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The organization of responsiveness: innovation and recovery in the trading rooms of Lower Manhattan

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What is the organizational basis of responsiveness under conditions of crisis? In this essay we examine a trading room that was damaged in the September 11th attack on the World Trade Center. What did the crisis reveal about the social practices and the technological tools of trading? Drawing on ethnographic field research prior to September 11th, we show how the heterarchical (as opposed to hierarchical) organization of the trading room contributed to innovation on an ongoing basis. Drawing on our subsequent observations in the relocated trading room and focus group discussions with executives in other World Trade Center financial firms, we show that similarly heterarchical features contributed to innovation in response to crisis. Under conditions of radical uncertainty, one cannot know in advance what resources one will need, or even know in advance what might be a resource. Laterally distributed intelligence and a tolerance of multiple registers of valuation and interaction provide generative structures of resourcefulness where the replicative redundancy of contingency planning confronts its limits. We conclude with a brief discussion of the implications of our findings on innovation, location and responsiveness for the changing urban geography of finance and the redevelopment of Lower Manhattan.

Keywords: Organizational theory, heterarchy, contingency planning, socio-technical networks, economic geography, September 11th

JEL classification: N220 Economic history, financial markets and institutions; L230 organization of production

1. Introduction

In this essay we examine a trading room that was damaged in the September 11th attack on the World Trade Center (WTC). The trading room, part of a major international investment bank, was located in the World Financial Center, directly adjacent to the WTC. On the evening of September 11th, the management team of the trading room regrouped in an emergency facility in New Jersey and estimated that it would take 3 weeks to 3 months to resume operations. Yet only 6 days later, when equity markets re-opened on September 17th, they were trading again. What kind of organization made such recovery possible? What did the crisis reveal about the social practices and the technological tools of trading? And what are the implications of the organizational bases of innovation and responsiveness for the broader recovery of Lower Manhattan?

We are fortunate that we can approach these questions on the basis of close familiarity with the practices of a Wall Street trading room. Two years before September 11th, we began ethnographic field research in the trading room as part of a project to study how the organization of trading was changing in response to new information technologies. What, we wondered, is the role of locality under conditions of global connectivity? Our findings, summarized in the first section of the paper, are rich in paradox: the more that timely information is available simultaneously to all market actors, the more advantage shifts from economies of information to processes of interpretation. The trading room, so abundant in information, is a place of interpretation. Innovation is the product of interaction across heterogeneous principles of evaluation, and it occurs within the physical proximity offered by the trading room.

Since September 11th, we continued our ethnographic research as we followed the traders in their relocation to New Jersey. Our findings there, reported in the second part of the paper, confirmed our preliminary insights that traders place a high value on physical proximity to facilitate the kinds of association that are so important for their work. It also revealed that trading rests not only on social organization but also within a complex set of technical relations. The attack on September 11th damaged the trading room and completely disrupted the technologies that are so fundamental to modern trading. This disruption lays bare the socio-technical character of these relations. The breakdown of technology is society made visible.

In addition to our direct observations in the relocated trading room, we also report, in the third part of the paper, on our conversations with senior managers of other financial firms in the WTC complex. How were firms able to respond so rapidly and effectively when their operations had crumbled, quite literally and so devastatingly, all around them? In passages from these conversations reported below, our interlocutors give voice to the fear and loss in which they were working in those terrible days, and they tell of how strong personal ties were keys in the recovery process. As we shall see, organizational responsiveness rested less on contingency plans and hierarchical

command structures than on heterarchical structures of self-organization and lateral coordination. In short, the kinds of distributed intelligence that are so important in the day-to-day operation of the trading rooms formed the basis of organizational response to crisis. Whereas innovation can be seen as responsiveness in the face of uncertainty, response to crisis can be seen as a particular instance of innovation. We briefly explore the relevance of this insight for the post-September 11th era when metrics of preparedness become more salient in company valuations.

The paper concludes with a brief discussion of the implications of our findings about innovation, location and responsiveness for the redevelopment of Lower Manhattan. Does the micro-locality of the trading room as a locus of innovation extend to the locality of Wall Street as a financial district centred around the New York Stock Exchange (NYSE)? The future of 'Wall Street', we argue, is the future of multi-centric networks of trading rooms governed less by their proximity to the NYSE than to each other. But location decisions are not driven only by factors of knowledge transfer among communities of practice, not to speak of rents, infrastructure or commuting time. In the wake of September 11th, according to one logic of preparedness, companies must disperse their operations not only across buildings but also across electricity grids, telephone codes and transportation hubs. How are these new concerns about security reshaping the urban geography of finance? The pull of proximity for innovation and the push of dispersion for security are posing new dilemmas for firms in New York's financial sector.

2. Location: communities of practice in a trading room

The equities room of pseudonymous International Securities, like its counterparts at the Trade Center, offers a sharp contrast to the conventional environment of corporate America. Enter the World Financial Center office complex. Take the elevator and go up one of its towers. As you exit the elevator on the 20th floor, a sea of desks with multi-coloured Bloomberg screens opens up. The desks are occupied by relaxed traders clad in business casual wear. Unlike a standard corporate office with cubicles and a layout meant to emphasize differences in hierarchical status, trading rooms are open-plan surfaces where information roams freely.¹ Instead of housing its support staff in the centre of the floor, as corporations do, International Securities sits its manager at the centre, where everyone can reach him. And instead of having its senior managers scattered on window offices around the exterior of the building (where the chance of bumping into them is minimized), the bank puts

¹ Gladwell (2000) discusses parallel efforts that exploit the ways in which architecture and organizational form are tightly intertwined. For example, he describes an advertising firm in California that has recreated the geography of a village in its headquarters, complete with notional streets, squares and neighborhoods.

managers in the same desk as their teams, accessible to them with just a movement of the head or hand. Underscoring the importance of trust and sociability, the bank has limited the number of people in the room to 150 employees and has a low-monitor policy so that people can see each other.

What about the traders themselves, those privileged inhabitants of the trading room? Their outlook and personality have been radically altered by a silent technological revolution that swept over Wall Street in the last two decades. This revolution—the quantitative revolution in finance—was ignited by the rise of derivatives such as futures and options, of mathematical formulas such as Black–Scholes, of network connectivity to electronic markets such as the NASDAQ and by high-powered computers. As a result, finance is nowadays mathematical, networked, computational and knowledge intensive. Mundane stocks are no longer the security of interest to professional traders: by January 2000, for example, the total notional amount of derivatives contracts outstanding world-wide was \$108 trillion, the equivalent of nearly \$18 000 for every human being on earth (D. MacKenzie and Y. Millo, unpublished manuscript). In this context, traders have evolved with the industry. Whereas the traders of the 1980s, acutely described by Tom Wolfe (1987) as ‘Masters of the Universe’, were characterized by their riches, bravado and little regard for small investors, the quantitative traders of nowadays have MBA degrees in finance and PhDs in physics and statistics, and are more appropriately thought of as engineers. None of them wears suspenders.

The trading strategy of choice of quantitative traders is arbitrage in its different blends and styles (for a detailed treatment of valuation and arbitrage, see Beunza and Stark, 2002).² Arbitrage hinges on the possibility of interpreting securities in multiple ways, and it produces profits by associating previously disparate markets. For example, arbitrageurs associate the markets for the stocks of two merging companies when the merger makes their value momentarily comparable. Or they associate the stocks of two companies that are in the same index, and hence move similarly; or a stock and a bond of the same company, whose value is linked by a legal clause that makes the bond convertible into stock. The point in every case is to avoid the conventional route of valuing a company by its intrinsic value or by how hot it is with market speculators, and to choose instead a lens that produces an opportunity—a new, original valuation that differs from the value that the market assigns to a company. Thus, like a striking literary metaphor, an arbitrage

² The emerging field of ‘social studies of finance’ brings social scientists with an interest in the capital markets (classic studies include Smith, 1990; Abolafia, 1996) together with sociologists who are interested in the production of knowledge (from the field of science and technology studies, see especially D. MacKenzie and Y. Millo, unpublished manuscript, University of Edinburgh; Knorr Cetina and Bruegger, 2002; D. MacKenzie, unpublished manuscript, University of Edinburgh). Other recent contributions include Uzzi (1999), Zuckerman (1999), Lepinay and Rousseau (2000), Lepinay (2002), Muniesa (2002), Preda (2002), Riles (2002), Scott and Barrett (2002) and Zaloom (2002a, b).

trade reaches out and associates the value of a stock to some other, previously unidentified security. The two securities used for arbitrage have to be similar enough to hedge exposure, but different enough that other traders have not seen the resemblance and realized the opportunity before. Each trade, then, is never exactly like the previous one. While alternative trading strategies, such as value investing or momentum trading, emphasize early access to information, arbitrage draws on novel interpretation. And whereas value trading is essentialist and momentum trading is extrinsic, arbitrage is associational (Beunza and Stark, 2002).

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 were to recognize only patterns familiar within their existing categories, they would not be innovative (Brown, 1997; Brown and Duguid, 1998; 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 telephone 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 trading room is equipped (quite literally) to meet this twin challenge of exploiting knowledge (pattern recognition) while simultaneously exploring for new knowledge (practices of re-cognition).³ 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*. Rather than bureaucratically hierarchical, the trading room is heterarchical (Stark, 1999; Girard and Stark, 2002). In place of hierarchical, vertical ties, we find horizontal ties of lateral, distributed cognition; in place of a single metric of valuation, we find multiple metrics of value; and in place of designed and managed research and development, we find innovations as combinatorics (Kogut and Zander, 1992) that emerge from the interaction across these co-existing principles and instruments. The trading room distributes intelligence and organizes diversity.

International Securities thus buzzes with a variety of arbitrage styles. Each desk in the room belongs to a distinct community of practice (Wenger, 1998; Brown and Duguid, 2000; Orlikowski, 2002) corresponding to a different strategy, such as merger arbitrage, index arbitrage or customer trading arbitrage. But the differences among desks is more than just operational: different desks have different principles

³ We are re-interpreting March's (1991) exploitation/exploration problem of organizational learning through the lens of the problem of recognition. On a separate but related challenge in a new media start-up, see Girard and Stark (2002).

of value and different forms of instrumentation corresponding to each (for details see Beunza and Stark, 2002). Traders at the merger arbitrage desk, for example, value companies that are being acquired in terms of the stock price of the company that is acquiring them. They specialize in asking themselves, 'What is the probability that companies X and Y might merge?' Analytical and calculating, for them companies are little more than potential acquirers and acquisition targets. In contrast, traders at the convertible bond arbitrage desk exploit the value of 'convertibility provisions' embedded in some bonds that give the bondholder the option to convert his or her bond into stocks. To do so, they look at stocks as bonds, and focus on information about listed companies that would normally interest only bondholders. Traders at the customer sales desk, to use another example, take and give buy-and-sell orders to customers. Sociable and gregarious, they trade, talk on the telephone and pass around Beef Jerky. The sound of their voices on the telephone gives the rest of the room a window on the anxiety level of the traders' customers and the sentiment of the market at large.

The associations established by the arbitrageurs are shaped by patterns of association in the room. Each arbitrage strategy associates securities that share a common property that makes their value comparable, such as convertibility, volatility, participation in a merger, liquidity or optionability. Since, as noted above, each desk in the room corresponds to a different strategy, interaction across desks helps traders in deconstructing the value of a stock or property into its constituent aspects, or properties. A merger arbitrage trade, for example, associates two stocks that share one property—a high probability of merger—but may be affected by a different property of the stock such as high volatility, a convertibility provision, lack of liquidity or pressure from an index. Physical closeness to other desks helps merger arbitrageurs in isolating the property of interest from unwanted ones; for example, overhearing nearby traders at the convertible bond arbitrage desk may make them aware of details of those provisions. In turn, traders at the convertible bond arbitrage desk may benefit from overhearing details about the volatility of a stock from traders at the nearby options arbitrage desk.

Co-location also allows traders to synthesize the strategies performed by different desks into original, innovative trades.⁴ At International Securities, for example,

⁴ Olson *et al.*'s (2002) concept of 'radically collocated work' is similar to our own, with an important difference that the interactions across the desks of the trading room are not taking place within a self-consciously defined project or team. Especially relevant is Galison's (1997) discussion of the architecture of science (see also Galison and Thompson, 1999) that shows that key innovations in the Manhattan Project came when the disparate communities of theoretical physicists and experimental engineers (each with their own distinctive epistemologies and tools) were brought together in the same building in the Massachusetts Institute of Technology's Rad Lab. This insight is supported by a quantitative analysis by Kraut *et al.* (2002), who found that having offices on the same corridor was a strong and significant predictor of collaboration among scientists even when they were not in the same field.

a desk called ‘special situations’ recently designed a novel ‘election trade’ by imagining themselves being merger arbitrageurs in a case that involved a stock swap. Looking at a swap as if it were a merger gave them a distinctive perspective, the best source of profits in an industry characterized by electronic markets and instant diffusion of information. The traders could do so because of their closeness to the merger desk. A trader is not an isolated and contemplative thinker, but is engaged in cognition that is socially distributed across persons and things.⁵

Thus, in trying to understand the *modus operandi* of the trading room we came to see that its *locus operandi* was crucially important. The more we observed, the more we could not ignore claims that electronic trading would eliminate the importance of physical location. We found that the more that trading becomes virtual, the more it heightens the salience of physical proximity—at least at the elite level. That is, the more that information is simultaneously available to nearly every market actor, the more strategic advantage shift occurs from economies of information to socio-cognitive processes of interpretation (Thrift, 1994; Brown and Duguid, 2000, 2001; Thrift, 2000; Grabher, 2002a, b). This particular trading room makes profits—considerably higher than industry-average profits—not by access to better or more timely information, but by producing communities of interpretation.

In addition to distributed cognition through co-location, technology is another key source of competitive advantage. International Securities, for example, invests massively in Bloomberg terminals that allow traders to represent financial value in a thousand different ways, such as spread plots, bond valuation models or active spreadsheet links. High-bandwidth connections to the market give traders a crucial temporal edge over retail investors by providing them with price data almost in real time. A computer platform (called the ‘trading engine’) automates all the clerical operations related to trading, such as registering trades, breaking them into small pieces to avoid detection by rivals, etc. And numerous traders use computer systems (called ‘trading robots’) to automate the buy-and-sell process according to a logic codified in an algorithm.

However, mindless engineering alone does not give International Securities its edge over rivals. The key lies in an interaction between technology and humans and ideas, a *socio-technical network* constituted by all these three elements (Latour, 1991; Callon, 1998; see also Lane and Maxfield, 1996 on ‘agent–artifact space’).

⁵ The notion of distributed cognition was developed in the work of Suchman (1987) and Hutchins (1995). Hutchins (1995) showed how the cognitive process of navigating an American warship is distributed across the members of a team, its artifacts, and internal and external representations. Similarly, Suchman (1987) noted that, in most situations in which expert systems inscribed in photocopying machines failed to help their human users when they encounter a difficulty, a fellow human in the room would have no trouble in providing the correct advice. The reason, Suchman argued, is that expert systems critically fail to jointly constitute intelligibility with the user by not being attuned to the unfolding situation.

Trading robots are a good example of that interaction. A robot is a system made up of connections, algorithms and computer hardware that receives market data and sends trading orders according to some theoretical principle of finance such as ‘mean reversion’. But there is a lot that is social among those cables, chips and lines of code. In the development of the robot, for example, the algorithm is programmed collaboratively by computer programmers and traders in a special meeting room designed for rapid informal collaboration (‘the whiteboard’). The robot is monitored by a human trader, a so-called statistical arbitrage trader, whose job is to stop the algorithm whenever the market situation is no longer consistent with the theory that inspired the code. For example, when two companies merge, the principle of mean reversion no longer applies and the robot, if not turned off, would perform money-losing trades. To supervise the robot, the statistical arbitrage trader makes use of humans in the rest of the room. For example, the trader obtains crucial hints about which companies are about to merge by overhearing conversations at the nearby merger arbitrage desk. Similarly, the human monitor of the robot uses the room to find out whether the data arriving at the robot are delayed (and therefore a dangerous misrepresentation of real prices). This is done by paying careful attention to expletives or panic among the computer technicians that sit close by instead of relying exclusively on the dials and speedometers built into the robot. If the statistical arbitrageur hears expletives, it means that there are technical problems, even if the computer dials say ‘fine’.

The trading room of International Securities, like other trading rooms at the WTC that disappeared in the attack, assembled together an original set of social, spatial and technical elements that need to be understood to appreciate what ‘finance’ meant in Lower Manhattan. In this elite world of finance, social relations matter: the interpretative process that took place in it drew on non-hierarchical social relationships, trust and lateral ties. Space also mattered: the room and its desk-based spatial configuration promoted communication and distributed cognition across teams. And technology mattered too. The room relied on highly automated trading technologies such as trading robots and trading engines, and these technologies took advantage of the constant communication across traders afforded by the co-location in space.

2.1 Relocation: socio-technical networks revealed

On September 11th, a deafening explosion interrupted the work of the arbitrageurs at International Securities. As they rushed to the windows on the east side of their trading room they saw the adjacent building, the Trade Center, go up in flames as the first terrorist plane hit Tower One. The second plane crash brought terror and a tumultuous escape to the Hudson River. By the time the towers fell, the traders were already in the ferry to New Jersey. Fortunately, none of the employees at International

Securities was harmed. The building, however, was badly damaged, making the trading room dangerous and inaccessible. The Trade Center had collapsed at its doorstep. Its windows were shattered with the explosion and pierced by debris from the fallen towers. Dust, ash and dirt, possibly containing asbestos and toxic chemicals, entered the room and penetrated the computers, clogging their fans, overheating them and rendering them unusable and unsafe for repair. The data they contained were lost. The building was deemed structurally unsafe, and access to it was prohibited for months. As a result, the lively trading room that had once supported the innovative work of interpretation became a dark hole with no electricity, no connectivity and no assurance of safety from toxic chemicals.

On an emergency meeting on the night of September 11th, the team in charge of equity trading at International Securities concluded that the recovery from the attack would be long and hard, and that it would take from 3 weeks to 3 months for them to be trading again. The bank had only one equities trading room in the USA and there was no backup site to which they could go. The bank did have another available facility, a back office in a suburb of New Jersey, but the only resource that the traders could count on there was spare space in a basement where the firm stored corporate-style mini-computers for processing payroll data. The basement had no workstations, no desks and no connectivity.

Yet, barely 6 days after September 11th, by the time the NYSE re-opened on September 17th, the traders at International Securities were trading again. We were privileged to witness how this was accomplished. Several days after the attack, we sent an e-mail of concern to ask whether everyone had escaped unharmed. To our relief, we learned that no one was injured. To our surprise, the return e-mail included an invitation—indeed, an insistence—that we come over to New Jersey to witness the recovery process. ‘It is chaotic,’ wrote the manager of the trading room, ‘but also very inspiring.’ Our presence would be ‘a reminder of normal times.’ As ethnographers, we felt enormously honoured to be welcomed to document these extraordinary efforts.

Thus, on September 19th, we were back among traders in our role as observers, this time in an improvised trading room in a converted basement warehouse in New Jersey. The temporary trading room was barely an hour’s drive away from Manhattan, but it felt a universe away from the excitement and activity of Wall Street. Located in a suburban corporate park, the building was surrounded by similar low-rise corporate offices, used by manufacturing companies such as Colgate or AT&T. Just around the corner, a farm announced ‘Hay For Sale’. The surroundings offered an endless succession of down-market shopping malls, Wal-Marts and Dunkin Donuts; one could drive around for an hour and not be able to find espresso coffee. What had been the back office of International Securities had, in effect, become its front office too. Our traders were Wall Street traders... in New Jersey.

The trading room was located in the basement of the building. To reach it we had to pass several rows of corporate-style cubicles and beige carpet; after the cubicles, we reached the trading room—perhaps the most unexpected sight in such an environment. A huge open-plan space, complete with traders, desks, computers, outsized television screens and multi-time-zone clocks. The room had a makeshift feel to it: no windows, a low ceiling and walls painted in industrial yellow, more fitting for a storage room than a trading room. Indeed, one week before our visit the place was still being used to store the mainframes and tape machines used by the bank's data centre. The floor-level air-conditioning ducts used to cool the machines were still working on September 19th, chilling our legs from the shoes up. Inside the room, workers in the technology department constantly moved up and down among spare cables, keyboards and mouses interspersed with empty cans of Diet Pepsi and Mug root beer.

Our traders were not just makeshift arbitrageurs—they were survivors. 'I don't have to tell you how close we were,' one of them told us, referring to their narrow escape from the building adjacent to the WTC. A huge American flag hung in the middle of a wall, and dozens of small ones coloured the top of many traders' screens like flowers in a green field. Of the three home-cinema-sized televisions (typically used in the Financial Center trading room to get market news), one was switched from CNBC to CNN for news of the impending war in Afghanistan. The dress code had shifted from business casual to jeans and boots. The room was noisy, but the sound, as one trader put it, was 'a wonderful sound of life'.

Our traders were in New Jersey, unquestionably in a basement storage room in New Jersey. But a sign taped prominently on the wall gave different bearings: '20th Floor, Equities'. In other parts of the same enormous room one could read other signs: '21st Floor, Fixed Income' and '19th Floor, Risk Management'. Our traders were still between the 19th and the 21st floors, but now horizontally rather than vertically. Moreover, within the constraints of those temporary quarters, they had arranged their desks to reproduce the layout of the Financial Center trading room. For example, every trader in the 'agency trading' desk remained together, sitting on the same desk. In the Financial Center trading room they sat on a spacious desk between the 'stock-loan' and the 'special situations' desks. In New Jersey, they camped on a table partly occupied by two photocopiers and three fax machines, in what used to be the fax station of the data centre. They camped, but they stayed together. The desks also preserved their relative locations, reconstructing the cognitive order of the trading room at the Financial Center. When the managers of the agency and special situations desks found themselves sitting again in front of each other, they reverted to their old routine of checking perceptions against each other, probing into each other's beliefs and designing together new arbitrage trades. At some point, one of them exclaimed in exhaustion, 'Everybody seems to be thinking with my brain today!'—a reflection that the distributed cognition afforded by the desk pattern was again taking place.

The traders could replicate the floorplan of the Financial Center trading room, but not the technology. Direct data from the NYSE were not available. ‘Trade Manager v1.4a’, the platform of hardware and software that registered and processed trades (also called the ‘trading engine’), was not working. The customary telephone turrets with 20 lines each were also not available, and the traders had to make do with off-the-rack single-line telephones (which they slammed with the usual energy). Instead of Sun workstations, they were working on Pentium IIs and laptops, some brought from the traders’ homes, some rescued from the data centre, some hurriedly purchased in the days following the attack. Instead of having virtually unlimited bandwidth, they now had to adapt to limited network connections that did not allow all desks in the room to trade simultaneously.

The traders’ response to September 11th contains important insights for a socio-technical view of organizations. In the sections above we have argued that arbitrageurs associate stocks by associating people, artifacts and ideas in the same place. Conceptually, it is tempting to split this socio-technical network into humans and machines—people who think and talk *versus* machines that obey pre-programmed commands. But such separation is misconceived. ‘Technology’, writes Bruno Latour (1991, p. 1), ‘is society made durable.’ Yet, what happens when technology breaks down, when traders who were accustomed to 20 dedicated telephone lines apiece must share telephones, when traders whose style of trading is based on speed and volume must suddenly operate with minimal bandwidth? The breakdown of the trading technology at International Securities opened up for us a window on its socio-technical network—a network that operated seamlessly and invisibly in the Financial Center trading room. The breakdown of technology is society made visible.

The breakdown of technology revealed the ways in which people and artifacts are inextricably linked. For example, in describing the process whereby the bank established a connection to the NYSE, we noted that the head of technology at International Securities used ‘connection’ and ‘relationship’ interchangeably. On some occasions he would refer to ‘Mike’ and on some others to ‘the ISDN connection’, yet mean the same thing. The first attempt to connect was through electronic communication networks (ECNs) but the connection kept dropping every minute, which proved very problematic for the traders because they could not know their exposure. In the end, the bank managed to connect to the NYSE only through an ECN that brought their technicians to the trading room. And, in turn, the only reason that the ECN invested its resources (technicians, etc.) in this manner was that it had an ongoing relationship with International Securities and was interested in having the bank trading through its system, thereby providing volume and liquidity. Hence the tight link between social and technical ties. As the head of technology explained, ‘Once we establish a relationship with someone, it’s very easy to move on’ to a connection. Companies with wide social networks, this implies, should recover more easily from problems with their technology.

As society made durable, the technology of International Securities also reflected the regulatory environment in which it was developed. In the process of re-connecting the New Jersey trading room to the NYSE, our traders experienced great difficulty in finding appropriate modems for their machines. The reason, it turned out, was that in the past regulatory requirements limited banks to a slow 9.6 K baud rate connections to the NYSE in order to prevent speed races. Technology is also regulation made durable. Without modems specially configured in that manner, the traders in New Jersey were not able to send and receive data to and from the NYSE. But by September 2001, such modems old enough to crawl at 9.6 K baud could not be obtained through commercial channels. In order to be able to trade, the head of technology explained to us, he tried to rescue them from the Financial Center:

The modems were in the old Unix computers, and we could not find new modems for our computers. So I had to go back to World Financial Center to strip the computers, walking up 20 floors in a chemical suit and with a torchlight as there was no electricity.

A socio-technical network is far more complex than the simple sum of the social and technical ties in the organization. The severance of technical ties, for example, cannot automatically be fixed by new social ones. This became clear in the sign '20th Floor, Equities' placed on the wall, and its insistence in reproducing the old floor structure embodied in it. The sign not only reminded traders that the equities trading room was located between risk management and fixed income, but also led employees back to their jobs as traders: by reconfiguring the socio-technical network that had disappeared, it reduced the fundamental uncertainty that the traders faced. According to Callon, a socio-technical network:

... is not connecting identities which are already there, but a network that configures ontologies. The agents, their dimensions and what they are and do, all depend on the morphology of the relations in which they are involved (Callon, 1998, p. 15).

After the attack, the traders were left wondering whether their firm would continue to exist, whether the trading room would operate again, what they should do and even what they were. The basement turned those survivors back into traders. To the question, 'Who am I?', the computers, desks and open-plan spaced answered, 'A trader.' To the question, 'What should I do?', the '20th floor' sign answered, 'The same as you would in the Financial Center trading room.'

The ontological character of the socio-technical network was also manifest in the discourse of the company's traders. We found them engaged in a debate about the meaning of 'real data'. The problem they faced was that the proprietary direct data connections that linked International Securities with the NYSE ran directly to the Financial Center, and therefore could not be used in New Jersey. The traders had

to rely instead on data from Bloomberg L.P. But, the traders complained, ‘Bloomberg data is not real data.’ It had small, unannounced delays, which made it unsuitable for some trading strategies such as index arbitrage. Thus, the traders had to do real trades with data they did not consider real.

The traders were also proactive actors in repairing their standing as economic pillars of the organization. In the face of damaged technologies and missing tools, they recombined old and new tools to be able to trade again. On the agency trading desk, for example, junior traders manually performed operations that were previously automated by the trading engine, such as booking trades, registering them, breaking them up, etc., effectively taking the bank to the trading technology that it had 5 years before. Lacking seats, they stood up behind the lucky senior traders who had a seat and a computer, ready to help. When, in the middle of a telephone conversation, one such trader suddenly needed to record a transaction, at the shout of ‘gimme a ticket, somebody gimme a ticket!’ three junior traders scrambled to offer tickets, paper and whatever he might need. Another junior was sent to ‘help with the tickets’ and ‘relieve others’ in a different desk. But he was told that with a sensitivity to the situation characteristic of International Securities: following the indications, the senior trader who gave them added ‘Oh, and this isn’t permanent, by the way.’ So unusual was manual book-keeping for the junior traders—so radical the bricolage that it entailed—that some of them did not even know how to do it, or whether it was appropriate for them to do it.

Similarly, statistical arbitrage traders made up for the lack of direct data from the NYSE by transforming themselves from monitors of their trading robots into active participants into the price mechanism. ‘Welcome to cut and paste land,’ one statistical arbitrageur said to us by way of greeting as we approached his makeshift desk in New Jersey. By ‘cut and paste’ he referred dismissively to his non-stop activity, transporting orders from the e-mail system to the trading engine by force of pointing and clicking his mouse. He laboured in this fashion because the lack of price feed in the Unix system forced him to connect one interface to the other. As a result, he said, ‘I have very little time left to do anything else’, such as monitoring the market and the speed of the price-feeds, his typical job. The trader, then, had figured out to trade without repairing the trading engine—doing so manually.

At International Securities, insufficient connectivity gave rise to a situation in which not all traders had enough bandwidth to trade simultaneously. When, for example, the index arbitrage desk was active, other desks could not trade. Even though this pitted the bonuses of index arbitrageurs against those of other desks, the rest of the traders in the room did not let the bottleneck escalate into conflict among desks. The episode is an example of another, equally important, trait of bricolage: tolerance with a less-than-ideal situation.

What is the lesson from the makeshift trading room for the organization of responsiveness? Responsiveness, the experience of these traders suggests, is a

combination of anticipation and improvisation. The bank had a space, but it was far from a perfect replica of the trading room at the Financial Center. Yet, the traders managed to be trading it in from day one. How? By engaging in bricolage. The bank had a warehouse, with square feet and little else. In that square footage the traders saw a resource—and used it to arrange the desks in almost the same configuration as in their former trading room. The tools that the traders had at their disposal were rudimentary in comparison with the precision instruments that they were accustomed to. In New Jersey they had only single-line telephones, home laptops, reduced connectivity and single-screen terminals. But they made them work: they managed to talk to other banks, enter orders and connect to the market. Like good bricoleurs, the traders did not let imperfection stand in the way of accomplishing tasks. Instead of waiting for the trading engine to be restored or for new servers to be delivered, the traders readily recombined old and new technologies. They matched their do-it-yourself outfits—jeans and boots—with a corresponding willingness to solve problems. In this process, some traders became clerks, others manual operators and others became room-mates of bandwidth, sharing cable to the NYSE. These changes in role status did not detract from their status as traders; in fact, it is how they reaffirmed their status as traders. Sometimes things have to change to remain the same. Their identities as traders were inscribed on their business cards. But what do traders do? They trade. By repositioning themselves in the damaged socio-technical networks, the traders found ways in which to trade. Innovation is not having new resources to accomplish new tasks but recognizing configurations that others would not see as resources. Responsiveness is grounded in this resourceful recognition.

3. Recovery as innovation

Following our observations at International Securities, we had to wonder whether our case was typical or exceptional. What had happened in other firms? And what were the experiences in WTC firms directly affected by the attack? We began to talk about response and recovery with numerous firms. We spoke with managers in large companies as well as in small- and medium-sized firms, individually and in groups. And we made extra efforts to speak with the people responsible for technology, for contingency planning, preparedness and continuity management. As part of this effort, Columbia's Center on Organizational Innovation, joint with Columbia's Interactive Design Laboratory, held a roundtable discussion on December 5th, 2001, with senior information technology and communications executives from key WTC firms as well as major consulting and technology firms. The companies included Merrill Lynch, Cantor Fitzgerald, Deutsche Bank, Sun Microsystems, Guy Carpenter, Accenture and Fred Alger Associates. The roundtable was not open to the public. We promised the participants that we would

report here only their comments, without attributing them to specific persons or companies.⁶

What did they tell us? No one said, ‘David, technology saved us’ or ‘Daniel, our plan really worked.’ Despite being technology officers, they all pointed to social relationships as a key feature of organizational response. Of course, they did talk about contingency plans and about technology. They told us, for example, that it mattered that the Trade Center had been bombed once before in 1993 and that their planning and preparation subsequently made a difference, or that extra back-ups in preparation for Year 2000 had proven for them to be very important in recovery. But sound planning was not sufficient in dealing with the uncertainties created by such a disaster. According to five of the executives who spoke with us:

Without that human element of commitment to the task, commitment to each other, preparedness wouldn’t have done anything. The best plan would have never opened up.

Well, yes, we could not have done without the corporate technologies that we had in place but what surprised us, in the initial hours and days after the attack, was how important were the technologies [pagers, personal cell telephones, Blackberries, Palm Pilots, etc.] that the company hadn’t invested in.

A business plan is one thing but you need a people plan, and everybody needs a responsibility.

I’m sure preparedness contributed . . . but even where preparedness was not there, people just innovated around it.

If you’re talking about measuring preparedness, the key question is how effectively can people work together and collaborate.

We can summarize our findings as follows. Recovery was a combination of planning *and* spontaneity, of redundancy *and* self-organization. To give texture to these abstractions, we present some accounts of recovery in the words of our informants. The first, appropriately, is a story about stories from an executive at a major bond trading firm in the Trade Center that suffered terrible casualties. On the evening of September 11th, the survivors of the leadership group met, knowing that they had to be trading when the bond markets opened in the same week. The firm had followed all the guidelines for contingency planning. They had backed up their data—at not just one but, in fact, two off-site locations: one across the river, one across the Atlantic. But they could not access the system. As the executive recounts:

We had 47 hours to get [ready for] September 13th, when the bond markets reopened and there was one situation that our technology

⁶ More information on the roundtable with Trade Center companies affected by September 11th is available at http://www.coi.columbia.edu/pdf/infrastructure_interface_program.pdf

department had that they spent more time on than anything else... It was getting into the systems, [figuring out] the IDs of the systems because so many people had died and the people that knew how to get into those systems and who knew the back-up, and the second emergency guy—they were all gone. How did they get into those systems? We sat around as a group, and talked about where they went on vacation, what their kids' names were, what their wives' names were, what their dogs' names were, you know, every imaginable thing about their personal life. And the fact that we knew things about their personal life to break into those IDs and into the systems to be able to get the technology up and running before the bond market opened, I think [that] is probably the number one connection between technology, communication and people.

With such an emotionally compelling account, the researcher must first pause and contemplate the sorrow in such a moment, exemplary in so many respects. By 4 am they had opened the systems; but the stories they told, we must recall, were tales of personal loss.

The account is exemplary, of course, in analytical ways as well. First, it is a gripping illustration of the insight that crisis reveals that any technology is always a *socio-technology*. All the technical back-up systems were in place, but without knowledge—in this case, the system passwords—you had no technology and no information. The interface between humans and technology and data was a social interface (Kelly and Stark, 2002). Secondly, the knowledge that was used to access the codified knowledge (literally codified—the system codes) was itself non-codified. More accurately, the case is an illustration of Orlikowski's (2002) challenge to the codified/non-codified distinction and related taxonomic dichotomies. As she argues, successful knowledge performance, 'knowledge in practice', requires combinations of explicit and tacit knowledge. The system codes were accessible through non-codified, personal knowledge in interaction with algorithms that translated personal knowledge into the actual passwords.⁷ Thirdly, the account reveals the organizational form that supports such knowledge. Employees knew the names of their colleagues' spouses or where they went on vacation or their favourite movies or music—but not because the organization had formally inquired and entered this information into some central database. The key in this case was how well they knew each other personally—details of private life that are, in the strict sense, irrelevant to their status as co-workers. From our field research in the intimacy of the trading room, we were not surprised that employees shared such knowledge.

⁷ In discovering the passwords, the technologists typed in the name of a family member to be converted into a numeric notation of the patterns of numbers and letters on a telephone keypad, *vice versa* for birthdates to alphabet, or multiplying, adding, reversing or scrambling numbers and letters, and so on. That is, in this case, the interface was also *socio-technical*.

Our broader interviews indicated that such ties extended beyond immediate work teams as our interlocutors spoke repeatedly about the importance of ‘cross-training’ and ‘lateral ties extending across department boundaries’ as network resources in the crisis. In short, within teams and across departments, people knew each other in multiple registers. Within these firms there was not a single logic, but multiple logics, in which actors were adept at switching codes (White and Mische, 1998).

The ability to draw on multiple codes, including not only the spoken but also the nonverbal, was critical to recovery because firms were managing people who were in fear and grief:

This was not a fire in a building which just destroyed two floors . . . Most everybody lost people they knew. They were traumatized, there was fear of war. Nobody knew if the next day there was going to be more. I had a guy walking around with a picture of his wife and kids in his pocket and was looking at it every two minutes because he was afraid he was never going to get home again.

In this circumstance, ‘what made the difference,’ as one manager noted, ‘for every company that came back successfully [was] that kind of touch, high-touch, low-tech solution.’

Strong social bonds within teams, of the kind that include figuring out where everyone is likely to meet when all the telephone lines are down, were important in the first hours after the attack:

You realized that the buildings had gone down. There’s a moment where you really do believe that you are the only person left in this company alive and right from the beginning I think it was more instinctual than it was ever organizational. Within an hour and a half after the first plane hit, the four remaining members of my team (I had 10 at the Trade Center) were at my front door. They had come from downtown, from wherever they were, whether it was in a subway on the platform, in the concourse, and they showed up at my door for no reason other than we had to do something.

Similarly, porous organizational boundaries that led to strong social ties with clients, vendors and consultants also proved crucial. According to another Trade Center executive,

Vendors and suppliers in our information technology areas, in communications and almost across the board really, were absolutely outstanding. It’s very easy to criticize these people routinely. They’re the brunt of bad jokes. It’s sort of corporate yucks to go around and make fun of the infrastructure and who supplies it. But in this case it was exceedingly generous. I can’t begin to tell how much we could count on the relationships

we had with vendors, consultants and clients. People were willing to do whatever they had to do to reconnect to us and whether that meant working around the clock so that we could be open on the 14th, they were there. You know, those relationships can never be replaced with anything.

In short, like the inter-organizational network ties that promote innovation among biotechnology firms (Powell, 1996), lateral social ties were critical for response.

What is the organizational basis of response to uncertainty? We can think, first, of responsiveness in the face of uncertainties that organizations confront as part of their 'normal' operations: businesses, universities, museums, hospitals and non-profit and public sector agencies face the imperative of organizational innovation as they confront conditions of radical uncertainty. That uncertainty is brought about by an extreme volatility of markets and rapid technological change. To cope with these uncertainties, organizations are flattening their hierarchies, distributing their intelligence, promoting collaborative structures and increasing lateral coordination for flexibility. But we can also think of responsiveness as response to the radical uncertainties brought about by crises of the kinds we saw on September 11th. Our research indicates that new developments in organizational theory have applicability to thinking about preparedness in response to crisis.

Mid-20th century, there was general consensus about the ideal attributes of the modern organization: it had a clear chain of command, with strategy and decisions made by the organizational leadership; instructions were disseminated and information gathered up and down the hierarchical ladder of authority; design preceded execution with the latter carried out with the time-management precision of a Taylorist organizational machine. By the end of the century, the main precepts of the ideal organizational model would be fundamentally rewritten. The primacy of relations of hierarchical *dependence* within the organization and the relations of market *independence* between organizations became secondary to relations of *interdependence* among networks of organizations and among units within the organizations (see the essays by Powell, Stark and Westney in DiMaggio, 2001).

The traditional view on preparedness shares much with the mid-20th century view of effective organization: establish a plan for contingency management with a clear chain of command. At the heart of such thinking is the concept of redundancy, that is, having back-up systems that replicate critical functions in the event of breakdown—more than one telephone system, one computer system, one trading room, etc. (Kelly and Stark, 2002). September 11th demonstrated the importance of such redundant systems. Having a back-up trading room, as some investment banks did as a result of contingency plans following the 1993 Trade Center attack, became key to guaranteeing continuity of business operations. There is much merit in this concept—no trading room can survive, for example, without backing up

data. But the limits of planning for crisis are similar to the limits of planning under conditions of complex strategy horizons (Lane and Maxfield, 1996): under conditions in which the future is radically uncertain,⁸ one cannot know in advance what resources one will need, or even know in advance what might be a resource.

Thus, in addition to *replicative redundancy*, our research also suggests the importance of *generative redundancy* in response to crisis. This redundancy differs from slack that merely duplicates the same type of resource (Grabher, 1994; Grabher and Stark, 1997). Generative redundancy is a ‘redundancy’ of difference. And it is for this reason that it can be generative. In situations of radical uncertainty, diversity of ties and diversity of means increase the likelihood that interaction will yield unpredictable solutions through ‘creative abrasions’ and ‘generative friction’ (Brown and Duguid, 1998; Girard and Stark, 2002). Lateral ties that cut across official vertical structures are redundant but not simply replicative; knowing your co-workers, home telephone number or other ways of getting in touch with them is a non-replicative redundancy; and organizations that tolerate more than one way of doing things are similarly willing to sacrifice some allocative efficiency in the short run in the interest of dynamic adaptability. These redundancies contributed to emergent self-organization when nodes in the corporate hierarchy were damaged or destroyed, and they allowed for the flexible redefinition of roles and resources in a time of crisis.

This discussion has relevance not only for how we think about preparedness but also for how metrics of preparedness might figure when valuing companies. One executive at the December 2nd, 2001, Columbia roundtable noted that creditors and investors will be giving renewed attention to preparedness as a factor in company valuations in the wake of September 11th:

The most forward-thinking and strategic of the things that we have learned is that it’s now our view that going forward companies are going to be valued on something that I would call preparedness. I think that that is going to become an integral part of how investors, employees, fiduciaries, everybody, counterparties, everyone looks at a company’s worthiness. It will become analogous and perhaps even part of your credit rating, and these preparedness issues come down to some of the most mundane things...like mail processing, air travel, workplace security, data security and data infrastructure, personal identification and personal accountability, and then even things like new accounts and sources of funding.

⁸ As one of our informants observed, ‘You know that line from Tolstoi that goes something like “All happy families are the same, but unhappy families are uniquely miserable.” It’s the same for us. Every normal day is like every other, but every really big crisis is unique. That’s why you can’t just plan for crises.’

In the conventional view, there exists a trade-off between preparedness and competitiveness. Replicative redundancy is a necessary business practice, but it is a pure cost that does not contribute to organizational competitiveness. This view of preparedness typically gives advantage to companies that are larger and more bureaucratic. Generative redundancy, on the other hand, might contribute to preparedness *and* contribute to effectiveness/competitiveness. Heterarchical structures that contribute to responsiveness in times of crisis can facilitate innovativeness throughout the organization in responding to its environment more generally.

4. The changing urban geography of finance

In April 2002, the traders from International Securities returned to the World Financial Center, together with other companies such as Merrill Lynch, Commerzbank and American Express, providing hope for the future of Lower Manhattan as a financial district. But choices made by other firms affected by September 11th suggest caution rather than optimism. Despite a city and state programme of economic incentives to keep companies in Lower Manhattan, an exodus seems to be in place, with companies such as Lehman Brothers, Aon, Pillsbury Winthrop, Dresdner Kleinwort Wasserstein and ABN Amro leaving the area to more expensive locations in Midtown or more distant offices in Brooklyn and Jersey City (Bagli, 2002). For several decades the district has already been losing a competition against Midtown Manhattan as the location of choice for financial companies, and forced relocation has accelerated that trend. The debate about the redevelopment of the WTC site (Sorkin and Zukin, 2002) must consider these historic trends as well as take into account changes in technology that, according to some, remove the need for a district in finance.⁹ Our research on trading prior to September 11th and on the dynamics of recovery afterwards bears directly on this debate.

During the last decades of the 20th century, Wall Street has gone through a veritable quantitative revolution, based on three legs: high-speed network connectivity, high-powered computation and the development of mathematical finance (Dunbar, 2000; D. MacKenzie and Y. Millo, unpublished manuscript; Knorr Cetina and Bruegger, 2002). Their overall effect on the choice of location by financial firms is uncertain because each of the legs exerts forces for and against proximity.

Consider first the rise of electronic markets. Those who espouse a utopian vision of a virtual, place-less and perfectly competitive financial sector point to the success of the NASDAQ, the world's first purely electronic market and its world-wide

⁹ For overviews on the geography of finance, see papers in Corbridge and Thrift (1994), Leyshon and Thrift (1997), Martin (1999) and Clark *et al.* (2000).

imitators,¹⁰ as proof that network connectivity reduces the salience of physical proximity. According to *The Economist*:

Lower Manhattan... may be the world's largest single electronic marketplace. In the days when banks' vaults were full of bearer bonds and stock certificates transferred by 'runners' after trades were done, trading firms had good reason to cluster together. Yet proximity is little or no help in implementing trades (Anonymous, 2001, pp. 68–9).

Indeed, the instant availability of price data, market news and virtually any other type of information from the Internet, financial television and other sources is partially what allowed America's largest mutual funds to thrive despite being located away from Wall Street. Funds like Fidelity, Janus or Vanguard are as distant from Lower Manhattan as Boston, Denver and Philadelphia, their respective locations.

But some aspects of network connectivity heighten the salience of proximity. As electronic markets make hard information instantly available to everyone, knowledge in soft or more tacit forms of interpretations, impressions and perceptions of others becomes the key source of competitive advantage (Amin and Thrift, 1992; Thrift, 1994, 2000; see also Grabher 2002*a, b*). This puts a premium on immediate proximity at the level of the micro-locale: profitable arbitrage trades, as we found in our research at International Securities, are ultimately instances of innovation, and innovation takes place within close proximity such as a shared corridor or a desk (Allen, 1977; Kraut *et al.*, 2002; Olson *et al.*, 2002). The deliberate way in which arbitrageurs at International Securities attempted to reconstruct the layout of the trading room in New Jersey revealed how acutely aware the traders were of these dynamics.

At the more aggregate level of the district, our research at International Securities has shown that proximity to other financial firms is crucial for some arbitrage strategies, such as merger and convertible bond arbitrage. In the case of merger arbitrage, for example, traders bet on the likelihood of a merger. As part of their strategy, they must determine the commitment of two firms to merge, and to do so they find it crucial to attend companies' presentations. As the traders told us, it's not enough just to hear the meeting webcast on the Internet—one needs to be there, to see the faces in the audience or around the table as firms make their bold claims, to bump into ex-colleagues in the corridors and to have lunch with the people

¹⁰ Frankfurt's DTB and Paris's MATIF (both merged into Eurex in 2000), London's LIFFE and Stockholm's and Madrid's exchanges have already migrated to an electronic form. Other markets, such as the recent ECN-turned-exchange Island Futures Exchange LLC, began in electronic form. And others, most significantly the Chicago Mercantile Exchange, have developed a dual physical–electronic system by keeping its pits and developing an electronic system, Globex, that complements rather than threatens it (Muniesa, 2000; Milo, 2001; Scott and Barrett, 2002; Zaloom, 2002).

involved. There are additional advantages from being close to other traders that belong to the same community of practice: finding out new trading techniques, labour-market dynamics of recruitment, etc. (Kim, 1991; Porteous, 1999).

This search for ever more nuanced interpretations explains why companies such as Chase and Citigroup have moved their high-value-added trading operations to Midtown *despite* higher real-estate costs than Lower Manhattan (Berman, 2002). The same can be said for the recent move of Lehman Brothers to Times Square following September 11th (a location that is at best no safer than Lower Manhattan) or the planned move of Cantor Fitzgerald to a nearby area at Union Square. Furthermore, the evidence from the relocation patterns of the firms displaced by the events of September 11th suggests that most WTC firms that have survived have moved to Midtown Manhattan: from a sample of 500 of a total of 700 WTC firms, a team of *New York Times* investigative reporters found that 39 had folded, 50 operated from homes and about 270 had relocated to Manhattan addresses above Chambers Street—in effect, to Midtown Manhattan (Flynn *et al.*, 2002). Midtown is not only attractive to banks for its transportation network: as the rich amenities and accommodation facilities of the area attract travelling businesspeople and non-financial corporations, the district draws Wall Street firms to their vicinity, in accordance with a time-bound tradition whereby Wall Street firms follow the owners of capital.

In a similar vein as the rise of electronic markets, the spread of low-cost computing and the development of mathematical finance also have dual, push–pull effects on Wall Street companies' choice of location. Take the rise and spread of Nobel Prize-winning mathematical formulas. By codifying the knowledge of how to combine securities into profitable trades, the firms that put the formulas together multiply the possibilities of benefiting from the knowledge they contain. But the possibilities for imitation by competitors are equally multiplied (Kogut and Zander, 1992). The resulting pressure to protect such volatile knowledge pushed Long Term Capital Management (LTCM), America's largest and most sophisticated arbitrage-based investment firm, away from Manhattan into Greenwich, Connecticut, in the hope of minimizing the contact of its traders with competitors and the resulting threat of imitation (for an account of LTCM's downfall see MacKenzie, unpublished manuscript).

The rise of financial formulas, however, has also had the reverse effect, pulling firms closer together. In our research at International Securities we found that the firm has re-focused its trading strategies towards complex, ambiguous cross-deal trades that cannot be easily captured by a formula. The company relies instead on the tacit knowledge about different markets and synthetic financial products contained in its different desks, and counts on interaction among desks for the different pieces of the puzzle to come together. This strategy acts like a centripetal force, as

desks at International Securities actively search proximity to each other and to the larger arbitrage community on Wall Street.

The diffusion of low-cost computing has a similar two-sided effect. As high-speed trading becomes accessible to every financial firm, the time advantage is eroded. The response of firms like International Securities has been to bring their technology personnel into the core of their practices, hiring systems technicians with cross-training in finance to streamline their 'trading engines' (automated book-keeping and reconciliation of trades) or to widen the bandwidth of the connections to the market so that trading robots can buy and sell at ever higher speeds. At International Securities, entry-level operations personnel sit in the same room as the highest-earning traders, barely one desk away.

On the other hand, the secular reduction in computing cost has made traditional operations departments a lesser source of competitive advantage, liable to be outsourced or relocated to the periphery of the firm. That is, whereas technology personnel are being brought into the core of the trading room, hardware is being relocated to sites distant from it. This is the force behind the recent development of the New Jersey waterfront. In the past 15 years, Manhattanites have witnessed the striking transformation of that area from an officially declared blighted neighbourhood to an attractive (if unglamorous) line-up of high-rises wired for fast connectivity. They are the outposts of the operations divisions of investment banks such as JPMorgan Chase. Similarly, Citigroup sent its operations division away from Manhattan to Queens, in search of lower real-estate costs and faster access to medium-salaried employees. That the move was driven by cost-cutting and convenience is clear from even a cursory glance at Citigroup's building, an undistinguished high-rise that sticks out almost painfully in a neighbourhood notable for its modest low-rise single houses, ethnic restaurants and family businesses.

Our research suggests, therefore, that one cannot read the future urban geography of finance directly from the technologies of trading. The quantitative revolution—the rise of electronic markets, mathematical formulas and low-cost computing—is actively re-shaping the geography of Wall Street, but in complex and multi-directional ways. Proximity has become crucial for some companies and obsolete for others, a source of profits for some departments and a threat to the existence of others. But, to be clear, the spatial agglomerations that result will not necessarily be in Lower Manhattan.

In the public debate about finance and Lower Manhattan many academics, policy-makers and even people in business identify Wall Street with the NYSE. This identification would have been correct for most of the 20th century: trading rooms began as extensions of the NYSE that investment banks built inside their corporate skyscrapers in order to carve out and better process the information that they obtained from it. Nowadays, however, the equation that identifies Wall Street with the NYSE

is obsolete. Our research indicates that the real locus of modern finance is not the Exchange but the trading rooms. As a result, we should abandon visions of finance in Lower Manhattan as having a radial or mono-centric urban form—the NYSE surrounded by trading rooms—and embrace instead a multi-centric understanding of Wall Street. The Trade Center was not some sort of back office to the NYSE. And its trading rooms were more like scientific laboratories than replicas of the exchange. Wall Street is better thought of as a web of trading rooms in which each node is anchored to the area by its proximity to others, rather than to the Exchange.¹¹

While proximity to other financial firms is important, this does not, in itself, imply being in Lower Manhattan. The various functionalities that were concentrated in the traditional financial district, we expect, will be de-coupled. In the resulting plurality of micro-districts, Wall Street will become a distributed concept, spatially distinct from the street in Lower Manhattan whose name provides the metonym for the sector.

To the transformations outlined above in the urban geography of finance, September 11th have added a new element: security. In the 1993 bombing of the WTC and the Year 2000, financial firms learnt about the importance of back-up facilities and contingency planning. The lesson of September 11th, according to the WTC executives that we interviewed, is to disperse operations. ‘Are we going to have a single operation, a single site in New York City?’ asked one executive. ‘The answer clearly is no, we’re not going to...’ was his reply. Other WTC executives explicitly linked dispersion and security:

Number one, we have decidedly rethought our strategy of having all mission-critical applications and functions, whether they be electronic or human, in one location, and that just is not restricted to buildings but geography.

As executives consider decisions to disperse their operations not only across buildings but also across electricity grids, telephone codes and transportation hubs, they confront new challenges. On one hand, effective innovation, and in particular the type of innovation that makes for profitable trades, requires proximity to other departments in the same firm and to rival firms. On the other, security concerns regarding potential attacks require firms to disperse their operations. As a result,

¹¹ In their analysis of the German capital markets, Lo and Grote (2001) have separately arrived at a similar conclusion. The authors argue that ‘with the virtualization of stock exchanges, informational spillovers with other traders and the headquarters of traded firms become the main determinants of the location of stock traders’ (Lo and Grote, 2001, p. 2). For example, the Eurex exchange in Frankfurt took advantage of newer technology to attract the German Bundt away from London. But the knowledge required for the trades remained situated in the communities of London traders. As a result, the German Bundt is traded in Frankfurt, but the traders remain located in London.

financial firms are caught between the pull of proximity for innovation and the push of dispersion for security.¹² One of the Trade Center executives that we interviewed voiced this concern:

So when I think about measuring preparedness, one of the things that ... I heard loud and clear this morning again is an organization's ability to operate geographically dispersed, effectively, and those are two very distinct concepts that have to mutually exist.

The trend towards dispersion challenges policy-makers as well as executives. In the process of dispersing, companies will inevitably relocate some of their fragmented bits of office space beyond Lower Manhattan. How will policy-makers, currently concerned with rebuilding Ground Zero and Lower Manhattan, respond to these dynamics?

One obvious answer for policy-makers concerned with the viability of the district is to replicate what was in place before the destruction of September 11th, including the tight identification of Lower Manhattan with Wall Street. Build new towers (two or 20) with exactly the same square footage of office space and hope that the financial firms will return. The Empire State Development Corporation (ESDC), for instance, appears to take it for granted that the interests of both Wall Street and Lower Manhattan are best served by keeping financial companies where they are. The public agency has put together a programme of customized subsidies, negotiated individually in the case of large firms, to stem the tide of leaving firms. And every time one such firm decides to leave Lower Manhattan, the ESDC takes the decision as a defeat.

But at this point, we should ask whether the interests of Lower Manhattan are really better served by maintaining its pre-September 11th identification with Wall Street and its attendant problems of a nine-to-five schedule, deserted streets after dusk, decaying commercial activity and dreary night-life. By preventing financial firms from leaving and freeing up space for new tenants, subsidies impede the area's evolution, worsening its shortcomings instead of addressing them. This will, in turn, call for renewed subsidies.

The opposite public policy strategy is to anticipate what finance is going to become 20 or 30 years from now, and attempt to design accordingly. The problem with this approach becomes apparent when we reflect on the revolution in quantitative

¹² Amin and Cohendet (2003) point to a way out of this impasse for financial firms: the ability of organizations to use spaces other than the physical one to transfer knowledge. Organizations have, according to the authors, mechanisms that resemble 'communities of enthusiasts with like interests (e.g. vegetarians, DIY groups, road protestors, clinical psychologists) held together by cheap travel, the internet and specialist literature. It includes diaspora communities based on migratory ties and transnational cultural connections affiliations' (Amin and Cohendet, 2003, p. 128).

finance that has swept the industry. Thirty years ago, the Trade Center was being built as a 'vertical port' that would house and promote the traditional trading companies located on the harbour of New York: firms that bought commodities such as cocoa in one continent and shipped and sold it in another. The move was anticipatory in spirit (it addressed the transition from an industrial to a service economy) yet no-one foresaw the WTC as a centre of financial trading. And no one is likely to have predicted that finance would go through the tripled features of the quantitative revolution. The Black–Scholes formula for pricing derivatives (one of the key applications of mathematics to finance) was developed in 1973 and was hardly on the radar screen of policy-makers. In 1973, computers were those things the size of a room that were used to process payrolls. And to speak about the 'World Wide Web' and 'high-bandwidth Internet connectivity' in 1973 might have provoked suspicion that one's connection to reality had been clouded by too many highs on recreational drugs. In short, the quantitative revolution in finance would have been difficult to anticipate and even more difficult to design for. With this retrospection as a cautionary note, who can say with confidence what finance will be 30 years from now?

In place of predicting the future or of replicating the recent past, the citizens of New York City should encourage their representatives to rebuild Lower Manhattan with an emphasis on increasing diversity of types of organization—not simply more large corporations but medium-sized and start-up firms, not simply in financial services but a broader sectoral range, not simply businesses but educational and cultural institutions. Diversity accomplishes two tasks. First, it would make Lower Manhattan a more vibrant and exciting locale, and thereby more attractive to the knowledge-intensive firms that will be a source of economic vitality for the city. Why do energetic, ambitious, young people come to New York City? Because other young, ambitious, energetic people like them come here too. The more a city, or a district in a city, is a place of wonder and excitement, the more it can stimulate these tipping point effects. Secondly, greater diversity among the types of organization produces a broader 'gene pool' out of which innovative recombinations can emerge.

Will such a strategy come from the financial sector itself? Like the generative strategies—with their lateral, heterarchical ties—that proved so resilient and effective in the first days and weeks of recovery, a generative strategy for rebuilding Lower Manhattan will require broader, horizontal ties actively involving citizens and civic associations. Like the trading rooms themselves, the new associations that will make for innovation in redevelopment will require distributed intelligence and the organization of diversity.

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