options, swaps, etc) are deemed worthy of study in The Journal of Finance, these material instruments supposedly belong to the province of handymen, contractors, and electricians. But traders know they are important, if only because they spend so much time acquiring skills to use, construct and maintain these instruments. Without instruments for visualizing properties of the market, they could not see opportunities; and without instruments for executing their trades, they could not intervene in markets. No tools, no trade.

To see opportunities, traders put on the financial equivalent of infrared goggles that provide them with the trader's equivalent of night-vision. They also delegate calculation to robots that single-

mindedly execute their programmed theories, and they scan the room for clues that alert them to the limits in the applicability of these theories.

One cannot appreciate the degree to which quantitative finance is knowledge-intensive without considering the complexity of the trader's tools. According to Knorr Cetina and Bruegger (2002), traders do not quite match up to scientists: when compared to high-energy physicists and their twenty-year long experiments, traders appear as having flat production functions that instead of transforming data merely transpose it onto the screen. By contrast, we found our traders' tools remarkably close to Latour's (1987) definition of scientific instruments as inscription devices that shape a view. Scientific instruments, whether a radio telescope, a Geiger counter, or a Petri dish, display phenomena that are often not visible to the naked eye. They reveal objects in space, radiation waves, or minuscule bacteria that could otherwise not be discerned. Similarly, the trader's tools reveal opportunities that are not immediately apparent. Both scientists and traders derive their strengths – persuasiveness in the former, profits in the latter – from original instrumentation.[11]

Perhaps the most salient instruments at International Securities are the traders' Bloomberg workstations and their individually-customized screens. These dramatic extra-wide high-contrast Bloomberg flat panel monitors serve as their workbench. Bloomberg terminals include a specialized monitor, color-coded keyboard and a direct Intranet cable connection to Bloomberg L.P. Even more expensive than the physical terminals is the software that comes with them, structured around five areas that include data (prices, volume, etc.), analytics for parsing and visualizing the data, news (from 1000 journals around the world), trading support, and information on trade execution. Just as traders are on the look-out for specialized software, they individually taylor their digital workbenches in ways as elaborate as they are diverse: At International Securities, no two screens are the same. Screen instruments are not mere transporters of data, but select, modify and present data in ways that shape what the trader sees.

Take, for example, the case of Stanley H., junior trader at the customer trading desk. Like others at his desk, Stan executes arbitrage trades for clients. He does not need to come up with new trades himself, but only to find out the points in time in which he can execute the client's orders. For this purpose, he needs to know the general direction of the market, current developments regarding the companies he is trading, and whether he can trade or not. His is a world of the here and now. To grapple with it, Stan has arranged on his screens instruments such as a "magnifying glass," trading "baskets," and "active links."

Stan's point of departure is the baseline information that everyone has: a Bloomberg window that graphs the Dow Industrials and the NASDAQ market indexes to give him information on the market's general direction, bullish or bearish. Next to it, another instrument provides a more personalized perspective. A window that he calls his "magnifying glass" displays 60 crucial stocks that he considers representative of different sectors such as chips, oil, or broadband. Visually, the numbers in this window momentarily increase in size when an order is received, resembling a pulsating meter of live market activity. Stan complements the magnifying glass

[11] For insightful treatments of the interaction between valuation and technology in the field of finance, see Preda's (2002) historical study of the ticker and its effects on investor behavior, and Muniesa´s (2002) study of the use of telephones in trading rooms.

with the “footprints” of his competitors in tables that display rival banks’ orders in the stocks that he trades.

Stan’s screens include a clipboard for his operations, an arrangement that simplifies and automates part of the cognitive work involved in making the trades. This is composed of several “trading baskets,” windows that show the trades that he has already done. An additional instrument shows pending work. This is contained in an Excel spreadsheet in which Stan introduces entries with “active links” to stock prices, that is, cells that are automatically updated in real time. In the cells next to the links Stan has programmed the conditions that the clients give to him (e.g., “set the spread at 80,”). As a result, another cell changes color depending on whether the conditions are met or not (cyan means they are; dark green means they are not). The computer, then, does part of the calculation work for Stan. Instead of having to verify whether the conditions hold to execute each of the trades, he follows a much simpler rule: trade if the cell is cyan do not trade if it is dark green.

Stan is a toolmaker as much as a “trade maker,” a craftsman of tools as much as a processor of information. He devotes considerable deliberation to the conscious inscription of his screens. Everyday, one hour before the markets open, he arrives to the trading room to prepare his setup; part of that preparation is readying the screens. One by one, Stan opens each of his windows and places them in their customary place, ensures they have their own color and size and creates new active links as customers order new trades, and discusses possible technical issues with the computer programmers.

Two desks away, Richard C. at the convertible bond arbitrage desk looks at stocks from a very different perspective – as if they were bonds. As noted above, traders in convertible bond arbitrage such as Richard seek to exploit the value of the so-called “convertibility” option that is sometimes included in bonds. These allow the bondholder to convert the bond into a stock, in effect morphing one type of security into another. To assess the value of the option to convert, Richard uses Bloomberg’s proprietary “Convertible Bond Valuation” model, that returns an estimated value of the bond given basic parameters such as volatility of the stock, its delta, gamma, etc. Richard’s models can be seen as a pair of goggles that highlight the hidden value of convertibility options.

Close to the bond arbitrage desk, Max Sharper at the merger arbitrage desk exploits profit opportunities when companies merge. As noted, merger arbitrage traders long the company that is the acquisition target and short the acquirer. In doing so, their trades end up as a bet on the probability that the merger will take place. To decide whether or not to bet on a merger, Max plots the “spread” or price difference between the companies in merger talks. If two companies merge they will be worth the same, and their spread will be zero. As the merger unfolds, a small spread denotes market confidence in the merger, and a large spread denotes skepticism. Max plots the spread in time to read back from it the “implied probability” that the market assigns to the merger. As with the other traders, Max’s spread plots serve as an optical device that brings into focus actors’ confidence about a given merger.

The visualization techniques of on-screen instruments, then, are as varied as the principles of arbitrage that guide each desk. Stan's desk executes trades, and the magnifying glasses, trading baskets, rivals’ footprints, and active links on his screens display momentary instances of open

windows of opportunity in a geometric array of white, green, blue, and cyan squares with numbers dancing in them, lending it the appearance of an animated painting by Piet Mondrian. Richard's desk buys and sells convertible bonds, and the bond valuation models on his screens display a more conventional text interface, a boxy black-on-white combination suggestive of 1980s-style minicomputer screens. The spread plots for betting on mergers on Max's screens show charts, narrow white lines that zigzag in a snake-like manner from left to right over the soothing blue background of his monitor.

The traders' reliance on such goggles, however, entails a serious risk. In bringing some information into sharp attention, the software and the graphic representations on their screens also obscure. In order to be devices that magnify and focus, they are also blinders. According to one, "Bloomberg shows the prices of normal stocks; but sometimes, normal stocks morph into new ones," such as in situations of mergers or bond conversions. If a stock in Stan's magnifying glass – say, an airline that he finds representative of the airline sector – were to go through a merger or bond conversion, it would no longer stand for the sector.

An even more serious risk for the traders is that distributing calculation across their instruments amounts to inscribing their sensors with their own beliefs. As we have seen, in order to recognize opportunities, the trader needs special tools that allow him to see what others cannot. But the fact that the tool has been shaped by his theories means that his sharpened perceptions can sometimes be highly magnified misperceptions, perhaps disastrously so. For an academic economist who presents his models as accurate representations of the world, a faulty model might prove an embarassment at a conference or seminar. For the trader, however, a faulty model can lead to massive losses. There is, however, no option not to model: no tools, no trade. What the layout of the trading room – with its interactions of different kinds of traders and its juxtaposition of different principles of trading – accomplishes is the continual, almost minute-by-minute, reminder that the trader should never confuse representation for reality.

Instead of reducing the importance of social interaction in the room, the highly specialized instruments actually provide a rationale for it. "We all have different kinds of information," Stan says, referring to other traders, "so I sometimes check with them." How often? "All the time."

Hence, just as Latour (1987) defined a laboratory as "a place that gathers one or several instruments together," trading rooms can be understood as places that gather diverse market instruments together. Seen in this light, the move from traditional to modern finance can be considered as an enlargement in the number of instruments in the room, from one to several. The best scientific laboratories maximize cross-fertilization across disciplines and instruments. For example, the Radar Lab at MIT in the 1940s made breakthroughs by bringing together the competing principles of physicists and engineers (Galison 1996; on the architecture of science, see Galison and Thompson 1999). Similarly, the best trading rooms bring together heterogeneous value frameworks for creative recombinations.

Monitoring the price mechanism

Another example of distributed calculation can be found in "robots," computer programs used by statistical arbitrage traders that automate the process of buying and selling stocks. As with the

other market instruments of the trading room, robots bring benefits but also pose new challenges that are solved by intermingling the social, the cognitive, and the artifactual.

Robots are representations as well as tools for automation. Inscribed with the trader's beliefs, they execute only the trading strategy they were programmed to perform. For example, in deciding whether to buy or sell stocks, a mean reversion robot only takes into account whether the prices are close or distant from their historic average price, while an earnings robot only considers the companies' earnings. Robots enact a complex set of assumptions about the market, and they process an active selection of the available data that are consistent with it.

Sociability in the room is crucial from the moment of the robot's inception, a process of codifying tacit knowledge into algorithms and computer code. This takes place at the whiteboard, in meetings of heterogeneous perspectives that might include, for example, an index arbitrage trader, a computer programmer, and a merger arbitrage trader. Starting from the whiteboard, an idea for a trade mutates in form from a trader's utterances, to graphs on the board, to abstract models, to mathematical equations, and finally into computer code. The robot is quite literally codified knowledge.

Once codified into a computer program, the robot goes to work with traders specialized in implementing computer programs such as the statistical arbitrage desk. But the story does not end here. Piloting a robot requires inputs from a kind of emergent traffic control – cues and signals from other parts of the room.

Consider the case of Tom, a trader at the statistical arbitrage desk. Instead of trading manually Tom uses and maintains a robot. Automated trading poses the same challenge as driving a car at a high speed: any mistake can lead to disaster very quickly. "I have," Tom says, "a coin that comes up heads 55% of the time." With margins as low as 0.05, the only route to high returns is trading a very high volume or, as Tom says of the coin, "the point is to flip it a lot." As with Formula 1 car racing or high speed boating, traders need excellent instrumentation. Indeed, they have navigation instruments as complex as an airplane cockpit. Yet, as it turns out, these are not enough. The price mechanism has to be monitored, and calibrated; and for that purpose Tom obtains crucial cues from the social interactions at the desks around him.

To illustrate the sensitivity of results to timely data (in which the units of measurement are frequently seconds rather than minutes), Tom recounts an instance in which a slight time delay lost millions of dollars for a competing bank – and earned them for International Securities. On that specific day, some banks had been receiving price information with a delay because of problems with the Reuters server. Price movements had been large all through the day, and the market index had risen very quickly. In a rising market, a delay makes the index appear consistently below its real level. In contrast to spot prices, prices for futures contracts were arriving to all banks with no delay. As a result, index arbitrage traders at one bank (traders who exploit differences between spot and S&P 500 futures) perceived as inexpensive securities that were in fact very expensive, and bought extensively. Tom and others at International Securities, in contrast, were getting timely information on both spot and futures prices (see fig. 3). Tom recounts,

> While they were buying, we were selling... the traders here were writing tickets

> until their fingers were bleeding. We made $2 million in an hour, until they realized what was happening.

The episode illustrates the challenges of working with robots. When trading at Formula 1 speed, "the future" is only seconds away. When the speed of trading amplifies second-by-second delays, the statistical arbitrage trader must be attuned to a new kind of problem: by how many seconds are the data delayed? That is, traders have to remind themselves of the time lag that elapses between what they see – the numbers on their screens – and actual prices. The prices that matter are those that reside in the computer servers of the market exchange, be it the NASDAQ or the New York Stock Exchange, for that is where the trades are ultimately executed. What traders see on-screen are bits and bytes that have been transported from the exchange to the trading room in a long and sometimes difficult path of possible delays. If traders mistakenly take delayed data for real-time data, losses will pile up quickly. In that situation, delegating the trading decisions to the robot could lead to disaster. How do the statistical arbitrage traders prevent these disasters from taking place?

The first line of defense against the risks of high volume, high speed, automated trading is more technology. Tom's robot provides him with as many dials as a cockpit in an airplane. He trades with three screens in front of him. Two of them correspond to powerful Unix workstations and the third one is a Bloomberg terminal. One Unix terminal has real-time information about his trades. Across the top of one, a slash sign rotates and moves from side to side. It is a "pulse meter" to gauge the "price feed," i.e., the speed with which information on prices is arriving to him. The character stops moving when prices stop arriving. It is very important to be aware when this happens, because the price robot can get confused. According to Tom, "it thinks that prices aren't changing and it imagines false opportunities, while in reality prices are moving but not arriving to it."

Tom benefits from numerous additional dials. On the right hand-side corner of his second Unix station Tom has five squares; each of them is a speedometer that indicates how quickly the orders are getting through the servers of the specialists or electronic communication networks. If they are green, everything is fine. If they are yellow, the network is congested and deals are delayed. If they are red, servers are clogged. The clocks in the Unix workstations are synchronized everyday to the Atomic Clock. In addition to a large display of an analog clock in his computer, Tom has two "CPU-meters" which measure congestion in the bank's order flow. When it is engaged for long periods of time, orders take longer to execute. Thus, to monitor prices in the market, traders must monitor the price mechanism – literally, they must monitor the machines that bring and make prices.

Technology, however, is not the only answer to the problem of execution, for the dials that measure the accuracy of the technology are a representation themselves. Technology, in other words, answers one question, "is the robot getting the data?" but raises another one, "is the robot right in what it says?" We call this infinite-regress problem the "calibration" problem.

The nuclear accident at Chernobyl showed an acute case of calibration problems. Radiation was so high that the dials of the Geiger counters of the control room of the Soviet nuclear power station did not register any abnormal level of radiation even at the peak of the escape. The dials, calibrated to register nuances, failed to detect the sharp increase in radiation levels. Technology

permits the execution of automated tasks, but it requires appropriate calibration.

How to solve the calibration problem? Tom solves it by drawing on the social and spatial resources of the trading room. He sits in between the merger arbitrage desk and the systems desk. According to Tom,

> When you hear screams of agony around you, it indicates that perhaps it is not a good time to trade. If I hear more screams, maybe I should not use the system even if it's green.

Similarly, price feed in stocks and futures has to come at the same speed. By sitting near the futures arbitrage desk, the stat arb trader can remain alert to any anamoly in the data feed. In addition to getting a sense of when to turn off their robots, statistical arbitrage traders interpret cues from nearby desks to gauge when to take a particular security out of automated trading. The instruments of representation that make up the technology of finance retain their value only so long as they remain entangled in the social relations that spawned them. A trader's tools are socio-technical.

This socio-technical character, finally, governs the placement of the robots in the trading room. While promoting association through proximity, the trading room also uses distance to preserve the requisite measure of variety among the robots. Instead of minimizing differences to produce a "one right way" to calculate, the trading room actively organizes diversity. Of the four statistical arbitrage robots, a senior trader observed,

> We don't encourage the four traders in statistical arb to talk to each other. They sit apart in the room. The reason is we have to keep diversity. We could really get hammered if the different robots would have the same P &L [profit and loss] patterns and the same risk profiles.

Seemingly at odds with the policy of putting all the traders of the same function at the same desk, the statistical arbitrage traders and their robots are scattered around the room. Why? Because the robots, as the traders say, are partly "alive" – they evolve. That is, they mutate as they are maintained, re-tooled, and re-fitted to changes in the market. They are kept separated to reduce the possibility that their evolution will converge (thereby resulting in a loss of diversity in the room). But they are, of course, not pushed out of the room entirely because a given stat arb unit cannot be too far from the other types of arbitrage desks – proximity to which provides the cues about when to turn off the robots.

Conclusion

In the preface to Novum Organum, one of the founding documents of modern science, Francis Bacon (1620/1960) wrote that "in every great work to be done by the hand of man it is manifestly impossible, without instrumentation and machinery, either for the strength of each to be exerted or the strength of all to be united (Bacon, 1620/1960:35)." These observations about the importance of instrumentation were a key part of Bacon's broader goal to outline a new course of discovery. Writing in an age when the exploration, conquest, and settlement of territory was enriching European sovereigns, Bacon proposed an alternative strategy of exploration. In

place of the quest for property, for territory, Bacon urged a search for properties, the properties of nature, arguing that this knowledge, produced at the workbench of science, would prove a yet vaster and nearly inexhaustible source of wealth.[12]

Just as Bacon's experimentalists at the beginnings of modern science were in search of new properties, so our arbitrage traders at the beginnings of quantitative finance are in search of new properties – as different from the old notions of property of value investors or momentum traders as Bacon's was from the conquest of territory. And just as Bacon, in the more standard reading, was advocating a program of inductive, experimentalist science in contrast to logical deduction, so our arbitrage traders, in contrast to the deductive stance of neo-classical economists, are actively experimenting to uncover properties of the economy. But whereas Bacon's New Instrument was part of a program for "The Interpretation of Nature,"[13] the new instruments of quantitative finance – connectivity, equations, and computing – visualize, cut, probe, and dissect ephemeral properties in the project of interpreting markets. In the practice of their trading room laboratories, our arbitrage traders are acutely aware that the reality "out there" is a social construct consisting of other traders and other interconnected instruments continuously reshaping, in feverish innovation, the properties of that recursive world. In this co-production, in which the products of their interventions become a part of the phenomenon they are monitoring, such reflexivity is an invaluable component of their tools of the trade.

Economic sociologists, we have argued, need to make the study of technology a part of the tools of our trade. When economists or sociologists study technology, it is most frequently as a specialized subfield, e.g., the social studies of science or the economics of technological innovation. Such research is invaluable. But we should also incorporate the study of technology in the core subfields of our disciplines. In our epoch organizational design, for example, is inseparable from design of the digital interface. Similarly, to understand not only the mathematics but also the machines that makeup the sophisticated market instruments of quantitative finance we need to analyze the entanglements of actors and instruments in the socio-technology of the trading room laboratory.

[12] We owe this insightful reading of Bacon's writings, including Novum Organum and his (often unsolicited) "advices" to his sovereigns, Elizabeth I and James I, to Monique Girard.

[13] *Novum Organum* translates as "New Instrument." Bacon contrasts the deductive method of "Anticipation of the Mind" to his own method of "Interpretation of Nature" (Bacon 1620/1960:37).

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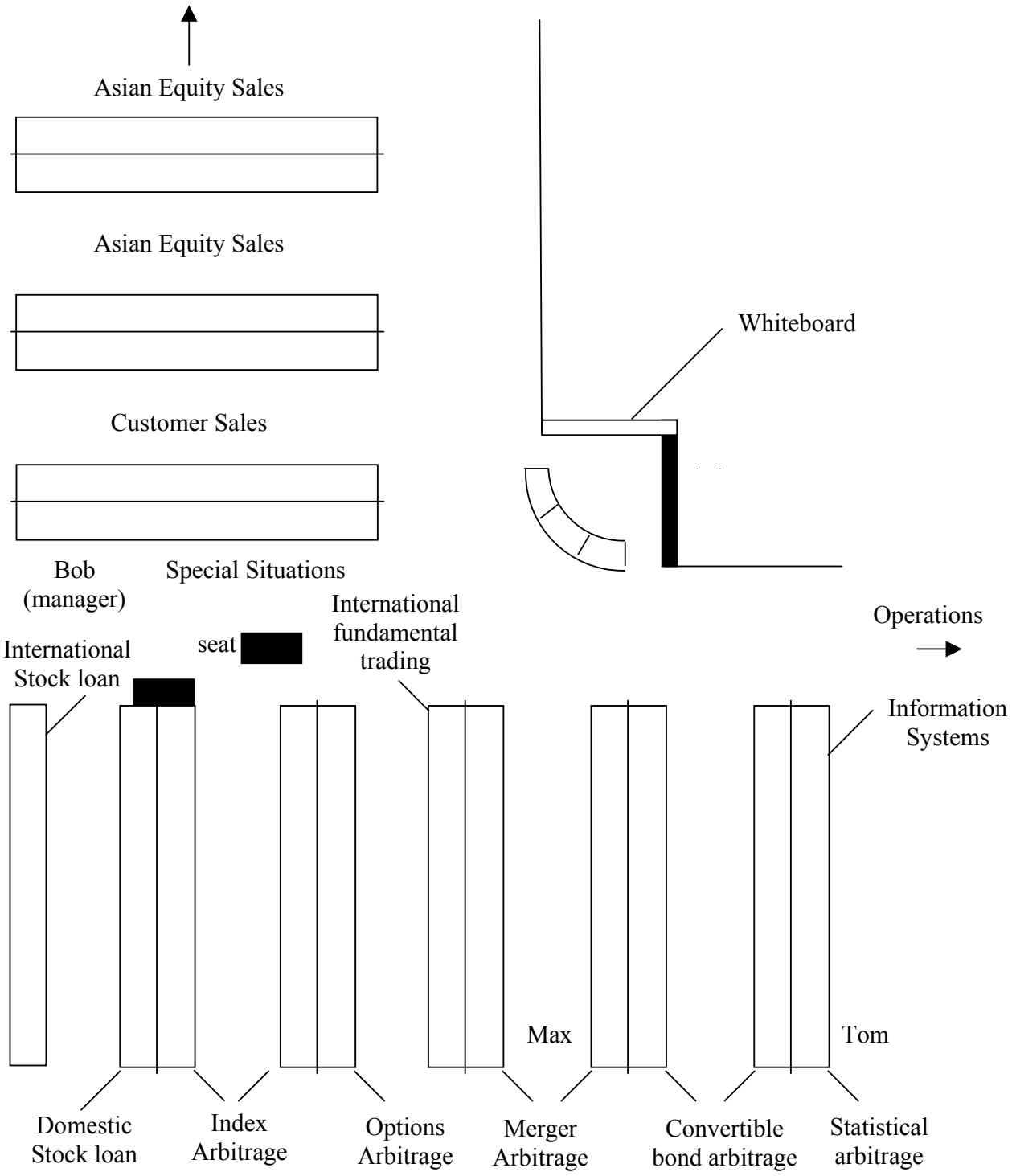

Figure 2: **Schematic of the Trading Room at International Securities**

Table 1: The valuation principles, formulas and tools of arbitrage strategies.

Desk	Valuation Principle	Typical Formula	Tools
Merger arbitrage	The value of an all-stock acquisition target will converge to the price of the acquirer	$P_T = P_A \cdot r \cdot p_M$ See note (14) for explanation	• Index plots • Spread plots
Index arbitrage	The price of the index futures contract will converge to the spot price of the constituent stocks	$F_0 = S_0 e^{(r-q)^T}$ See note (15) for explanation	• High-bandwidth connections to market data
Convertible bond arbitrage	The value of convertible bond can be expressed as the value of a bond and an option to convert into stock	N.A.	• Bloomberg valuation model • Proprietary valuation model
Statistical arbitrage	The ten-day moving average of stock prices reverts to the mean.	$E_T(X) = \frac{1}{T}\sum_{t=t_0}^{t=t_0+T} X_t$ $E_T(X) \to 0$ when $T \to \infty$ See note (16) for explanation	• Robot • Atomic clock • Order traffic speed indicator
Customer sales	Execute client's order. No sales on downtick trades.	Orders given by clients	• Telephone • Market indices • Magnifying glass • Footprints •Active cells

[19] P_A= stock price of acquirer, P_T= stock price of target, r= exchange ratio, p_M= probability of the merger. Source: Reverre (2001)

[15] F_o= price of the futures contract, q= dividend yield rate, r= risk-free interest rate, T= maturity date. Source: Reverre (2001)

[16] X= stock price, T= time, $E_T(X)$= ten-day moving average of X. Source: Reverre (2001)