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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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> "Certainly if in things mechanical men had set to work with their naked hands, without help or force of instruments, just as in things intellectual they have set to work with little else than the naked forces of understanding, very small would the matters have been which, even with their best efforts applied in conjunction, they could have attempted or accomplished. ... [I]n 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." (Francis Bacon, *Novum Organum*, 1620/1960:34-5)

Introduction

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. We examine how these associations come about by studying their material basis in the deployment of persons and things in the Wall Street trading room of a major international investment bank where we have been conducting ethnographic field research.

We focus on arbitrage because it is the trading strategy that exposes most acutely the problems of valuation and calculation that should be at the center of economic sociology. Economic sociology was founded through a pact with economics in which

economists study value while sociologists study values; they 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 (Boltanski and Thevenot 1991; White 1981, 2001; Thevenot 2001; Stark 2000; Girard and Stark 2002; Callon and Muniesa 2002; Callon et al. 2002). To constitute economic sociology as something more than a sociology of business, its object of study should be the problem of worth. The first steps must be detailed accounts, across a range of settings, of how actors engage in such fundamental activities as calculating value and constructing equivalences. Trading provides such an analytically privileged case.

A trading room is an engine for generating equivalencies. Making associations among securities takes place *in situ*, that is, in a particular place where formulas are formed by associations among persons. But the story we tell is not yet one more example of social embeddedness (Granovetter 1985). Drawing on the work of Callon (1998), Latour (1987, 1991), and Hutchins (1995), we examine socio-technical processes in which calculative practices are distributed across a network of persons and artifacts. Our analysis thus 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 (objects, instruments, 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 things (Latour 1988, 1991).

We focus on arbitrage also 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. 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 formulas for pricing derivatives such as the Black-Scholes formula in 1973, traders gained powerful mathematical tools. And with the dramatic growth in computing power and the declining costs of such, traders were able to combine these equations with powerful computational engines. This mix of formulas, 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 Bruegger and Knorr Cetina (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). Just as the eyes of traders in a commodities pit are glued to the gestures of other traders, so Bruegger and Knorr Cetina 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 Bruegger and Knorr Cetina 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 *perform 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: Bruegger and Knorr Cetina examine electronic trading, but ignore formulae entirely; MacKenzie and Millo address the role of formulae but ignore 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: connectivity, knowledge, 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. Our approach differs yet more fundamentally. First, unlike these sociologists of science and technology,[2] the trading room is for us a laboratory to explore

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

[2] Not by accident, leadership in the emerging field of "social studies of finance" has been taken by sociologists who were earlier established in the field of science and technology studies. Because the latter field has carved out an approach to the production of knowledge as well as crafted analytic tools for understanding the development and application of

core problems of value, equivalence, and calculation. 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 – spatially, around the room, and socially, across the tools of 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 judgement. 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.[3] In the field of arbitrage, to be opportunistic you must be committed to a principle.

Second, we differ from the sociologists of science and technology by taking into account the dynamics they identify but drawing radically different analytic conclusions. For Bruegger and Knorr Cetina, 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

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technology, it is well-situated to yield new insights about the roles of knowledge and technology in economic life. For important contributions to the new field see Smith 1990; Abolafia 1997; Uzzi 1999; Zuckerman 1999; Muniesa 2000; Lepinay and Rousseau 2000; Zaloom 2002a.

[3] Zaloom (2002b) 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.

instantaneous information. By studying sophisticated derivative traders, able to produce formulas 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 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 (Brown and Duguid 2000; Weick 1979). 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 about how the diffusion of formulae shapes markets, we go on to ask the next question. If everyone is using the same 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 fosters innovation and facilitates interpretation? 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 Bruegger and Knorr Cetina dismiss physical locale in favor of interactions in cyberspace, we found that trading practices are intimately tied to the deployment of traders

and things 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 manuevering in the uncertain environment of markets, like manuevering in the fog of battle, requires situated awareness[4]. As we shall see, the configuration of the trading room, as a specific locale, provides the socio-spatial resources for this sense making.

As for the process of innovation in general, the cognitive challenge facing our arbitrage traders 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).[5] Each desk (e.g.,

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

[5] 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.

merger aribtrage, 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. As we shall see, the trading room distributes intelligence and organizes diversity.

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. Over the past two years we have been following trades, observing interactions, sharing lunch at their desks, and interviewing traders and managers throughout the room. 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.

In the following section we make the case for a sociology of arbitrage as a distinctive trading strategy that operates by making associations among securities. Subsequent sections are structured through a simple rule of increasing complexity: to examine the organization of the trading room, begin with persons and in each new subsection add progressively more "actants" (actors, entities, human and non-human, see Latour 1988) – desks, principles, formulae, financial instruments, computing instruments, user interfaces, hardware, programs, robots. Thus, we examine first the architecture of arbitrage, exploring how association among traders contributes to association among properties. Second, we examine how these traders are grouped into desks, exploring the specialized functions by which each recognizes patterns through distinctive financial

instruments. Next, we examine the trading room as an ensemble of desks, exploring how this ecology of 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

If retired traders from our pseudonymous International Securities were to visit these days their former firm, they would find the trading room changed beyond recognition. To appreciate the changes, consider the following description of a typical Wall Street trading room in the 1980s (Wolfe, 1987, p. 58):

> 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.

This boiler-room imagery is absent from the Wall Street trading room of International Securities, the pseudonymous 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 in a background of numbers flickering 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 standing up, walking around, and even having coffee among themselves. Instead of writhing arms and torsos, we see

equations and formulas 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."

Mobilizing the tools of quantitative finance, the traders at International Securities are engaged in arbitrage. Its contemporary variants are as different from textbook arbitrage as the contemporary trading room is from its raucous predecessor. In understanding arbitrage in the era of quantitative finance, textbook treatments by finance economists are helpful only to a point, typically limited because they remain too closely tied to classical notions of arbitrage; some sociological treatments of brokerage have relevance, but can be misleading if, in the extrapolation, analysis conflates brokerage and arbitrage. Whereas brokerage exploits gaps by linking buyers and sellers in the same market, 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 the opportunitities where different evaluative devices yield discrepant pricings at myriad points throughout the economy.

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 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.

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, and 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 formulas 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) turn away from scrutinizing companies towards monitoring the field of other market actors (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 them by making associations. Instead of claiming superior abilities 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, confronted by a stock with a market price, seeks some other security – or bond, or synthetic secuirity such as an index composed of a group of stocks, etc. – that is related to it, and prices one in terms of the other by establishing a value equivalency between the two. Modern arbitrageurs never buy and sell the same stock: 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 seen the resemblance before or cannot adequately gauge the extent of the similarity and realized the opportunity before. The tenuous or uncertain strength of the equivalence (or similarity) reduces the number of traders that can play a trade, hence increasing its potential profitability.

Thus, whereas value trading 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.[6] 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

[6] 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).

all. Their strategy is to use the tools of financial engineering to shape a trade so that exposure is limited only to those equivalency principles in which the trader has confidence. Derivatives such as swaps, options, 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 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 as much not betting on what you don't know as much as betting on what you do. In merger arbitrage, for example, this strategy of specialized betting 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, merger arbitrageur, in effect, are betting about the likelihood of a discrete event. You cannot go to

a betting window to put down money 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 of heart. Arbitrage is about tailoring the trader's exposure to their position vis-à-vis the market, biting what they can chew, betting on what they know best, and avoiding risking their money on what they don't. 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 picture on 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 be exposed where they are most confidently attached. As Callon (Callon and Muniesa 2002, Callon et al. 2002) argues, calculation and attachment are not 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.

Facilitating Sociability to Make Associations

The architecture of the trading room at International Securities would be unfamiliar to someone whose only experience with a big-city office tower was of the corporate variety. Gladwell (2000) nicely captures the hierarchical character of the typical corporate layout:

> The center part of every floor is given over to the guts of the building: elevators, bathrooms, electrical and plumbing systems. Around the core are cubicles and interior offices, for support staff and lower management. And around the edges of the floor, against the windows, are rows of offices for senior staff… The executive in one corner office will seldom bump into any other executive in a corner office. Indeed, stringing the exterior offices out along the windows guarantees that there will be very few people within the critical sixty-foot radius of those offices (Gladwell, 2000: 64).

In the traditional corporate office, space is used to emphasize differences in status in the organization as the system of concentric rings effectively isolates the highest status employees. At International Securities, by contrast, space is used to create an atmosphere conducive to association. The open plan, not unlike a newsroom or a new media design studio, contains no cubicles or partitions (see Figure 1). 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."

Insert Figure 1 about here.

Moreover, the 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-stakes 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 within the desks,

> 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 say, 'Oh, I did too.' 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 Bruegger and Knorr Cetina 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 accutely 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 <u>situated calculation</u>. 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 provided, in large part, by the room.

This tension between electronic markets and physical rooms is a particular case of what can perhaps be referred to as the "Castells axiom." How, Castells (2000) asks, has the role of space changed in a network society structured by the Internet and information technology? Castells distinguishes between spaces of place, that is, locales "whose form, function, and meaning are self-contained within the boundaries of physical contiguity," and spaces of flow, which he defines as "the organization of purposeful, repetitive, programmable sequences of exchange between physically disjointed positions." According to Castells, as information technology creates spaces for repetitive, preprogrammed, machine-like interactions (spaces of flows, such as airports), the original, spontaneous,

unexpected interactions found in physical spaces (spaces of place, such as mixed-usage urban neighborhoods) can provide an ever-increasing source of competitive advantage. Thus, for example, as surgical techniques develop together with telecommunications technology, the surgeons who are actually 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.

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

We now move from the individuals that compose the trading room as a simple society of persons to 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 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," the derivatives that lend the desk its name, and so on. The desk is an intensely social place. The extreme proximity of the work setting 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 to look at the market, based on the principle of equivalence that it to uses to calculate value and the financial instrument that it enacts in 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?" Analytical and calculating, for them 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 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. Traders at the index arbitrage desk value market indexes with the prices of the companies that constitute them, and specialize in executing high-volume high-speed trades that exchange indexes for their baskets whenever the accuracy of indexes are upset. 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 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 company 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 consistency of tools and thoughts can be found at other desks.

Such joint focus on visual and economic patterns creates, at each desk, a distinctive community of practice within a principle of equivalence with its own tacit knowledge. Traders on 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, confided in us that, to him, statistical arbitrage is "like playing video games. If you figure out what the other guy's program is you can destroy him. That's why we don't do program trades," he added, 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, employ Black-Scholes equations, or draw from 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 it than on following for months the evolution of the spread between two merging stocks.

Insert Table 1 about here.

These functional teams are thus markedly different from cross-functional "projects" in fields such as film, new media, construction, etc., where heterogeneous evaluative principles are combined (Grabher 2002, 1998; Girard and Stark, 2002). A new media project, for example, is typically composed of programmers, business strategists, and designers. Within it, different members may find the value of a web site in metrics as varied as its speed, ease of use, profit-making abilities, or beauty and elegance. By contrast, within an arbitrage desk all traders find value along the same equivalency principle. 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.

Connecting for cutting, co-locating for dissociating

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. Recall also that cutting and slicing (dis-associating) requires making associations (identifying 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 to do the cutting. Figure 2 presents the 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 this isolation is difficult to accomplish completely. Because of these difficulties, even after the slicing and dicing, traders can still end up exposed to qualities of the companies different from that which constitutes the equivalency. We found that traders reintroduce the overflow 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, 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, some companies have A- and K-class stocks, depending on the voting rights they

carry. According to Max, "Arbs hedge with the As, because they are easier to borrow, but actually get the Ks," creating the subsequent challenge to transform the K into A stocks. Here the merger arbitrage desk can turn to the index arbitrage desk for help since index arbitrage profits from the fact that A stocks are included in indexes while K stocks are not.

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 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 close together the 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 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. Or it can be as formalized as a meeting (extraordinarily rare at International Securities) that brings together actors from the different desks. And much in between. A trade is a project.

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 recombines 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. They had, in other words, "symbolic" or "hierarchical" rationalities, as opposed to a purely financial profit-maximizing approach.

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, 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 them 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 not certain and cast in stone, but tenuous and uncertain (and that was what made them so profitable – the fact that no one had done them before). 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. The details of the case were as follows: 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 were to elect 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?" entails a highly complex search problem, as stock ownership is typically fragmented over diverse actors in various locations with 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 the get?

For some shareholders, the answer was straightforward: the companies were large and well known, and their strategies easy to predict. 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 across the question to the merger arbitrage team here who were doing the same and work 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 allows 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 in 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

distributed across desks in the trading room. In this section we extend the argument to the material basis of arbitrage. Calculation, we argue, is not exclusively mental and abstract, but 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 night-vision. They also delegate calculation to robots that single-mindedly execute their theories, while drawing on cues from the room to 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 Bruegger and Knorr Cetina (2002), traders do not quite match up to scientists: when compared to high-energy physics 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.[7]

Perhaps the most salient instruments at International Securities are to be found on the traders' screens. These dramatic extra-wide high-contrast Bloomberg flat panel monitors serve as their workbench. On these digital workbenches, the traders pack veritable instrumentation panels that are 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

[7] 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

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 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 Steve introduces entries with "active links" to stock prices, that is, cells that are automatically updated in real time. Stan has programmed in the cells next to the links 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 verifying 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, Steve 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.

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behavior, and Muniesa´s (2002) study of the use of telephones in trading rooms.

Two desks away, Richard C. at the convertible bond arbitrage desk looks at stocks with 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 convey 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 spreads serve as goggles that extract from the market information about actors' confidence on a given merger.

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 zig-zag in a snake-like manner from left to right over the soothing blue background of his monitor.

This reliance on the goggles, however, entails for the traders a dangerous risk. Distributing calculation across their instruments amounts to inscribing their senses with their own beliefs. The traders run the risk of confusing their perception with their calculation in ways that might lead to massive losses. 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. But instead of reducing the nature and importance of social interaction in the room, the instruments actually provide an additional rationale for it. "We all have different information," Stan says, referring to other traders, "so I sometimes check with them." When asked how often this happens, his response is, "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 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-pollination across 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 goggles, robots create new challenges that are solved by intermingling of the social, the cognitive, and the artifactual.

Robots are representations as well as tools for automation. They are inscribed with the trader's beliefs, in the sense that they execute only one possible trading strategy, that which 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 contain in them a complex set of assumptions about the market and undertake an active selection of the available data that is consistent with it.

Sociability in the room plays an even greater role in the use of robots than it does in the case of the goggles. The room is crucial from the moment of the robot's inception, a process of (literally) 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. At the whiteboard, an idea for a trade mutates in medium 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 traders specialized in implementing computer programs such as the statistical arbitrage desk. End of the story? Not really. 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 interaction 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?

Insert Figure 3 about here.

The most immediate recourse to the challenge of execution 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 of them there is a slash sign that rotates and moves from side to side. It is a "pulse meter" to gauge the speed with which information on prices is arriving to him, or "price feed". The character stops moving when prices stop arriving. It is very important to realize when this happens, because then the "price robot" gets confused. According to Tom, "it thinks that prices don't change and 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 will get through slowly. If they are red, their 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 how congested the database that deals with the bank's order flow is. 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.

However, technology 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 calibration problem became notable following the nuclear accident at Chernobyl. An unfortunate circumstance that reportedly made the damage much worse was

that 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 had been calibrated for registering nuances, so the sharp increase went unnoticed. Technology, then, helps in execution of automated tasks, but needs 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. There he hears what the system people tell others through their microphones, getting a sense of how well the systems are running. 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. Hence sitting near the futures arbitrage desk is helpful in answering the question of whether there is something anomalous in the data feed. In addition to getting a sense of when to turn their robots off, statistical arbitrage traders can also benefit from interpretive cues from nearby desks about situations in which to take a particular security out of automated trading. As with these cases, Tom's solution to the calibration problem suggests that when technology and the existing representations come under doubt, traders turn to 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 the work of cleansing differences that produces "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 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 Novum Organum, one of the founding documents of modern science, Francis Bacon (1620/1960) outlined 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.[8]

[8] 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.

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,"[9] 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.

[9] *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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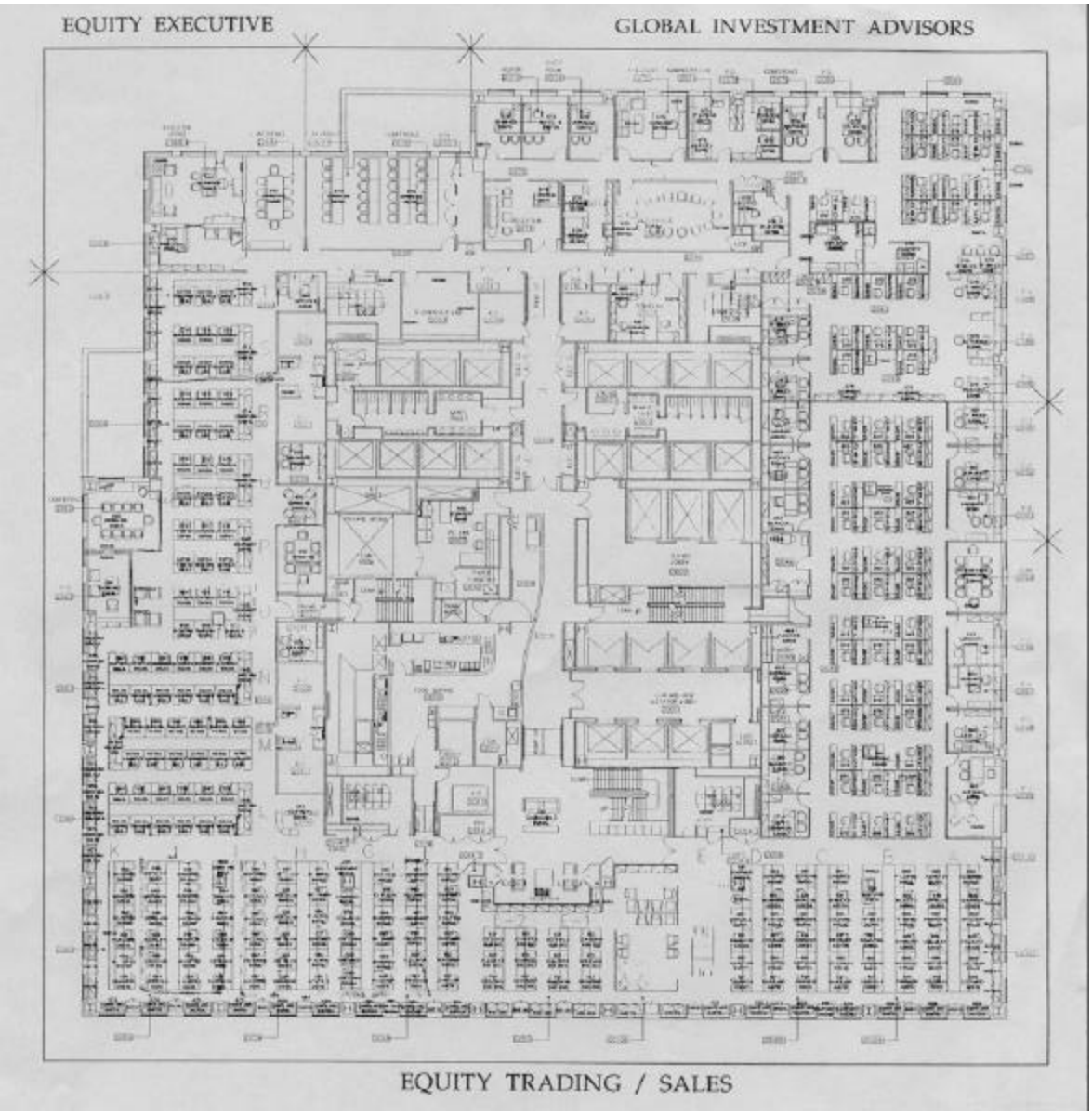

Figure 1: The Architecture of Arbitrage

On this map, the trading room at International Securities is located on the left and bottom sides with research and analysis departments on the right hand side.

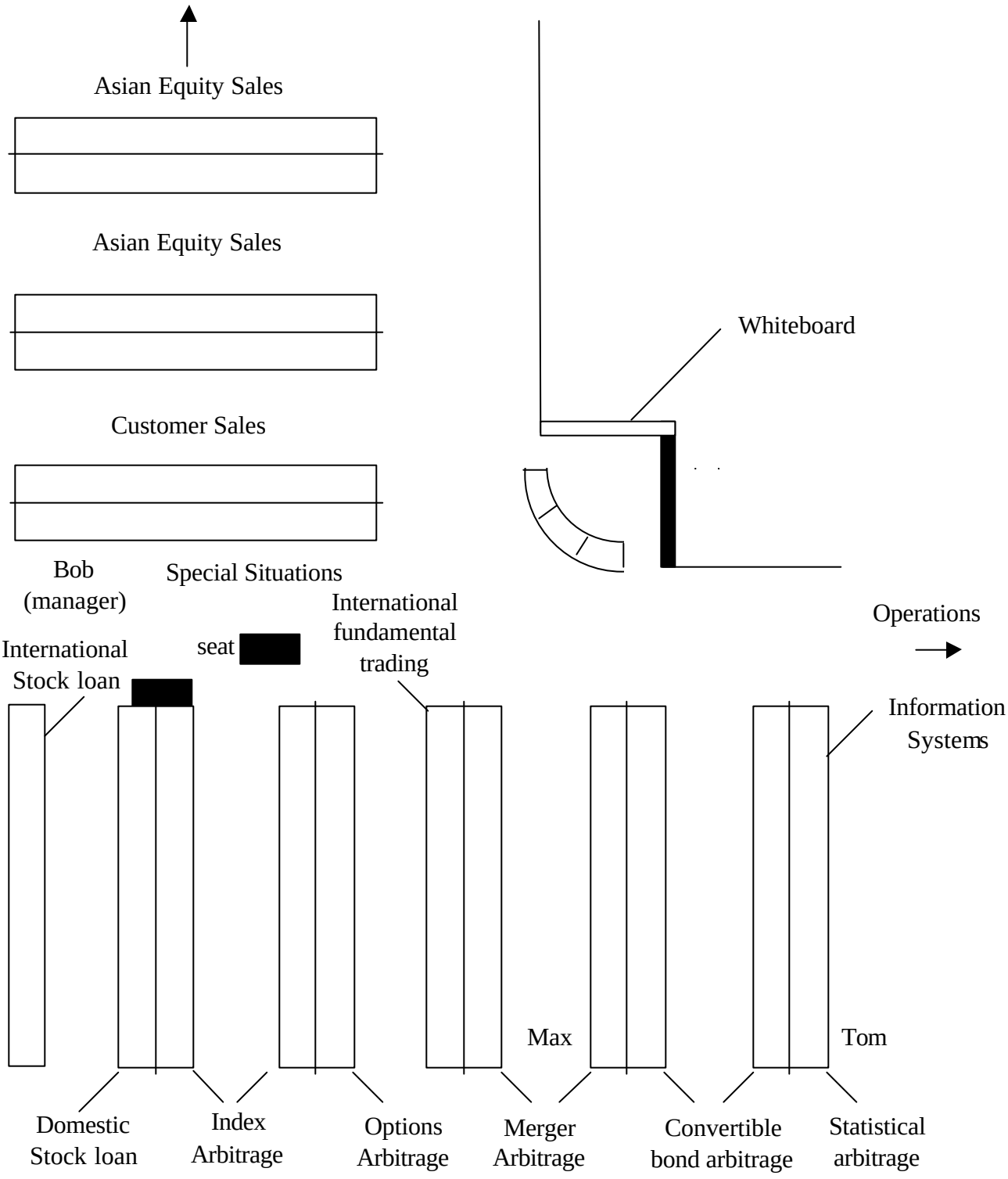

Figure 2: **Schematic of the Trading Room at International Securities**

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 (10) 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 (11) 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 (12) 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

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

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

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

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

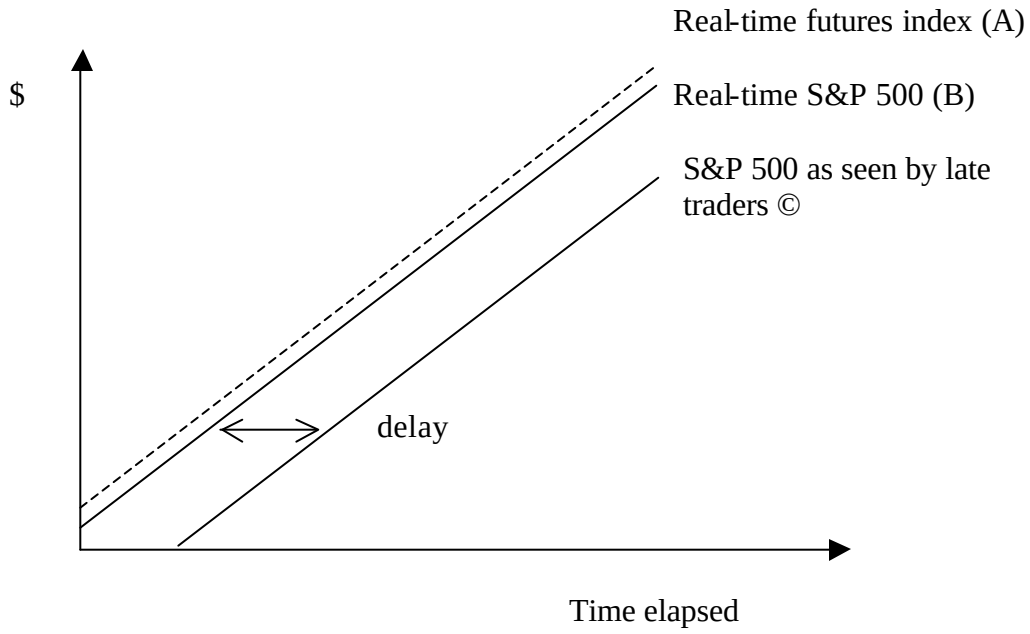

Figure 3: **Paying a High Price for Delay in Automated Trading**.

In automated trading, an slight undetected delay can create large losses. The distance between futures and spot-market indexes denotes time delay. It creates the spurious appearance of an opportunity for statistical arbitrage (A-C) but the real-time spread (A-B) is much narrower.