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From dissonance to resonance: cognitive interdependence in quantitative finance

Daniel Beunza and David Stark

Abstract

This study explores the elusive social dimension of quantitative finance. We conducted three years of observations in the derivatives trading room of a major investment bank. We found that traders use models to translate stock prices into estimates of what their rivals think. Traders use these estimates to look out for possible errors in their own models. We found that this practice, *reflexive modelling*, enhances returns by turning prices into a vehicle for distributed cognition. But it also induces a dangerous form of cognitive interdependence: when enough traders overlook a key issue, their positions give misplaced reassurance to those traders that think similarly, disrupting their reflexive processes. In cases lacking diversity, dissonance thus gives way to *resonance*. Our analysis demonstrates how practices born in caution can lead to overconfidence and collective failure. We contribute to economic sociology by developing a socio-technical account that grapples with the new forms of sociality introduced by financial models – disembedded yet entangled; anonymous yet collective; impersonal yet, nevertheless, emphatically social.

Keywords: financial models; cognitive interdependence; quantitative finance; performativity; risk; arbitrage.

As the term 'financial engineer' suggests, the recent history of finance is part of the broader rise in systems engineering over the last half of the twentieth

Daniel Beunza, Department of Management, London School of Economic, Houghton Street, London WC2A 2AE, UK. E-mail: d.beunza@lse.ac.uk
David Stark, Department of Sociology, Columbia University, USA. E-mail: dcs36@columbia.edu

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century. Models, computers and electronics have reshaped Wall Street as much as the jet engine changed aviation. Whether in industrial engineering or in financial engineering, the new tools of practice have proven faster, bolder and more complex, opening up the scope for gains in speed, efficiency and power. But they have also opened up the possibility of disasters. Indeed, it is no coincidence that a new body of expertise, cybernetics, was developed to deal with the complexities of advanced technological systems in the age of machine intelligence. Writing in the aftermath of one of the most automated (and lethal) wars to date, Weiner (1948), McCulloch and Pitts (1943) and Von Foerster (1958) laid out the principles for the governance of systems marked by interdependencies and positive feedback. But, whereas these concerns arguably helped system engineers limit (though not eliminate) the dangers of nuclear accidents or massive air traffic fatalities, the equivalent has not yet been developed for financial engineering. 'Systemic risk', 'circuit breakers' and related expressions populate the day-to-day parlance of regulators, but existing theories of the market do not explicitly focus on the interdependencies caused by financial modelling. Positive feedback, tight coupling or lock-in hang menacingly over the portfolios of investors. As the credit crisis of 2008 comes to show, the large technological systems at the core of the industrial economy may be better prepared for the risks of complex engineering than modern finance.

We explore the aforementioned risks to market stability by examining the social use of financial models. How are spreadsheets and equations deployed in banks and hedge funds? Do models replace, complement or fundamentally alter the ways in which traders rely on their judgement and social cues? What happens to a network when social interaction is mediated by an artefact such as a model? Following the methodology of the emerging literature in the social studies of finance (Beunza & Stark, 2004; Knorr Cetina & Bruegger, 2002; MacKenzie & Millo, 2003; Preda, 2006) we conducted a three-year ethnographic study of the daily operations of the trading room of a major international investment bank, pseudonymous 'International Securities'. Our focus was its merger arbitrage desk, a team involved in a well-publicized arbitrage disaster in 2001. In this study we combine the findings of our detailed ethnographic observations with a historical reconstruction of the arbitrage disaster in question. Merger arbitrage is a particularly appropriate setting because it is also free from the self-referential loops and 'beauty contests' outlined by Keynes (1936), as merger completion is a decision taken by the companies with relative independence of the bets placed by the arbitrageurs (more on this below).

Our findings point to the existence of a new socio-technical mechanism that results from the use of financial models. Arbitrageurs, we found, do not use models only to develop their own estimates of relevant variables. Crucially, they also deploy models to check their own estimates against those of their rivals. Thus, in place of models *versus* social cues, we observed traders *modelling social cues*. We refer to this practice as *reflexive modelling*. This procedure, known as 'backing out,' among finance practitioners, is at the centre of the use of models in quantitative finance and was rated by Chester Spatt, recent Chief Economist at the Securities and Exchange Commission, as the second most important financial innovation of the past four decades, alongside Black-Scholes (interview conducted by the authors).

Reflexive modelling offers important benefit to individual funds. It gives individual participants a way to leverage the cognitive efforts of their rivals. In that sense, reflexive modelling suggests that the price mechanism is not only a device for aggregating disperse information, as Hayek (1945) famously put it, but that it can go much further and serve as a means for distributed cognition (Hutchins & Klausen, 1995). That is, a way that allows market participants to think collectively about the issue.

Our study further demonstrates that these precautionary practices can also be dangerous. Reflexive modelling creates a form of cognitive interdependence that can amplify mistakes. When a sufficiently large number of arbitrageurs overlook a critical factor driving merger failure, the dissonance that is at the core of reflexive modelling turns to resonance. It is this resonance that creates misplaced confidence, leading to widespread and oversized losses. The occurrence of such losses has been well documented in the academic finance literature, and is referred to in terms of 'arbitrage disasters' (Officer, 2007). An arbitrage disaster is specific to merger arbitrage, as it is defined as 'deal failures that cause merger arbitrageurs worst-loss day exceeding $500 million' (Officer, 2007, p. 12).

Our analysis contributes to economic sociology by outlining the contours of the new sociability ushered in by quantitative finance. As repeatedly described by scholars of finance (e.g. Knorr Cetina & Bruegger, 2005; MacKenzie, 2006), the introduction of financial models and electronic markets has been characterized as a replacement of personal networks with anonymous transactions, and social capital with human capital. However, the existence of reflexive modelling demonstrates that quantitative traders have not actually replaced social cues with financial models. Instead, traders *use models as an instrument to observe and measure social cues*. As a result, the dysfunctions of an over-embedded financial market – herding, self-fulfilling prophecies – are now less prominent. But new risks such as resonance have developed in their place.

Understanding interdependence in quantitative finance

How is quantitative finance a social endeavour? The current debate has emphasized either the social or the technical aspects of the capital markets, but failed to take both simultaneously into consideration. Our review below examines the various approaches to 'the social' in behavioural finance, economic sociology and science and technology studies (STS). The conclusion emerging from it is that grappling with modern markets calls for an understanding of the novel forms of economic engagement introduced by financial models. We characterize these as a form of cognitive interdependence, created by the distributed cognition that is afforded by financial models.

Behavioural finance and the need for a socio-technical account

The challenges involved in characterizing quantitative finance are aptly illustrated by the limitations of existing behavioural approaches to risk. These shortcomings are clear in 'black swan' accounts that attribute financial crises to the overuse of financial models. Building on the Knightian distinction between risk and uncertainty, several authors have argued that crises occur when the unquestioned use of financial models leads banks to underestimate uncertainty (Bookstaber, 2007; Derman, 2004; Taleb, 2007). The models used by these investors, the argument goes, assume a future that is an extrapolation of the past. Investors assume, for instance, that stock returns follow a normal distribution – but in practice financial markets are subject to unpredictable extreme events, or black swans. Instead of a normal distribution, stock returns are more accurately described by fat-tailed distributions. To the extent that investors do not incorporate these exceptions into their models, their trading will be subject to the risk of disaster.

Although appealing, the black swan is ultimately an under-socialized explanation of the risks created by models. The black swan presents financial actors as hopelessly unreflexive about the limitations of their models. Confronted by uncertainty about the model, we would expect market actors to rely on the social cues around them – which brings us back to the question of how actors combine the social and the technological.

In contrast to this, another stream of behavioural literature has explained financial risk in terms of imitation among financial actors (Scharfstein & Stein, 1990; see also Banerjee, 1992; Bikhchandani *et al.*, 1992 on information cascades). In the seminal account by Scharfstein & Stein (1990) herding takes place when actors have an incentive to mimic the actions of others, even if their private knowledge would dictate doing otherwise. This typically takes place in situations that couple uncertainty with an overly comparative reward structure. Consider, for example, two salespeople who are to choose whether to sell wine in the east or west end of a city. There is uncertainty as to how much demand there is in both ends, and each of them has some private information about it. If the salespeople are paid a straight commission on their sales, each of them will choose whichever side of town they think will have greater demand. Consider now what happens if they are paid according to a comparative scheme, in which agent one chooses first and agent two's bonus is based on how much she sells over or below agent one. If that is the case, it will be in the best interest of agent two simply to follow salesman one's decision, even if her private information suggests that demand is greater on the other side of town. Doing so avoids the worst possible outcome, namely, one in which the first agent is lucky and the second one is not. As Keynes puts it, 'worldly wisdom teaches that it is better for reputation to fail conventionally than to fail unconventionally' (Keynes, 1936, p. 158). Mechanisms of 'social proof' such as this have been used to explain financial risks and the dynamics of financial bubbles (Shiller, 2000; Smith *et al.*, 1988). A related model of imitation is given by studies of information cascades (Banerjee, 1992; Bikhchandani *et al.*, 1992).

Cascades and herding, however, do not account for the existence of technology in the decision-making process. In the classic account of herding described above, actors do not change their opinion but simply *disregard* it for the sake of conforming to the actions of others. Beliefs are replaced rather than combined, with actors metaphorically disconnecting their brains to act according to the dictates of the mass. Admittedly, this might have been a realistic portrayal of financial actors before the 1980s, when decision-making was primarily embedded and institutionalized (Abolafia, 1996; Baker, 1984). But the introduction of computers, equations and models into financial markets during the past three decades has also changed the attitudes and procedures in the trading rooms (Beunza & Stark, 2004; MacKenzie & Millo, 2003). For instance, trading with a model is not the same as trading without one: it entails handling and manipulating a body of codified knowledge that cannot simply be put to the side for the sake of copying someone else's decision – at least, not without fundamentally abandoning the trading strategy.

Economic sociology and the problem of anonymity

The dominant paradigm in economic sociology is equally unprepared to grapple with the technological aspect of quantitative finance. Economic sociologists have traditionally presented market activity as social by emphasizing that transactions are embedded in social ties (Baker, 1984; Granovetter, 1985). But the notion of embeddedness – developed before the full impact of the quantitative revolution on Wall Street – needs to be reconsidered in settings where networks of people have been augmented by socio-technical networks, including connections, computers and financial models. Whereas embeddedness presupposes the existence of personal acquaintance among social actors, current financial markets are in some ways shaped by deliberate anonymity. What, then, is the counterpart of embeddedness when the only actor that a trader sees is through a screen?

Beyond embeddedness, the social can also be construed as a process of institutionalized belief formation. In this sense, the sociological notion of self-fulfilling prophecy offers a crucial analytical first step. As Robert K. Merton (1968) observed in his analysis of a run on a bank, economic activity can be social despite being anonymous. Banking, according to Merton, is a special form of activity in that it is subject to positive feedback between beliefs and behaviour – that is, to self-fulfilling prophecies. Because a depositor's decision to draw out his or her funds reduces the liquidity available to other depositors, the collective perceptions of a bank's solvency among its different depositors end up sealing the fate of the bank.

Merton's account, however, needs to be reformulated to fit a modern context of models and financial technology. In the standard Mertonian set-up, self-fulfilling prophecies entail an over-abstracted, almost tautological portrait of how crises happen. *If* a sufficiently large number of depositors fear a crisis, the run on the bank will surely happen. But, as Callon (2007) asks, *how* do these beliefs arise in the first place? One answer might be that these beliefs are a shared convention. But this poses the additional question of how depositors coordinate their views around a given convention in the first place.

The answer, Callon suggests, points to the material basis of belief formation. A line forming outside a retail bank branch can be enough to prompt fears of a bank run, but the line itself is manifestly material – a systematic formation of human bodies, positioned on the sidewalk of the street and in full display for the rest of the city. In more advanced forms of financial activity, financial models could be one such form of belief coordination. In this respect, the application to markets of the analytic tools of STS offers useful guidance. To understand anonymous transactions, argue Callon and his colleagues,[1] we must analyse the materiality of calculation, including financial models (Callon, 1998, 2007). Models frame decisions and quantify alternatives, thereby exerting a mediating role on financial valuation.

Technology and cognitive interdependence

Callon's work has thus focused the debate on the problem of calculation. As he demonstrated, allowing for the role of technology in economic decision-making calls for accepting that market devices allow actors to enter the type of quantitative engagement that economists posit in their models. Callon's (1998) early emphasis on materiality focused on the tools, attributing an actor's ability to calculate to the separation ('disentanglement') between the transacting parties and the economic object being exchanged. This had the advantage of explaining how actors are able to calculate with complete independence from each other: the device replaces social cues. But it had the disadvantage of failing to provide a theory of how market actors might rely on each other, as it focused on actors acting in complete independence.

In subsequent work, Callon has outlined the ways in which the social and material come together. Callon (2008) argues that decision-making is not purely driven by the calculative device, but also by interaction with other actors in a heterogeneous network of humans, tools and other elements. Thus, for instance, supermarkets offer a calculative device of sorts – a shopping cart, which allows consumers to ascertain the physical volume taken up by their purchases. But there is a social aspect that complements the tool: equipped with a mobile phone, shoppers can also include in their calculations the judgement of others in their personal network. This entails a critical move away from a tool-centred (in Callon's language: 'prosthetic') view of decision-making and towards one in which the actor is supported ('habilitated') by a network of people and things. Callon refers to this new perspective on market actors as 'homo economicus 2.0'. Extending Callon's new mix of the social and the material to the case of financial markets, we ask: what happens when traders use devices that bring other traders' opinions to bear on their calculations? We then go on to explore a further question: once social dynamics are introduced in calculative decision-making, do the dysfunctions of society also enter into the calculations?

In attempting this redefinition of 'the social', we draw on Knorr Cetina & Bruegger's (2005) notion of *scopes*, or observational instruments. Knorr Cetina draws a distinction between network-centred and scope-centred markets. In the former, personal relations carry the burden of coordination ('network architectures'). In the latter, objects are the central coordinating device. The actions of investors are projected onto a scope, creating a representation that investors can react to. Their reactions, in turn, become part of this representation. Investors do not react to each other, but to the aggregate traces of each other's actions – as seen on the scope. Such new rules of association – aggregation, anonymity and mediation through shared representation – offer fertile grounds to theorize the ways in which risk can originate in financial models. But the full benefits of scoping accrue only to those traders who combine the market device with a body of codified knowledge (i.e. a model) that turns this new representation into an input for decision-making that non-quantitative rivals do not have at their disposal.

This is, in many ways, the context explored by Beunza and Stark (2004) in their ethnography of a derivatives trading room. Their study begins to explore the distinct organizational properties of quantitative finance. Thanks to models, databases and electronic data, arbitrageurs can see opportunities that they otherwise would not be able to detect. The traders' reliance on such specialized instruments, however, entails a serious risk: in bringing some information into sharp attention, the software and the graphic representations on their screens also obscure other equally important information. Beunza and Stark (2004) analyse the organizational mechanism that traders deploy to minimize this risk. Each desk in the trading room had developed its own way of looking at the market; by clustering all the desks in the same open-plan space – and especially by putting in place integrative organizational policies that ensure the flow of knowledge across desks – the traders improved their understanding of the limits of their models. But, while successful at analysing both the organizational and the technical aspects of the market, Beunza and Stark (2004) portray a seemingly autarkic bank, where social interaction took place only among colleagues inside the room. Nowhere in their account is there an examination of inter-organizational networks, interactions in bars and restaurants, or of the role of geographical proximity on Wall Street.

In offering a theoretical account of the new sociality of quantitative finance, we also draw on MacKenzie and Millo's (2003) work on performativity and the

Black-Scholes formula for options pricing (see also MacKenzie, 2006; Millo & MacKenzie, 2009). Although not explicitly theorized as such, MacKenzie and Millo (2003) offer a theory of cognitive interdependence based on a model. In their account, options traders used the Black-Scholes formula backwards to translate option prices into a measure of the 'implied volatility' of a financial option; a measure, that is, of the estimates of future volatility made by rival traders. The transformation of the formula into an observation instrument gives rise to cognitive interdependence, as it lets some actors use the actions of others as inputs into their own decision-making. However, MacKenzie and Millo (2003) do not take the extra step of exploring the implications of this set-up for the new risks posed by quantitative finance.

Neither do the authors explore this dynamic in subsequent work. For instance, MacKenzie's (2006) analysis of Long-Term Capital's debacle in 1998 turns to a traditional conceptualization of 'the social' in the form of imitation following personal ties. Specifically, he explains the social dimension of the 1998 crisis as the result of 'consensus trades', that is, institutionalized trading strategies that arose from social interaction among investors. Yet financial models, we contend, create a distinct form of interdependence that needs to be understood in its own terms. Once traders rely on anonymous competitors for crucial insight, a novel mechanism of social influence has been created. What potential pitfalls does it pose?

By contrast, MacKenzie's (2011) analysis of the 2008 credit crisis is more in line with our socio-technical perspective. In it, MacKenzie focuses on the organizational aspect of valuation. The reckless mortgage lending that characterized the credit crisis, he argues, can be partly attributed to the lack of integration within rating agencies. Mortgage traders, traditionally specialized in asset-backed securities, drew on different knowledge sets, tools and techniques than those used by derivatives traders, traditionally specialized in collateralized debt obligations. The rise of mortgage-based derivatives, which combined the two spheres of activity, called for an integration of these two evaluation practices, but they were kept separate in the rating agencies, opening the door to questionable valuations. MacKenzie's (2011) study is thus exemplary in demonstrating that a faulty organization of modelling constitutes a pitfall in quantitative finance. It also illustrates the dangers of ignoring the integrative bank management policies outlined by Beunza and Stark (2004). However, MacKenzie's article says little about the interplay between models and sociality outside the organization. It is to this problem that we turn in our study.

Research methods

Research site

The data reported below are taken from our observations of the merger arbitrage desk at pseudonymous International Securities, a global bank with an active proprietary trading unit. The bank was among the world's ten largest in equity underwriting (Hoffman, 2006). Our observations centre on its equity derivatives trading room, located in Lower Manhattan. Proprietary trading units of this kind function as internal hedge funds within an investment bank, that is, they trade with the bank's capital rather than the client's, making their activity potentially riskier but also more lucrative.

Arbitrage constitutes an ideal site to examine models and their risks because arbitrage played a central role in many recent financial crises. These include the market crash of 1987, the crisis of Long-Term Capital in 1998 and the hedge fund 'mini-crash' of August 2007 (see Dunbar, 2000; Jorion, 2000; Khandani & Lo, 2007; Lowenstein 2000; MacKenzie, 2006; MacKenzie & Millo, 2003). Of the different trading strategies pursued by arbitrageurs, our study centres on merger arbitrage. This focus on mergers allows us to identify financial failure, as it allows us to separate the perceptions of financial actors on Wall Street from the actual events that unfold outside it.

Unlike other arbitrage strategies such as convergence trades, merger arbitrage is an 'event-driven' strategy. It boils down to informed speculation about a specific event – the completion of a corporate merger. The implication is that our traders are not simply monitoring the positions of others in order to anticipate 'where the crowd is moving'. Rather, they do so to derive the expectations of other traders about the likelihood of an event – the merger – that will, in the end, happen or not happen. And that event, the merger, is by and large independent of the collective wagers of the arbitrage community (although there is debate on this point – see Cornelli & Li, 2002; Hsieh & Walkling, 2005; Larcker & Lys, 1987). Thus, the specific form of specularity involved in merger arbitrage differs from Keynes' (1936) view of financial markets as beauty pageants (see Dupuy, 1989) in that arbitrageurs can collectively be wrong. This makes merger arbitrage ideal to understand financial crises.

We explore the role of models in merger arbitrage with a combination of ethnography and historical sociology. Our ethnography entailed a three-year engagement with the bank, extending to more than sixty visits between autumn 1999 and spring 2003. We complement our observations with a historical reconstruction of an arbitrage trade that ended up in disaster. On June 2001, a decision by the European Commission led to the forced cancellation of the GE-Honeywell merger, imposing losses of $2.9 billion on the merger arbitrage community. International Securities was involved in this trade, and lost $6 million in it. Using interviews and other historical data, we reconstruct what happened with this trade in light of the mechanism that we identified during our ethnographic observation.

Our combination of ethnography and historical sociology offers a powerful probe. Ethnography is particularly useful for understanding the complexities of financial modelling, for it places the researcher in the same position of uncertainty about the future that his or her subjects experience, thereby avoiding the danger of retrospectively underestimating uncertainty (Agar, 1986;

Barley, 1986; Orlikowski, 1992; Spradley, 1979). Partly for that reason, ethnography has been a method of choice in the social studies of finance literature (Abolafia, 1996; Beunza & Stark, 2004; Knorr Cetina & Bruegger, 2002; Zaloom, 2003).

Our study combines ethnographic observation with historical sociology. The examination of GE–Honeywell allows us to focus on a specific instance where merger arbitrage became problematic and potentially disastrous. Admittedly, we were not physically in the trading room while the GE–Honeywell merger unravelled – hence our treatment of it as historical sociology. But our ethnography provided us with access to the key traders who suffered the losses, as well as unique interpretation of the event based on the socio-technical dynamics that we did observe first-hand. Just as Vaughan (1996) was able to effectively reconstruct the Challenger disaster without being present at Cape Kennedy on the day of the accident, our research design did not find us on the trading floor on the very day of the arbitrage disaster – but we were there on multiple other occasions, both before and after.

Our mixed methods approach offers an important advantage. By providing a symmetrical treatment of success and failure, our study avoids the trappings of the sociology of error (Bloor, 1976), in which 'the social' is seen only as the source of dysfunctional behaviour. Thus, whereas models of herding and information cascades consider only the negative aspects of social interaction, our study explains disasters in the same way that it explains extraordinary success.

Reflexive modelling at a merger arbitrage desk

Our study of modelling at a merger arbitrage desk was part of a broader ethnographic study of a derivatives trading floor on a Wall Street investment bank. Following the downfall of Long-Term Capital in 1998, the over-arching goal of the study was to characterize quantitative finance in its various aspects: organizational, cultural and economic. What were the distinct challenges of managing derivative traders? How was the profession experienced by its practitioners? What was the rationale for the outsized returns (and bonuses) enjoyed by them?

Our journey into the trading room eventually took us to the merger arbitrageurs. We started the project by focusing on the manager of the trading room. We soon learnt that social interaction in the trading room was very different from traditional open outcry in financial exchanges: information technology and modern trading (arbitrage) had transformed trading rooms into more silent and intellectual spaces. We continued by seeking to understand arbitrage, interviewing the heads of various desks that comprised the trading floor – merger arbitrage, options arbitrage, index arbitrage, etc. We soon realized that we would be able to understand quantitative techniques only by engaging in detailed observation at one desk. We chose the merger arbitrage desk for three reasons. First, it employed a distinctly quantitative strategy (post-announcement trading) that was considerably evolved from the over-socialized practices of insider trading that brought down Ivan Boesky in the 1980s. Second, the merger desk was one of the most respected and profitable ones in the trading room. And, third, the head of the merger desk was regarded as a world-class expert in the industry. In the following account we report our findings from data gathered on the morning of detailed observation of merger arbitrage, 27 March 2003. However, the analysis of these data draws on observations from all three years of fieldwork.

Setting up the trade

Our morning of observation started at 9 am on 27 March 2003, minutes before the US markets opened. We found the arbitrageurs sitting at the merger desk, working quietly at their computers. Oswald, the junior analyst among the three, was absorbed in a succession of PowerPoint slides on his screen, isolated from the others by a pair of headphones. Max and Anthony, senior and junior traders respectively, were entering data from a sheet of paper into Excel spreadsheets. They worked in parallel to prevent clerical mistakes. As they typed, their conversation turned to data about other ongoing trades. 'What's your price for Whitman?' asked one of them. 'I've got bad data on it'.

An important merger had just been announced. Career Education Corporation, a private provider of vocational training based in Illinois, had stated its intention to acquire Whitman Education Group, a Miami-based competitor. The news had landed on the Bloomberg terminals of the traders at 5.58 pm of the previous day, with the market already closed. The arbitrageurs confronted the news on the following morning, minutes before our visit.

The traders were reacting to the merger announcement in their characteristic way, preparing a trade. The first step in this process was the elaboration of a memorandum. The memo summarized the key details of the Whitman-Career combination. Oswald compiled the memo after listening to the presentation that the merging companies put out for analysts; hence his headphones. The output of his work was a document stating the legal details of the merger: the cash and stock that Career would pay for Whitman, the expected closing date, etc.

Preparing the trade entailed a further step. The traders proceeded by codifying the document into an Excel spreadsheet, known as the 'Trading Summary'. This functioned as a brief of all the trades in which the desk was involved. On the morning of 27 May the traders were active in thirty-one deals, so the involvement in Career-Whitman meant the addition of a thirty-second row to the document. On the rightmost column of the Trading Summary, single words such as 'Judge', 'Chinese,' 'Justice approves' or 'watch' remind traders of the key aspect of the deal that they need to follow. Like the instrumentation panel of an aircraft, the Trading Summary made all financial action readily visible at a glance.

These early observations underscore the importance of quantitative infrastructure in modern finance. A merger trade requires the assembly of electronic scaffolding to supplement the arbitrageurs' mental processes: a PowerPoint presentation, followed by a Word memorandum, followed by an Excel spreadsheet, all of it condensed into a single live cell on a Trading Summary. In short, cognition is distributed at the merger arbitrage desk. Like the pilots and ship crew studied by Hutchins and colleagues (Hutchins & Klausen, 1995, 1996), arbitrageurs can reduce their cognitive overload – the extent of their bounded rationality – by turning to the machines and instruments around them. Arbitrageurs are aware and understand this process, and refer to it as 'setting up' the trade.

This first vignette also points to an important cultural trait at the merger arbitrage desk. The arbitrageurs, and Max especially, were keenly aware of the disastrous potential of mistakes, hence the routine of entering data in parallel. More generally, Max illustrates the cultural transformation on Wall Street induced by the introduction of models and information technology: an appreciation of factual accuracy and an accompanying attitude of scientific detachment. For example, on hearing us use the term 'buy a stock', Max winced and corrected us. He remarked:

> We don't say that. The most obvious thing that differentiates the professional from the amateur is that you talk about how you are positioned towards the stock – you are short or long. But you don't 'own it', with the commitment that it implies. It is much more dispassionate, professional, even-handed.

In other words, Max practises a distant form of economic engagement, and deems it a mark of professionalism.

A related trait of Max is his resolute drive to arrive at solutions on his own. This manifested itself, for instance, as conflict with the manager of the trading room over the location of the merger desk. Aware of the possibility for synergy across trading desks, the manager rotated the position of some desks within the room, and encouraged communication between people. But this clashed with Max's penchant for arriving at solutions on his own, especially when the manager proposed locating the merger traders near the sales desk. As the manager said,

> Max did not want to be near the sales force, guys who are trying to sell merger trades to the clients, yakking away it's gonna happen, it's gonna happen. He did not want that to influence him.

Max, we conclude, does not have the habitus of a trader inclined to follow the herd.

Taking a position

Amid the hubbub of the data entry, the arbitrageurs sized up the nature of the newly announced merger. Categories, analogies and other references to the past allowed them to engage in pattern recognition that would lead them to take a position. At 9.40 am, for instance, Max and Oswald engaged in a dialogue about Whitman and Career. 'Do they have regulatory approval?' asked Max, without taking his eyes off the screen. 'They do', Oswald replied, looking at his spreadsheet. 'Do they have accreditation?' Max inquired. 'What schools are these, anyways?' Max added emphatically, his eyes squinting at his screen. 'Technical, for adults', Oswald responded. 'They teach you things such as how to be a dentist's assistant', he remarked.

The conversation was an effective first step in sizing up the probability of merger completion. This probability is the figure that arbitrageurs care about most. The basic principle of modern arbitrage is to exploit mispricings across markets. These situations arise when two different regimes of value coexist in ambiguity (Beunza & Stark, 2004), and merger arbitrage is no exception. In the case of mergers, the ambiguity arises from the fact that a company is being bought. The acquiring firm typically buys the target company at a price well above its market capitalization, leading to two possible valuations: if the merger is completed, the price of the company will rise up to its merger value; if it is not, the price will drop back to the level before the merger announcement or lower. Arbitrageurs exploit the ambiguity as to which of the two will apply by speculating on the probability of merger completion. To the arbitrageurs, therefore, profiting from mergers boils down to successfully estimating a probability.

In their exchange, Max and Oswald established a set of facts that subsequently proved relevant to establishing this probability. For instance, they established that the merged company, if completed, would belong to the 'for-profit post-secondary education sector'. The usefulness of this categorization became clear at 9.45 am, as Max turned to examine a chart of Whitman's sales. 'Is it true that there's a summer drop-off in this business?' he asked Oswald, faced with what appeared to be weak summer sales. This mattered, because a common source of merger failure is negative results at one of the merging companies. But there was no reason to worry. 'It's the summer recess', Oswald replied. The weakness in sales was due to the school holidays – a normal part of the education industry. Because the companies belonged to the education industry, the cyclical drop-offs in sales were not a relevant merger risk. Categorizing Career and Whitman, we conclude, helped arbitrageurs interpret information that could have material implications for merger completion.

Arbitrageurs complement categorizations with analogies to past mergers. At 9.50 am, the conversation involved a discussion of another company in the for-profit education sector. 'This guy Edison', Max explained, 'a few years ago wanted to manage the primary school system. But then went down in flames'.

The entrepreneur mentioned by Max was Christopher Whittle, founder of Edison Schools. Edison began operations in 1995 with the promise to bring private-sector discipline to the bureaucratized education industry. But the company saw its stock price plummet in 2002 amid accusations of corruption. A scandal of the type that Edison experienced would immediately ruin the merger at Career and Whitman, so the probability of a scandal had to be factored in. Analogies, we conclude from our observations, help arbitrageurs anticipate possible merger obstacles. Like categories, analogies allow them to glean the future from the past. 'We look for patterns', Max explains, 'precedent, similar deals, either hostile or friendly, degree of product overlap, and earnings variability. We look at all the ways to slice the factors that weigh into the merger'. In the case of Career and Whitman, the analogy associated the two merging *secondary*-education firms with another firm outside their industry, the for-profit *primary* education company, Edison Schools. But the analogy with Edison, a firm previously marked by corruption, prompted a new concern: it led the arbitrageurs to focus on the honesty of the management teams at Career and Whitman. The flexible use of partly overlapping categories and analogies underscores that arbitrageurs do not just passively fit mergers into boxes.

Finally, the arbitrageurs also benefited from analogies with other deals in less obvious ways. Max recalls a merger between two junkyards that had incompatible databases. In the low-tech world of junkyards, one might not anticipate information technology to be a key factor in derailing a merger. But, Max explained, 'if the point of a junkyard is to find a door for that 1996 Volvo, you can imagine how important databases are'. He added, 'we had another deal with similar proprietary databases in a different industry [that] reminded me of that junkyard deal'. The analogy led the arbitrageurs to correctly predict the failure of the merger between the junkyards, and closed their positions early enough to avert any loss. As Max concludes, 'drawing parallels and linkages and saying "this reminds me of that" is at the heart of what we do'.

The traders, however, do not just rely on their own memory to draw those associations. At 9.55 am Max pulled up a black-and-white window on his screen. The screen displayed a set of old fashioned, 1980s-style Microsoft DOS characters. Pressing a combination of commands keys, Max obtained information on Edison to look for patterns that were similar to the Whitman–Career deal. The screen corresponded to a proprietary database that Max has meticulously assembled over the years, with information about all past mergers in which the desk had been involved, classified along numerous dimensions. This gives 'thumbnail' information about each company that merged. 'You think you would remember', Max said, 'but you don't. Memory is very deceiving'. Like the other arbitrage artefacts presented above, the database contributes to distribute cognition at the trading desk. Specifically, by providing a costless system of storage and retrieval of past information, the database helped arbitrageurs mobilize past deals to make sense of current ones.

After two hours of establishing associations, the arbitrageurs were beginning to develop an overall impression of the Whitman-Career merger. Max explained:

> There may be many issues with this company, but I can invest right away by knowing that they're a $5 million company and a $2 million company. This means it's not one company acquiring another that's the same size, which right away means that there are not financing issues involved. If there were, it would be a whole different game.

As the quotation shows, Max was optimistic: even though the industry – for-profit education – was tainted by a past scandal, the traders were still encouraged by the lack of other obstacles.

At 10.15 am, the market opened on Whitman Education with a price of $13.95. The arbitrageurs' spreadsheets showed the spread to be a generous 10 per cent, signalling to the traders a potential opportunity. 'I'd like to have a presence in the deal', said Max almost immediately. 'Let's bid $13.60 for 10,000', he added. Following the instruction, Anthony lifted the headset from his phone turret and called the block trader to place an order. Thus, barely two hours after starting to work on the deal, the merger traders at International Securities had taken a position in the Whitman-Career merger.

Why take a position within minutes of the opening? Arbitrage, we observed, is a game of speed. The longer arbitrageurs take to adopt a position, the more time their competitors have to seize the opportunity before them. As in Occam's razor, arbitrageurs take into account as many factors as they need to take a position, but not more. Taking a position thus involves a successive winnowing of the possible contingencies involved in the merger as the arbitrageurs think through the deal. The traders walk through a form of mental decision tree, in which each specific merger is considered in relation to similar deals that they encountered in the past. Max explains, 'it's almost like you've been in this road before and [the past incidents] direct you'. The advantage of this system, which Max describes as a 'process-driven arbitrage', is that numerous issues need not be taken into account. Arbitrage is fast, light and deploys resources in a strategic manner.

The arbitrageurs, therefore, are not simply performing a routine task of recognition – classifying mergers into pre-existing categories – but a far more active task of *re-cognition*. That is, they are changing, expanding and going beyond the existing categorical structure to ascertain the key merger obstacles in a given deal.

Representing the collective rival

Our analysis so far has established that the arbitrageurs deploy sophisticated quantitative tools. But as we shall see, no matter how sophisticated their tools, arbitrageurs are acutely aware that their models are fallible. Traders confront their own fallibility by distancing themselves from the categories and procedures that guided them to an initial position. This, however, is easier said than done. Mental awareness of the limits of one's view does not automatically provide a check against these limits. Traders, we found out, gain cognitive distance from their categories by exploiting the fact that *other* arbitrageurs have also taken positions on this trade. It is to the second moment of a distributed cognition – across a socio-technical network outside the trading room – that we turn.

At 10.30 am, the conversation between Max, Oswald and Anthony shifted from Career and Whitman to another ongoing merger. Five months before our morning visit, Hong Kong and Shanghai Bank (HSBC) had announced its intention to acquire Household International, an American bank specialized in subprime mortgages. The traders at the merger desk had been 'playing' this deal.

At 10.40 am Max typed a command in his Bloomberg terminal, producing a large black and blue graph on his screen. The chart, reproduced in Figure 1, displays the evolution of the 'spread' between HSBC and Household. The spread amounts to the difference in the prices of the merging companies, adjusted for the terms of the merger. In this case the spread corresponded to the difference in the prices of HSBC and Household over the five-month period in which the merger unfolded, weighted by the stock conversion ratio

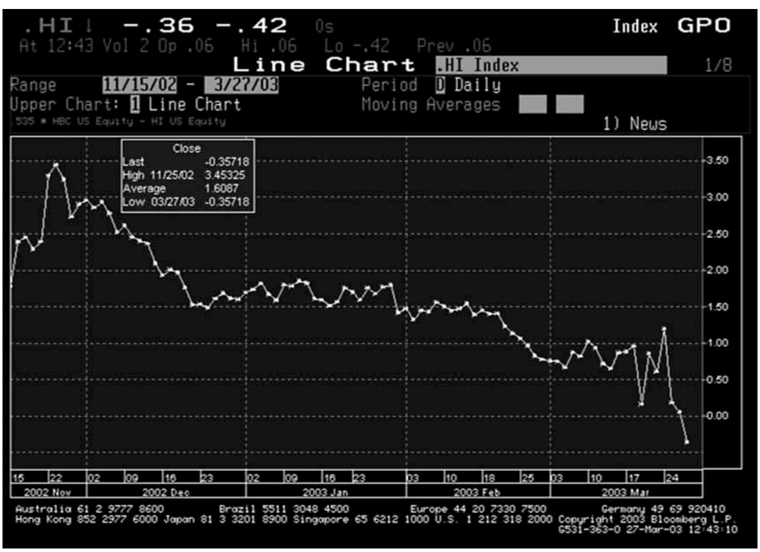

Figure 1 Charting the implicit probability of merger: Screen shot of a Bloomberg terminal showing the spreadplot of Household International and HSBC Bank, November 2002 to May 2004
Source: International Securities.

agreed by the merging partners: 0.535 shares in HSBC for each share in Household International.

Visualizing merger likelihood. The graph, known as the 'spreadplot', plays a key role in the work of the traders. Movements in the spread signal changes in the likelihood of merger completion. If a merger is completed and the two merging firms become a single entity, the difference in their stock prices – the spread – will disappear. Thus, arbitrageurs interpret a narrowing of the spread as a sign that other arbitrageurs collectively assign a greater likelihood of merger completion. Conversely, if the merger is cancelled and the equivalence between the two firms ceases to apply, the spread will revert to its wider level before the merger announcement. Thus, arbitrageurs interpret a widening spread as a sign that other arbitrageurs collectively assign a lower likelihood of merger completion.

Using the spreadplot in this manner involves semiotic sophistication. In this complex system of signs (Muniesa, 2007; Peirce, 1998), the spreadplot provides each trader with an indirect sign of the likelihood of the merger, achieved by signalling the aggregate of his or her rivals' assessment of that likelihood. For the very reason that they are deeply proprietary, the trader does not have access to the proprietary databases through which *particular* other rivals constructed their own independent probability estimates. And, indeed, to have such access would result in cognitive overload: how could one gain cognitive distance from one's own models if one had to engage in the time-consuming task of comparing them with those of dozens of other traders? The spreadplot reduces that cognitive complexity by representing the *aggregate* of the expectations of other traders.

The arbitrage trader, however, is not interested in the spreadplot as a sign of what others are doing in the market. They read the spread as a sign of an event that will or will not happen in the world – the merger. The promising aspect of *this* sign is that it is quasi-independent of a trader's own estimates of the probability of merger. The arbitrage trader is not a technical trader who, like the fashionista who monitors others to anticipate the hottest clubs, seeks to profit by anticipating market trends. Instead, arbitrageurs use the movements of their rivals *as a check* on their own independent opinion, rather than a substitute for it.

The HSBC–Household merger illustrates how the spreadplot helps traders identify potential obstacles to merger completion (see chart on Figure 1). The chart shows two clear spikes along a descending line. These correspond to instances in which market participants lost confidence in the merger. The first, on 22 November 2002, was inspired by funding concerns: was HSBC a financially unsound company, simply buying Household to get funding? This surge in the spread subsided after a general market rally. The second spike took place on 20 March 2003, following news that Household International was shredding documents. This reminded arbitrageurs of similar shredding at

Enron years before. The spread then fell again after the company received its approval from the financial authorities, and once HSBC reassured investors. The two spikes illustrate how plotting the spread brings into relief potential merger obstacles. Had the arbitrageurs not consulted the spread plot, these concerns might have remained unexplored – an abandoned branch in the traders' tree-like decision pattern. Checking the spreadplot, then, is a way to avoid the problem of cognitive lock-in identified by David (1985) and Arthur (1989).

Translating prices into probabilities. In using the spreadplot, a key concept used by the arbitrageurs is the 'implied probability' of a merger. By implied, the arbitrageurs refer to the probability of merger completion that rival arbitrageurs assign to the merger. Quantifying this probability entails manipulating the basic regularity governing arbitrage, the Law of One Price, in a process known as 'backing out'. The core idea behind this concept is that it is possible to extract useful information from mispricings in markets where arbitrageurs are present (Cox *et al.*, 1979; Harrison & Kreps, 1979). As the Law of One Price argues, the presence of arbitrageurs eliminates unjustifiable differences in prices across markets. (For instance, in the absence of transportation costs, the price of gold in London would not systematically differ from that of gold in New York without inviting the activity of arbitrageurs.) Once unjustifiable differences are arbitraged away, the difference in prices between New York and London that remain can be interpreted as the cost of transportation. Thus, by assuming that the Law of One Price applies, arbitrageurs can transform price differences into useful information.

Merger arbitrageurs apply this idea to corporate mergers. When a merger is announced and arbitrageurs are active on a stock, the stock price of the merger target should reflect the expected merger value. And, if the payment for the merger involves the stock of the acquirer, this value will itself be a function of the stock price of the acquirer. Thus, the difference in prices between the two stocks – the spread – can be read as a measure of the uncertainty that arbitrageurs assign to the merger.

In this sense, backing out is an indirect form of observation, in which the focal observer is looking at other observers. Consider the decision to carry an umbrella to work. Looking from one's apartment window and seeing a mostly clear sky, one might decide it unnecessary to prepare for rain. But, if one were to glance below and find pedestrians carrying folded umbrellas, one would deduce that others expect an impending storm, and perhaps check the weather websites for it. Similarly, arbitrageurs check for unexpected merger obstacles by monitoring the aggregate actions of their rivals. Dissonance can prompt doubt, stimulating additional search for what might have been missing in initial assessments.

Backing out probabilities, however, can only be done under certain conditions. In accomplishing the translation from prices to probabilities, arbitrageurs make two key assumptions: first, they assume that movements in the spread are dominated by merger considerations. Conversely, if the spread changed for some reason unrelated to the merger, the interpretation of the move as a change in merger likelihood would be erroneous. Second, the translation assumes that markets equilibrate rapidly. For that reason, unless rival arbitrageurs have seen the relevant prices, compared them to their own information and acted upon it, the spread will not convey their private knowledge. As we shall see, arbitrageurs are mindful of these two conditions and come back to them repeatedly whenever prices do not behave in an understandable manner.

Gaining distance

'Are we missing something?' By 12.00 pm, the spread between Whitman and Career remained at the same wide margin it displayed two hours before, 10 per cent. Early on, a 10 per cent spread signalled an opportunity. But its persistence posed a puzzle for the traders, for it could now be interpreted very differently. It could mean, first, that other professional arbitrageurs were not 'playing' the deal because they perceived problems that could derail the merger. Alternatively, the wide spread could mean the reverse of a threat: a better-than-expected opportunity. 'Can it be', Max asked, 'that the deal has gone under the radar screen of other traders?' The persistently wide spread, in short, was an ambiguous signal: it could be signalling incorrect modelling or a profit opportunity. Establishing which of these applied was crucial to the traders. The spread, in other words, was a wake-up call that prompted arbitrageurs to think twice.

The conundrum faced by the traders was symptomatic of the disruptive role of the spreadplot. Arbitrageurs, the chart reminded them, should not blindly trust their probability estimates, because it hinges on a representation of the merger – derived from a database – that could be incorrect. The database could have inaccurate data, the wrong analogy or a missing field. Given this, the spreadplot provides traders with a much-needed device for doubt: by displaying their degree of deviation from the consensus, it provides arbitrageurs with timely red flags.

Responding to dissonance. Max and his colleagues responded to the discordant spread by plunging into a search for possible merger obstacles that they might not have anticipated. 'Are we missing something?' Max asked the traders. The traders first turned to databases: at 12.10 pm, one of them typed the names 'Whitman' and 'Career' on an online proprietary database. Like a Google keyword search, the database presented them with several hits ranked by relevance. Skimming through the sources of each result, the trader was reassured to see familiar newspapers. The search, then, did not produce anything they did not know in advance.

The database search is an instance of the way in which arbitrageurs respond to the discrepancy induced by the spreadplot. Having observed the dissonance between their own probability estimates and the implied probability, the traders went back to search for missing information. In doing this, the database helped even though the traders hardly knew what they were looking for: by including news from local media that the national media might have overlooked, it provided leads for issues that needed to be dug deeper into.

The traders' approach contrasts with early neo-institutionalist views of markets. In the classic account, the availability of social clues leads actors to economize on their search costs by imitating others (DiMaggio & Powell, 1983; Meyer & Rowan, 1978). In contrast, knowledge of the spread stimulated the arbitrageurs to search *more*. The discrepancy illustrates an important point about arbitrage. The material tools allow traders to come up with more sophisticated answers than traditional investors precisely by inducing scepticism about the tools. Arbitrageurs, in this sense, are persistent but sceptical users of calculative devices.

Recourse to the network. Following the inconclusive search on Whitman, the arbitrageurs got on the telephone. At 12.20 pm, Anthony lifted the headset of his phone turret and called the floor broker who handled orders for Whitman at the exchange. 'John says buy this WIX [for Whitman], no one's really hedging it', he said to Max as he finished the conversation. No other arbitrageur, the floor broker implied, was active in the Whitman trade. From this, Max concluded that the merger had passed 'under the radar screen' of other arbitrageurs. He reacted by increasing the desk's exposure to the merger. 'Let's work another ten [thousand], but pick your spots', he said to Anthony, asking the junior trader to purchase additional shares in Whitman, but to do so carefully to avoid inflating the stock price.

Why did the arbitrageurs call up their contacts? Until 12 pm, the traders had interpreted the spread as the implied probability of the merger. The persistent discrepancy between the wide spread and the traders' estimates, however, created a dissonance that led them to question their own interpretation. Having re-checked the database, they decided to inquire about the identities of the shareholders, partially lifting the veil of anonymity that protects securities trading. In doing so, the arbitrageurs were seeking to clarify whether backing out made sense in this context: was the spread reflecting the information in the hands of rival arbitrageurs? The traders concluded it was not.

The traders, however, were emphatically not mimicking their rivals. Theirs was not a case of classic isomorphism or herding. Instead, they were attempting to disentangle overall market movements from the actions of the players who, in their view, were the only ones who really counted: their rivals, namely, other professional arbitrageurs. On learning that no other real player was hedging the stock, they concluded that the spread could *not* be interpreted as a measure of implied probability. The red flag, on closer inspection, turned out to be a green light. Thus, reflexivity at the merger arbitrage desk cuts both ways: whereas an hour earlier the spreadplot had led Max and his team to raise doubts about their database, their subsequent phone conversation stimulated doubts about the meaning of the spreadplot, the device for doubt itself.

In light of the above, consider now why Max told Anthony ‘pick your spots’. The expression reminded Anthony to cover his tracks as he increased the desks’ position on Whitman, with the aim of avoiding an increase in its stock price. The traders’ efforts suggest that Max and colleagues felt they were being observed by other arbitrageurs through the lens of the spread. Just as Max and his team engaged in a calculated game of guessing, so were rival arbitrageurs at other firms. Preserving an opportunity that had gone ‘under the radar screen’ of rival traders required avoiding warning competitors.[2]

Reflexive modelling. The developments described above suggest that the traders’ caution unfolds as the confrontation between two related magnitudes. A trader’s ability to mobilize prices for greater precaution hinges on the encounter between the probability of the merger (estimated at the desk) and implied probability (derived from the spreadplot). This comparison provides an invaluable advantage: it signals to traders the extent of their deviation from the market, warns against missing information, motivates additional search, prompts them to activate their business contacts and provides the necessary confidence to expand their positions.

This distinctive interplay of internal and external estimates points to a novel use of economic models, which we refer to as reflexive modelling. The expression denotes the process whereby dispersed market actors employ economic models to confront their own estimates. This confrontation pits a trader’s estimates against those of his or her rivals, thereby introducing dissonance in his or her calculations. This dissonance is attained through the construction of implied probability. This variable is a representation of an economic object that does not have a price, is otherwise not observable and is co-produced by the positioning of actors who use it to confront their interpretations and re-evaluate their positions. Collectively produced, the implied probability is a device for dissonance. Reflexive modelling thus denotes a heightened awareness on the part of the arbitrageurs about the limits of their own representations of the economy. The literature in the social studies of finance has already identified other instances of backing out. Thus, for example, options traders manipulate Black-Scholes to arrive at implied volatility (MacKenzie & Millo, 2003). And bond traders use implied interest rates (Zaloom, 2009). In short, the use of models in reverse to develop estimates of market consensus is not specific to merger arbitrage.

From personal networks to financial models. The use of the spread is a telling sign of the calculative orientation of the arbitrageurs. Up until the late 1980s, merger arbitrageurs focused on anticipating the merger *announcement* by pursuing rumours from the networks of the traders. Currently, however, arbitrageurs centre their bets on merger *completion*, which can be anticipated with the modelling tools described above, namely, the spreadplot and implied probability. Thus, whereas the typical strategies of investors traditionally entailed accessing information ahead of their competitors (Abolafia, 1996), merger arbitrageurs base their advantage on financial models. These models have given arbitrageurs enough precision to access profit opportunities that did not exist before.

Max emphasized this important shift with an example. 'Look at this jump', he said, in reference to the brusque price movement of Household International on the day its merger with HSBC was announced (see Figure 2). He added,

> This is the value that the [mutual] fund managers and the guys on the street are after. Once the jump has taken place, it's a matter of pennies. The value investors don't have the fine-tuned tools to position themselves in this spread, to determine if it's too wide or too narrow for them. We do.

Thus, the arbitrageurs eschew the fat margins that can be found by correctly anticipating the merger announcement, and only trade once the deal is officially announced. The narrow margins to be obtained once the announcement is made

Figure 2 The jump in the spread on merger announcement date: Spreadplot of Household International and HSBC Bank, before and after the merger announcement

Source: Bloomberg

Note: The jump in the spread in November 2002 corresponds to the merger announcement. Contemporary arbitrageurs, however, focus their trading on the post-announcement period.

are open to them, thanks to the precision of their quantitative techniques. Indeed, this shift in strategy was not motivated only by the availability of tools but also by the dangers involved in relying on rumours and privileged information. The indictment of merger arbitrageur Ivan Boesky in 1986 on charges of insider trading discouraged the rest of the arbitrage community from exploiting privileged information about unannounced mergers.

In line with this long-running shift from rumours to models, the traders have come to see nuanced interpretation, rather than raw information, as the source of their advantage. When asked about the reason for the disparity between their own assessment of merger probability and the merger spread, Max argued that it stemmed from a differential interpretation of the data. He said,

> The reason why the spread is large is that other traders have their own proprietary models for it. And they can all be right. At this point, it's all about the future, and we don't know the future. So their assumptions on volatility, for example, could be different than ours. Or their assumptions about timing.

The opportunity that Max saw, then, was not the result of privileged information. As Max said, 'right now, the data is all on the Internet, even the SEC filings'. Being widely available, information does not confer any advantage. To him, it resulted from his desk's distinct interpretation of publicly available data.

Our account so far presents the bright side of financial models. Thanks to reflexive modelling, arbitrageurs have increased the accuracy of their estimates, gaining access to new opportunities while reducing their risk. As we shall see, however, there is also a downside to financial modelling. Because arbitrageurs use models to check their positions against the rest of the market, the diffusion of reflexive modelling creates cognitive interdependence between otherwise independent rivals.

Resonance and collective failure in a merger arbitrage trade

Precisely because of its cognitive benefits, reflexive modelling poses an important danger, as this practice can produce collective failure. This problem became clear to us when analysing one concrete case. On 12 June 2001 the European Commission stated a firm opposition to the planned merger between two large American companies. The ruling put an end to the proposed combination between General Electric and Honeywell International, announced seven months before. As news of the ruling arrived on Wall Street, Honeywell's stock price fell by more than 10 per cent. The drop caused losses of more than \$2.8 billion to professional arbitrageurs – the hedge funds and investment banks that expected the merger to succeed. The magnitude of the losses was eloquently captured by the words of a Wall Street executive to

The Wall Street Journal. 'Obviously this has been very painful', he noted. 'The losses are going to be very big', he added (Sidel, 2001, p. C1).

Events like the GE-Honeywell merger failure have received increasing attention in the finance literature, and are known as 'arbitrage disasters'. An arbitrage disaster denotes a merger that is cancelled after being announced, leading to widespread losses for the arbitrageurs that bet on it. Importantly, not all merger cancellations are disasters – only those that have a damaging impact on the aggregate returns of arbitrageurs. Merger cancellations that are widely anticipated are thus not disasters. Indeed, only fifteen merger cancellations between 1984 and 2004 can be classified as disasters (Officer, 2007; see also Table 1 and Figure 3). The GE-Honeywell merger failure was the worst accident in that period. Another important disaster was the cancelled merger between Tellabs and Ciena in 1998, which imposed a loss of $181 million on Long-Term Capital and contributed to the downfall of the fund.

Understanding arbitrage disasters can shed light on the risks posed by quantitative finance. What causes them? Disasters can be seen as a direct outcome of information cascades; after all, the losses imposed by these blowups are typically experienced simultaneously by almost all arbitrage funds active in the failed deal. In what appears to be a classic case of lemming-like march towards the cliff, when disasters happen they tend to affect most desks in the industry. Arbitrage disasters could thus appear to be the outcome of imitation, herding or information cascades.

Arbitrage disasters can also be seen as black swans. These adverse events are typically associated with the presence of surprise: arbitrageurs suffer losses when two companies cancel a merger that the traders believed would happen. And, indeed, the history of GE-Honeywell is in many ways the history of a painful surprise – arbitrageurs did not sufficiently anticipate the danger of regulatory opposition to the merger. The merger traders had a reason to ignore it, as the anti-trust authorities in the United States and Europe had always coordinated their rulings. Never before had a merger authorized in Washington been blocked in Brussels (Bary, 2001, p. 43). This precedent was broken in the GE-Honeywell deal. Its leading protagonist, the famously rigorous European commissioner Mario Monti, called for a cancellation of the merger on the grounds that it would give the combined entity an ability to engage in anti-competitive 'bundling'. Given this unexpected cancellation, the disaster could be seen as a black swan.

Our analysis, however, suggests that GE-Honeywell was neither a black swan nor an information cascade. It was, we contend, an unintended consequence of reflexive modelling. To see how arbitrageurs thought about the GE-Honeywell deal, consider the spread between GE-Honeywell, as shown in Figure 4. As the narrow spread shows, arbitrageurs initially assigned a very large implied probability to the completion of the merger. Reports from the financial press confirm this point. As one arbitrageur put it to the financial press, 'people had it among their larger positions because they thought there was a large probability the deal would get done' (Sidel, 2001, C1).

Table 1 Arbitrage disasters, 1990–2003

Acquirer	Target	Cancellation date	Percentage holding by arbitrageurs	Implied total losses, $000s
General Electric Co	Honeywell International Inc	2 Oct. 2001	53	2,798,376
American Home Products Co	Monsanto Co	13 Oct. 1998	45	2,335,367
British Telecommunications PLC	MCI Communications	10 Nov. 1997	40	1,908,240
Tellabs Inc	CIENA Co	14 Sept. 1998	34	1,179,412
Investor Group	AMR Co	16 Oct.1989	36	712,042
Staples Inc	Office Depot	2 July 1997	44	558,804
Investor Group	UAL Co	18 Oct. 1989	29	542,058
Abbott Laboratories	ALZA Co	16 Dec. 1999	46	525,194
Tracinda Corp	Chrysler Co	31 May 1995	42	458,918
Revlon Group	Gillette Co	24 Nov. 1986	25	286,371
Mattel Inc	Hasbro Inc	2 Feb. 1996	228	228,557
McCaw Cellular Communications	LIN Broadcasting	10 Oct. 1989	50	219,937
Amway Co	Avon Products Inc	18 May 1989	29	165,816
Investor Group	Goodyear Tire & Rubber	20 Nov. 1986	25	145,344

Source: Officer (2007).

Note: This table contains details of the fifteen largest merger arbitrage disasters from 1985 to 2004. All dollar arbitrage losses are in 2004 dollars. Arbitrageurs' percentage holding is the percentage of target shares outstanding reported as owned by arbitrageurs at the first quarterly 13F reporting date after the bid announcement date. Implied dollar arbitrage loss is the total arbitrage loss multiplied by arbitrageurs' percentage.

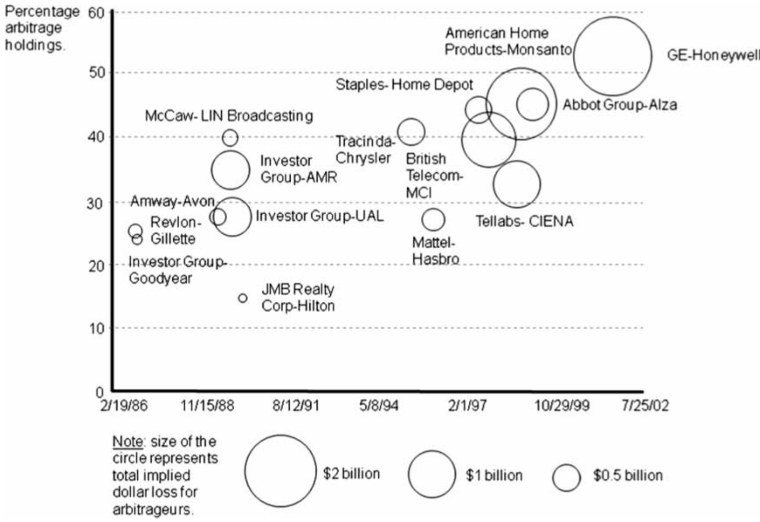

Figure 3 Merger arbitrage disasters
Source: Officer (2007, p. 27)
Note: Failed arbitrage deals, with total losses incurred by arbitrageurs (circle size) and relative participation of arbitrageurs in (y-axis).

Such high confidence had a legitimate cause. It was a direct consequence of the decision, taken by numerous arbitrage funds, not to give material weight to the danger of European regulatory opposition. This can be deduced from a comparison between the merger spreadplot and the media responses to the Commission's actions (see Figure 4). The bar chart in the figure shows the

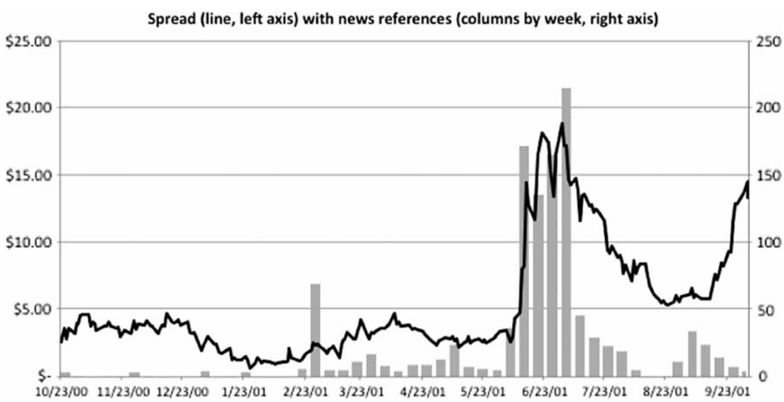

Figure 4 Arbitrageurs overlooked the danger of European opposition
Source: Bloomberg and ABI/Inform
Note: Spread between GE and Honeywell (line) and media concern over EC opposition to the merger (bar). The graph shows that the surge in media concern in late February was not matched by a corresponding increase in the merger spread.

number of weekly articles published in the major business press that included in their text the words 'Honeywell' and 'Monti'. These include publications such as *The Wall Street Journal*, *The Financial Times*, *The Economist*, etc. The spike in the number of articles on 27 February 2001 shows that the media had genuine concern about European opposition. But, even as it voiced these concerns, the narrow spread between the merging companies barely inched. The implication is that the arbitrage community did not share that concern. In short, the traders' models did not seem to be picking up the danger of European regulatory opposition.

But this case is not a simple story of omitted variables. Our interviews suggest that the size and magnitude of the disaster was an outcome of a subsequent move: the traders' reaction to the initial confidence. It was the social activity, coupled with the model, that produced such losses. As it turns out, International Securities was active in the GE-Honeywell deal, and lost $6 million on it. To clarify the precise mechanism that led to these losses, we interviewed the senior merger trader and the manager of the trading room. The latter made clear that the bank was reacting to the spreadplot. It increased its position, making things worse for itself. According to the manager of the trading room,

> Max traded it. . .everyone's database lacked a field, and the field was 'European regulatory denial'.. . . I encouraged him [Max] to increase his size. . .you have confidence, all of your fields are fine. . .so, instead of four million, I said six million.

In other words, the desk lost $6 million because it increased its exposure to the trade, and the increased exposure was a reaction to the spreadplot.

We checked our explanation of the disaster by asking Max directly. His reply encompassed reflexive modelling, arbitrage disasters and (crucially) the relationship between the two. First, Max agreed that he used backed-out probabilities to see mistakes. To him, the implied probability

> is a reality check. It's a number that's out there and it challenges everyday when you come in to have 85 per cent confidence in this deal, whatever that is. You could have a little sign saying, 'Are you challenging yourself in every day on every deal?'

Thus, in other words, Max agreed that he engaged in reflexive modelling.

Second, Max agreed with our explanation of the GE-Honeywell disaster. Arbitrageurs, he explained, were initially mistaken in their confidence on the GE-Honeywell merger. Max even generalized the case to others in a way that is consistent with our view: 'disasters', he said, 'happen when there is a [mistaken] first impression and people don't have a basis for handicapping it properly'. And in the GE- Honeywell case, Max concurred that the inability to handicap resulted from the lack of precedent: 'it was really the novelty'. Finally, Max agreed that reflexive modelling affects prices in a way that can lead to disasters. 'It's an interesting feedback loop', Max said about implied probability. '[Prices] are both cause and effect of market confidence'. In short, we find confirmation. Max admitted that he engaged in what we call reflexive modelling, agreed that other arbitrageurs were initially mistaken about GE-Honeywell and even added that reflexive modelling has a subsequent effect on the confidence on the deal.

Resonance. In sum, our examination of the failed GE-Honeywell merger points to a socio-technical mechanism of representation and calculated reaction. The losses at International Securities stemmed from a three-stage process. First, the arbitrageurs at International Securities independently underestimated the risk of regulatory opposition (their competitors did too). Second, when the arbitrageurs checked the spreadplot to confront their estimates against the rest of the market, they found confirmation: the spread was narrow, and was not moving with news of Monti. Thus reinforced, the traders then engaged in a third move: given their greater confidence, they increased their exposure. The combined result of these three steps was a reinforcement of the overconfidence of the various arbitrage funds, via the spreadplot. The spreadplot was thus the source of cognitive interdependence. Were it not for this device and the practice of reflexive modelling, trading losses would have been far less profound and widespread.

Reflexive modelling amplifies individual errors when a sufficiently large number of arbitrage funds have a similar model.[3] Whereas reflexive modelling improves trading on the basis of *dissonance*, it can lead to financial disaster in the presence of *resonance*. Such resonance takes place when the combined use of models and stock prices gives traders misplaced confidence on an event. Resonance, we argue, is cause of the GE-Honeywell arbitrage disaster. It is caused by the lack of diversity in the models and databases of the actors engaged in a deal coupled with the availability of tools such as the spreadplot that allow each arbitrageur to read the rest.

Exploiting resonance. One sign that resonance is an acute problem in merger arbitrage is the existence of funds that set out to exploit it. According to *The Financial Times*, the New York hedge fund Atticus Global had developed a strategy to exploit arbitrage disasters such as the GE-Honeywell deal (Clow, 2001). Atticus bet against mergers when other arbitrageurs were most confident in them. According to Clow, 'Most risk arbitrage managers followed their usual strategy of going long the target, Honeywell, and short the buyer, GE. Atticus shorted Honeywell and bought GE, making a 10 per cent return on its investment' (2001, p. 25).

Cognitive interdependence in quantitative finance

The above analysis sheds light on the socio-technical nature of quantitative finance. Understanding the full implications of the quantitative revolution, we found, calls for an appreciation of both social and technological aspects of markets – in short, of the cognitive interdependence introduced by financial models. The mechanism of resonance proposed above posits a form of interdependence that results from the traders' use of models for reflexive purposes.

A socio-technical account of reflexivity

The reflexivity exhibited by the traders is not a mental process or a solipsistic practice. In its simplest form, reflexivity rests on the contraposition of two material artefacts – the arbitrageur's screens. The first, an Excel spreadsheet, summarizes how the traders think about the merger. The so-called Trading Summary builds on a web of associations, including categories and analogies, leading up to the key issue facing the deal. The second screen, the spreadplot, is shared by all arbitrage funds and captures how competitors think about the merger by showing the difference in the prices between the merging companies. Reflexivity is made possible by the friction between the two screens. Friction offers cues that the arbitrageurs might be missing a relevant obstacle to the merger. Instead of substituting search with imitation, as in mimetic isomorphism, arbitrageurs use social cues to complement their search.

As a practice of using a model to gain cognitive distance, reflexive modelling is thus a cognitive process. But it is not taking place in the heads of the traders, as if cognition could be turned back onto itself. Just as the cognitive process of deriving their own probability estimates is socially distributed across the tools and instruments at the arbitrage desk, so reflexive cognition (Stark, 2009) is a socio-technical process of distributed cognition triggered by the spreadplot – a device for dissonance that is itself a socio-technically constructed object. The traders we observed were not engaging in some heroic mental feat, splitting and twisting their minds back on themselves like some intellectual variant of a flexible contortionist. Instead, as we saw numerous times in a single morning at a single trading desk, the taken-for-granteds of their models were cognitively disrupted by devices for dissonance.

The notion of reflexive modelling advances the concept of scopic markets by Knorr Cetina (2005). In reflexive modelling, the model itself is used for scopic purposes: for projecting the actions of others in a way that prompts action. But, instead of scoping the intrinsic qualities of the economic object – the profitability, solvency or merger likelihood of a publicly listed company – it focused instead on the behaviour of other actors in the market. This allowed traders to escape the impossible choice between models or social cues, because the model constituted the lens through which the social cues were revealed.

Indeed, models even go beyond displaying social cues: they quantify them and translate the resulting number into one that is commensurate with the likelihood estimates of the merger traders.

Reflexive modelling thus brings quantitative finance full circle: whereas the introduction of models and information technology in the capital markets brought in anonymity and a semblance of objectivity in the data, reflexive modelling makes it clear that traders are modelling not just the economic but also the social. Although anonymous and impersonal, quantitative finance brings back the interdependence among the actors – and, for that reason, its social aspect. But this form of sociability around models does not easily fit existing frameworks in economic sociology – it is disembedded yet entangled; anonymous yet collective; impersonal yet, nevertheless, emphatically social.

A socio-technical account of risk

Just as reflexive modelling can be a source of correction, it can also lead to the amplification of error. When this takes place, financial actors confront a situation of resonance. The concept of resonance contributes to economic sociology by complementing existing behavioural accounts of risk such as herding and the black swan. Resonance explains arbitrage disasters without the need to resort to individual biases. Instead, it explains them as the unintended consequence of a mostly functional system.

Given this, does quantitative finance add or reduce the risk faced by market participants? We see this as a false dichotomy. As Luhmann and other sociologists of risk have argued, risk is rarely eliminated in modern technological societies (Beck, 1992; Giddens, 1990; Luhmann, 1993). Given the limits of human knowledge in a modern economy, new technologies carry with them an irreducible degree of uncertainty. Efforts to mitigate risk, whether through such technologies or new organizational arrangements, can give rise to unintended consequences in the form of second-order dangers. Resonance can be seen as an unintended consequence of risk mitigation. Our study thus extends the work of Holzer and Millo (2005) on market crises such as the implosion of Long-Term Capital in 1998 or the role of program trading during the 1987 market crash. In both cases, as in ours, the unintended consequences of risk mitigation arise from feedback effects that come into play once an innovation in quantitative finance is widely adopted.

Conclusion

Our study has explored a distinct form of risk posed by financial models. It examined the risks posed by using financial models for the purpose of backing out, that is, using models to understand the views held by rival traders. The study compares two distinct moments in merger arbitrage within the same equity derivatives trading room. The first took place on the morning of 27 March 2003. Two education companies announced their intention to merge. Their merger allowed us to see how traders engaged in reflexive modelling, using the implied probability to ponder and reflect upon their own probability estimates. The second episode took us back to the year 2001. Almost all merger arbitrageurs on Wall Street were persuaded of the certainty of the merger between GE and Honeywell. But the merger unravelled. The cancellation of the deal led to a veritable red-coloured oil spill of losses across hedge funds and investment banks, totalling almost $3 billion.

The central contention of our analysis is that these first and second episodes are conceptually related. The cause of the GE-Honeywell arbitrage disaster, we concluded, was a malfunctioning of the same reflexive mechanism that we observed in the merger of the education companies. Reflexive modelling works by providing traders with dissonance whenever their estimates are different from those of the majority – and, therefore, possibly mistaken. But, if enough traders miss a key variable, their mistake will reverberate to the others through the implied probability. As resonance develops in the system, traders will gain a false confidence that their views are correct, leading to extraordinary losses in the event of merger cancellation.

Unlike most existing research, the notion of resonance reflexive modelling engages with quantitative finance by taking *both* social and technological factors into account. Resonance is additionally appealing in that it does not require the assumption of individual biases on the part of financial actors, whether it is unreflexiveness or a tendency to conform. On the contrary, our account is compatible with a view of individual actors as intelligent, creative, thoughtful and independently minded. In doing so, it brings out into sharper relief the dilemma involved in the social use of financial models: their use can ameliorate financial risks, but it increases the potential of even greater dangers.

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Notes

1 See also Callon (1998, 2007), MacKenzie and Millo (2003), Mackenzie (2006); for reviews, see Fligstein and Dauter (2007), Fourcade and Healy (2007), Ferraro *et al.* (2005). A related stream of work (Dodd, 2011) has examined the sociology of money,

especially in the context of the quantitative revolution and more recent rise of credit derivatives.

2 The merger was successfully completed on 1 July 2003, and produced an annualized return of 17 per cent for Max and his team.

3 Khandani and Lo (2007) explain the crisis of August 2007 by the similarity in strategy across hedge funds.

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Daniel Beunza is Lecturer in Management at the London School of Economics. He has taught at Universitat Pompeu Fabra (Barcelona) and at Columbia University. He has studied derivatives traders, securities analysts and his current research is on financial exchanges and responsible investment. Along with others, Beunza's research has led to the development of the social studies of finance.

David Stark is Arthur Lehman Professor of Sociology and International Affairs at Columbia University where he directs the Center on Organizational Innovation. Stark's most recent book, *The sense of dissonance: Accounts of worth in economic life* (Princeton 2009) examines the perplexing situations in which organizations search for what is valuable.

Appendix A: Backing out implied merger probability from stock prices: A formal approach

The implied probability of a merger can be derived from the merger spread. The method is based on the classical results of the Arrow-Debreu theory of contingent claims, and the probabilities that are derived are known as risk neutral probabilities. Here we follow the notation of Vidyamurthy (2004, p. 177). See Jarrow and Turnbull (2000) for an expanded treatment.

According to Arrow-Debreu, any two bets with the same expected pay-off have the same current value. Denote by S_0 the merger spread at time zero. Upon the successful completion of the deal, the spread will converge to zero. A long position in the merger target is reversed at no additional cost at time T, and the reward earned by the investor will be $e^{rT}S_0$, with r being the interest rate. If there is cash paid out as well, the pay-off will be $e^{rT}S_0 +$ cash. If, on the other hand, the deal ends up in failure, the spread will not converge to zero, but will rise to a value of S_T. The net pay-off will then be $e^{rT}S_0 - S_T$.

By the no arbitrage condition, the expected pay-off is zero. Writing out the equations, we have:

$$\pi_{\text{success}}\left(e^{rT}S_0 + \text{cash}\right) + \pi_{\text{failure}}\left(e^{rT}S_0 - S_T\right) = 0 \tag{1}$$

$$\pi_{\text{success}} + \pi_{\text{faliure}} = 1 \tag{2}$$

Solving the two equations, we have:

$$\pi_{\text{failure}} = \frac{e^{rT}(S_0 + e^{-rT}\text{cash})}{S_T + \text{cash}} \tag{3}$$