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Money's eyes:
The visual preparation of financial markets

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Abstract

Drawing on recent interviews with those involved in developing and using the latest visualisation software within some of the key markets of global finance, this paper examines the implications of these new techniques of representation and suggests how visualisation techniques empower modern finance with fresh eyes designed to interpret and manipulate data and thus to enable participants 'to see more and understand faster'. The paper argues that the contemporary visualisation of financial data raises issues about the visual in cultural economic debates concerning the formatting and framing of financial markets.

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Introduction

> Financial institutions survive on the ability to collect and react to data. Today's financial community is bombarded by massive amounts of information from real-time datafeeds, risk management systems and other intelligence sources. Analytic and historical databases hold formidable amounts of data imperative to decision making. In the time it takes to organize and process this information opportunities are often missed.
>
> (*Financial Engineering News* http://www.fenews.com/fen6/visualizing.html accessed 17th May 2005)
>
> The world is complex, dynamic, multidimensional; the paper is static, flat. How are we to represent the rich visual world of experience and measurement on mere flatland?
>
> (Tufte 1990, 9)
>
> Visualization is much more than image creation; data are not just passively displayed, they are depicted in such a way as to generate new knowledge. In visualization the image is not the final output; the viewer interacts with it to find new patterns and relations in the data. It is this feature that makes visualization potentially so important: to go beyond display and invite people to think in new ways about their world …
>
> (Taylor 2004, 120).

> Technology shapes the foundation of financial knowledge
>
> (Zaloom 2003, 269).

The organs of global finance rely upon and face an avalanche of numbers. These data range from official figures published by the likes of the Federal Reserve and the IMF, real-time market data from market exchanges such as Chicago Board of Trade, to news and market reports supplied by 'secondary economy' suppliers such as Reuters and Bloomberg. While the growing availability of market data has benefits it also creates problems, most especially those relating to questions of meaning, judgment and intervention: how to make sense of these flows – how to see the 'market', its futures and thus act pre-emptively. One solution to this cluster of problems is said to reside in the development of new technologies of representation, in particular, the design and application of visualisation software. Such software is being introduced not only to enable better visual imagination of and interaction with markets, but also to help visualise new financial products; that is, the software equips the agents of global finance to better track and act in relation to the seemingly abstract movements of modern financial markets.

Based on recent interviews with those involved in developing and using the latest visualisation software within some of the key markets of global finance, this paper adopts a cultural economy[1] of finance perspective to examine the implications of these new techniques of representation and suggests how visualisation techniques empower modern finance with fresh eyes designed to interpret and manipulate data and thus to enable participants 'to see more and understand faster'. The paper argues that the contemporary visualisation of financial data raises issues about the visual in cultural economic debates concerning the formatting and framing of financial markets. Moreover, as the examples presented suggest, the workings of such software needs to be explored as it arguably central to understanding how through processes that generate and make visible what are in effect financial topologies, finance gains its latest power to spatialise.

The data flows reduce a host of spatialities and temporalities to supposedly easily digestible numbers that stream into financial organizations and which may then be acted upon by calculative agencies of modern finance. While the ability to hook the latest data into calculative devices might seem like good news for those involved - input into models, market positions…all may be made that much crisper and less risky as a result, at least in theory – problems arise to dowse the enthusiasm, all of which serve to contextualise the growing interest in visualisation software. First, access to such data by all market actors dramatically reduces the opportunities of making a profit: simply put, it is no longer possible to hold and to act upon a piece of data that no other player has. New ways to 'mine data', to find investment niches for instance, must thus be looked for. Inter alia this has witnessed the application of software to help humans deal with the data avalanche. The software is engineered into 'interpretive communities' in the trading room (Beunza and Stark 2004, 372–373) and elsewhere. Nowadays, the way to make profits is to innovate not to add more data streams. Second, while the growing availability of market data has benefits for market participants (it's helpful to know what going on that might influence 'the markets'), it also raises a simple question: how to make sense of such continuous flows and their possible futures. How do traders for example 'get a feel' for markets when a sudden surge of market activity is simply represented as a board of shifting and flashing prices on the screens in front them?

The complexities don't end there; a third related problem emerges. Concealed in these volumes are the criss-crossings of financial products or instruments designed to cope with and exploit risks and the market opportunities they present. Risks, such as credit risk, for example, can now be specially tailored and packaged in a growing number of market areas (see IMF 2006). Put differently, less than straightforward mathematical-financial techniques can produce instruments, such as options, whose payoffs may be structured so that they depend on

more than one underlying risky asset[2]. The risk profile of one instrument is used in other words as the basis for the innovative development of another. One consequence is that within financial organisations heads of, say, risk management find themselves not only having to keep track of overall market developments but the risk position of individual traders. Their task is to attempt to judge the overall impact of dealing in criss-crossed markets on the bank's day-to-day risk position. A fourth problem is that the development of new financial instruments is arguably now so complicated that even 'the quants' (the name given to those specialising in the techniques of quantitative finance) need a way to see the math. Number in other words is not everything; complex mathematical expressions and financial interpretations of the variety of hazards such as credit risk within financial markets and specific market characteristics such as volatility 'skews' and 'smiles', for instance, more and more need to made visible. With a slight touch of irony it seems that even the quants now require the qualitative to make sense of the quantitative and to be able to communicate their solutions to others; they wish to turn the 'numbers into pictures'.

The remainder of the paper is as follows. Section 2 briefly reviews what is felt to be the most influential work on the visual and financial markets in order conceptually to locate the rise of visualisation software within financial markets. Section 3 considers how the centrality of forms of visualisation that enable interaction and manipulation may be influencing how knowledge within financial markets is now woven. By way of a discussion of current examples of visualisation software and their associated techniques, three shorter sections (sections 4, 5 and 6) explore and develop the conceptual influences discussed thus far. The conclusion is used to consider what the introduction of software that gives finance its latest calculative eyes might mean for how contemporary financial 'markets' are understood, and what are the wider, 'worldly', effects of such techniques for preparing and performing financial markets.

Approaching finance, markets and the visual

The turn to the analysis of finance by those working within for example the social studies of finance, economic sociology, social anthropology, and geography have been noticeable in recent years[3]. Much of this work however leaves largely untouched the visual box of tricks that lies at the centre of the key markets of modern finance. There are of course notable exceptions. The work of Karin Knorr-Cetina (2003) (and her collaboration with Urs Bruegger (2000, 2002a–c)), Daniel Buenza and David Stark (2004), together with recent intriguing work by Caitlin Zaloom (2003, 2006), are rare examples where inquiries into the workings of financial markets have not just recognised the presence of props to aid the visualisation of markets – the rise of 'screen based' rather than so-called 'open outcry' floor based trading - but have placed these technical artefacts[4] at the centre of the analysis. It is helpful to review the work of these authors to help locate the discussion of the latest visualisation software which absorbs the remainder of the paper.

In their work on the organization of trading floor in Wall Street, Beunza and Stark (2004) demonstrate the various ways in which daily traders deal with a core problem – 'how to recognize an opportunity' in the markets. Although they encountered a 'world abundant in information, with dazzling, dizzying speed' they recognised that strategic advantage in the derivatives markets they were studying lay not in economies of information and having the right mathematical formula (see MacKenzie and Millo (2004)) but in the 'socio-cognitive process of interpretation' (ibid, 372). They noticed that the financial organization they were studying purposefully organized the trading floor to facilitate such interpretation. The careful production of the space of the trading floor aims to aid profitable innovation through collaboration amongst the hybrid collective gathered to make sense of market movements and to move these markets. As they explain in relation to the market they were studying

> The cognitive challenge facing our arbitrage traders – a challenge central to the process of innovation – is the problem of recognition. On the one hand, they must be adept at *pattern recognition* (matching data to models, etc.). But if they only recognize patterns familiar within their existing categories, they would not be innovative (Clippinger, 1999). Innovation requires another cognitive process that we think of as *re-cognition* (making unanticipated associations, reconceptualising the situation, breaking out of lock-in). It involves a distinctive type of search…where you do not know what you are looking for but will recognize it when you find it.
>
> The organization of 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). Each desk (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
>
> (2004, 373 original emphasis)

Arbitrageurs seek qualities, 'categorical attributes' of say a company, rather than see an asset or stock in pure quantitative terms; they deal in 'abstract qualities'(ibid, 376–377). Financial engineering in this sense is not wholly focused on welding together sure-fire data; it requires forms of what might be termed techo-sociation within purposefully designed financial spaces: spaces, that is, in which technical artefacts, such as screens and software, and human traders together weave effective calculative agencies. In such spaces, the screen world does not dominate (as is suggested by Knorr Cetina and Bruegger in their study of foreign exchange, quite a different 'global financial market'); here atmosphere is highlighted, cognition is distributed through the room across what the Beunza and Stark call 'socio-technical networks of tangible tools' (2004, 378). As Nigel Thrift, Manuel Castells and Sakia Sassen have argued, the greater the flows, the more need there is for places where financial actors can get together to talk through market developments. Within financial organizations, the conversations don't flag; technical artefacts keep things moving – they are integral to how the markets think and see. Beunza and Stark put it bluntly "without instruments for visualizing properties of the market, they [the arbitrageurs] could not see opportunities…No tools, no trade" (2004, 389). These authors found that the traders' Bloomberg workstations and customized screens were crucial instruments or tools.

> These dramatic, extra-wide, high contrast Bloomberg flat-panel monitors serve as their workbench. Bloomberg terminals include a specialized monitor, color-coded keyboard and a direct intranet cable connection to Bloomberg LP. Even more expensive than the physical terminals is the software that comes with them, structured around five areas that include data (price, volume, etc.), analytics for parsing and visualizing the data, news (from 1000 journals around the world), trading support, and information on trade execution…Screen instruments are not mere transporters of data, but select, modify and present data in ways that shape what the trader sees
>
> (Beunza and Stark 2004, 390)

The 'best trading rooms', as Beunza and Stark note, are those that 'bring together heterogeneous value networks for creative combination' (2004, 393). Multiple time-spaces are fed into trading places, reworked through software to appear on screens in a variety of forms – such as graphs, tables or coloured squares – to enhance and transform data codes into say investment opportunities that can be cognised visually. The arbitrage traders are 'actively experimenting to uncover properties of the economy' (see Thrift 2004, 584-585); 'the new

instruments of quantitative finance – connectivity, equations and computing – visualize, cut, probe and dissect ephemeral properties in the project of interpreting markets' (ibid).

Knorr Cetina (2003) and Knorr-Cetina and Bruegger (2002a and b) locate their discussion of screens within what they refer to as the 'flow architecture' of contemporary finance in which participants and the market itself have become disembedded. In addition to being best described as 'microstructured' (rather than simply network/relationally structured, as Knorr Cetina points out), flow architectures are dependent on "global 'scopic' systems" to make sense of the 'numerical flux'. These regimes both project market realities and bundle markets along in the flow. Surfaces such as screens reflect and project; the 'coordination and activities respond to the projected reality to which [market] participants become orientated. The system acts as a centering and mediating device through which things pass and from which they flow forward' (Knorr Cetina 2003, 8). What is needed then to understand this architecture of flows are temporal concepts rather than as she says, the social relational thinking of networks that arguably fails to capture what for her are the 'more reflexive temporal forms of coordination' that best describe financial markets such as FOREX (an inter-dealer rather than an exchange based market) where screens dominate to 'display the market' and to 'conduct' trading (2003, 9). In making markets, the human traders and the screens 'melt together'. For Knorr Cetina the focus of attention is what she terms a 'global reflex system', a concept she introduces to capture the "constellation of technical, visual, and behavioural components packaged together on financial screens that deliver to participants a global world in which they can participate on a common platform, that of their shared computer screens" (2003, 8).

For Knorr-Cetina and Bruegger "the terminals deliver the reality of financial markets – the referential whole to which 'being in the market' refers, the ground on which the traders step as they make their moves, the world which they literally share through their shared technologies and systems. The thickly-layered screens laid out in front of traders provide the core of the market and most of the context". The layers are formed by prices, trading conversations, market stories, and news headlines and so on. "It is this delivery of a world assembled and drawn together in ways that make sense and allow navigation and accounting which suggest the globally reflexive character of this from of coordination – and the scopic nature of traders' screens" (Knorr Cetina 2003, 11).

A similar emphasis is to be found in Caitlin Zaloom's work. What she noted in her study of futures traders in London and Chicago, the software had been designed to provide the simplest visual cues ("bold faced numbers in rectangular boxes") to 'represent market action': "numerical representation shapes the traders' informational environment by elevating numbers to the status of the market itself". The software aims to flush out all hidden information and display it on the screen, she notes; by design, the numbers are meant to draw "traders toward the market…the market is represented in numbers" (2003, 264–265). Yet, despite the efforts of the software designers to "aesthetically rationalize the trading screen" and thus to turn traders into "observers" (176), as she notes they "do not passively consume the representations of the market' that the screens provide": they "seek out nonquantitive information that is located within the market numbers" (2003, 269).

Knorr Cetina's observation of the FOREX dealers would seem to share this observation: the system is reflexive and performative: "it affords the possibility of performing the market transactions and other interactions through its technological and software capabilities" (Knorr Cetina 2003, 11). The reality of screen contains the trader's lifeworld (Knorr Cetina and Bruegger 2002c).

Knorr Cetina talks of the 'mirrored market' 'that is comprehensively projected on computer screens' and which 'acquires a presence and profile of its own, with its own temporal and other properties'. What this means is that traders are 'not simply confronted with a medium of communication through which bilateral transactions are conducted…They are confronted with

a market that has become a 'life form' in its own right, a 'greater being'…a being that is sometimes coherent but at other times dispersed and fragmented" (2003, 12). Because more than prices pass through the architecture of flows (rather than the network of trades), screens have in an important sense "enlarged the world" (ibid) of Forex. And in the process the screen has become "a building site on which a whole economic and epistemological world is erected": price histories, the best prices for currencies world-wide, custom made calculating techniques…feed this screen world. Screens then are not mere "'mediums' for the transmission of pre-reflexive interactions" (2003, 13; see also 2002b); they are the way the world is known.

As this brief review of recent research highlights, the visual tools such as screens herald changing practices of calculation within key financial markets. Money's latest eyes provided by the application of the latest visualisation software do not just represent existing market activity, mainly in the form of number, however; they use these numbers to generate new visions of the space-times of financial markets[5] . The software in many cases enables the visualisation of overlooked or even undetectable market characteristics lost in previous representations of markets. Significantly this is active rather passive representation in the sense that the visualisation is achieved through software that allows the interrogation and manipulation of the 'pictures' generated by financial number and market movement. In this sense, the visualisation software brings markets or perhaps more correctly critical components of markets (such as the so-called volatility smile central to options pricing or key spreads central to the Treasuries markets) into full being and in so doing these technological artefacts stand to alter the formation of financial knowledge.

Visualisation: 'altering the contours and trajectories of financial knowledge formation'

The reduction of everything to number certainly aids the performance of calculation yet fulfilment of the calculative promise calls for the re-presentation of number to facilitate more qualitative techniques often associated with markets, such as judgement, evaluation, review and observation. The growing emphasis on visualisation software [6] (in all its broad interpretations) software seems to be market based recognition of the sensual side to the performance of financial economics and the need to do more than capture information; there's a requirement to turn information flows into knowledge about the markets. The shift from spreadsheets to 3D visualisation of data, the use of screen space to visualise the temporalities of the markets, and so on, is more than simple move up the IT chain. Such a technological development is arguably a 'transformative' shift in the way the world is presented and becomes known to financial market participants. Moreover, it might be said that the digital formation pieced together around the latest visualisation techniques is 'constitutive' of 'new social domains of action' (Lathan and Sassen, 2005, 3). This then raises not just an issue about how the visualisation of financial data helps to constitute financial knowledge of the world but how knowledge in large part produced visually shapes the relationship between these markets and the world. As Thompson remarks graphs, figures, even tables should not be seen as

> as primarily 'representational' in the sense of their ability to communicate something, but rather as primarily significatory. They always signify but need not necessarily represent (something else). This is an important distinction. It enables us to approach visualisation (in its multifarious forms) as constitutive of a reality rather than as a mere reflection of it (however accurate or distorted). And this pertains to all forms of visualisation. Thus from this perspective intelligibility, knowledge or sense are the effects of the form of visualisation …not the conditions of their possibility or existence

(1998, 286, emphasis added).

Thompson takes this further (286–7) in arguing alongside Ian Hacking that visual techniques are 'interventionary' as well as significatory. Being both significatory and interventionary visual techniques may alter the 'contours and trajectories' of knowledge formation which holds implications it is contended for the making of financial knowledge through visualisation software. "Visual aids give you a different dynamic – instead of looking at just the amount on offer, you get a feel for what's going on, whether it's one guy or a lot of smaller offers" as one US Treasury trader reported to the *Financial Times* (Hughes and Baxter 2005; see also section 5 below). Similarly, the spaces of potential strategies open to organizations such as hedge funds facing increasing competition to find new funding opportunities. As a strategist specialising in financial risk for Banking and Capital Markets, Microsoft Financial Services notes, in addition to such factors as the significant developments in computing power (interviews; see *Wilmott* 2006, 14), another significant innovation affecting financial markets lies in the area of what he refers to 'business insights visualisation'. As he continues "'What you see is what you Risk' and 'Seeing what is happening in the business is the cornerstone of good execution [decisions to buy or sell]…Today, financial institutions are looking beyond tabular, grid-based views of their business data – views to easily spot trends, see anomalies, or connect different data contexts" (*Wilmott* 2006, 16). The capabilities contained within visualisation software include the faster means to view data in innovative ways, to spot tends and acquire 'actionable insight'.

The application of visualisation techniques discussed later in the paper (all but one of which was designed originally for use in areas away from finance, such as medical research and geology), enable the financial economics and market components to be seen in a range of colours and shapes; outcomes of 'economic' action have shape and colour which aid the progress of markets. What seems to be a growing commonplace within financial markets from global equities to US Treasuries is a desire to play with the market and its constituent parts. For example, there is a desire to slow the market so as to enable a review of price formation and movements, or to divert certain data into other more digestible forms of representation. Similarly there's a growing awareness of the usefulness of seeing the multidimensionality of markets in order fully to evaluate the interrelationships amongst variables (such as price, market volatility, profit, and volume of transactions) in order to judge how the variables interact and thus to spot trends and make better decisions. Achieving this through visualisation techniques stems in part from the general agreement that images are supposedly better at communicating such relationships to the viewer - they help the viewer to improve their understanding of the interactions – hence the ealier emphasis on 'pattern recognition'. "Using color, size, shape, and animation, visualization tools condense dozens of market screens, databases and financial reports allowing users to process information more effectively. Normal correlations become familiar to traders and analysts, through abnormalities in pattern and color they can discover opportunities", (Higgins 1998; see also *Panopticon* 2005; Tufte 1990).

The new ways of visualizing the markets and their movement actually gives an added sensual depth to the way markets have been talked about previously. For instance it is now possible to see 'market depth' (see section 5); the metaphor takes on an added dimension[7]. As a representative from a leading US broking firm active in the development of financial data visualization put it "Visual cues can give you additional information you wouldn't necessarily get from numbers" (*Financial Times* 2005). Such developments seem to go hand in hand with the ethereal qualities associated with finance (see Zaloom 2003, 2006). The more abstract and interconnected are the movements in price and risk, the less able are the 'old fashioned' means of dealing with numbers, such as spreadsheets, to cope with the requirements of agents dealing, strategizing, reacting…in real-time. The growing pace and abstract nature of financial data and the interconnectivity of financial instruments require economic agents to employ the senses in different combinations. The visual sense seems to be been being brought

to the fore in sensing financial market change and seeing more clearly the economics of finance (the mathematical expressions, the components and formation of market prices, etc.) and their implications, so much so that it is tempting say that the technical enhancement of the visual sense is today central to the creation of meaningful market worlds amongst the hectares of fast moving number.

Yet this is not simply to insist that the 'screen is now the market'. Nor is it solely to do with the 'flow market'[8]; the way that is the screen offers a reality which is "*processual in the sense of an infinite succession of non-identical matter projecting itself forward as changing screen*" (Knorr Cetina 2003, 16 emphases in original). For what seems to be common to all of the software, is that the design and implementation of the software is not just seeking to re-present the market, to settle abstract signs within the screen and thus to bring them within reach, as it were; interaction with the screen[9] and thus the market seems to be a central objective: 'Moving the market around' (on screen) (section 5), 'drilling through' a market's components (section 6), changing the viewpoint (sections 4 and 5).These sorts of comments about the design and use of the software reflect the reported pressing need visually to make sense of markets, to refine aspects of a market, to steady a market's movements as it evolves, even to run back through a day's trading. The representations are re-represented, manipulated, and then meaningfully engaged. Tracking financial market developments and making market judgements through such software becomes a highly sensual affair and foregrounds the visual, the qualitative, rather than being left solely to the quantitative approaches favoured in key markets in recent years. Yet to appreciate the turn to the qualitative there is a need to rehearse briefly the arrival of the quantitative approaches to key financial markets. For it is even amongst these diehard number-engineers that the latest data visualisation techniques are proving attractive.

Enter 'the quants'…

New techniques and established market practices tend to mix like oil and water. The micro-worlds of financial markets are equally averse to change. Market cultures die hard and cultural skirmishes can turn into full blown wars. Nevertheless, in recent decades alternative technological techniques for trading and discovering market possibilities have emerged within a number of markets central to contemporary finance. The arrival of screen based trading in equities and foreign exchange are now commonplace in these and related markets. Another example is the use of electronic platforms to execute trades which has grown apace and seems destined to be the only way to transact in many key markets. Screens and electronic platforms, and the manner in which they have been adopted by human traders and integrated into the practices of market calculation, are not isolated illustrations of how a financial culture can be encouraged to shed old techniques and to regroup around some new technical artefact.

The influential rise of so-called quants and the associated growth of quantitative finance, are perhaps less obvious examples of the emergence of a socio-cultural-technical practice that arguably has led to dramatic change within key financial markets. The entrance of the quants began in the 1970s, but gathered pace from the 1980s onwards(see Das 2006, 183; MacKenzie 2006, 136-137). First introduced into the large US investment banks such as Goldman Sachs and the recently departed Salomon Brothers, the 'rocket scientists', a tag that stuck to the new entrants with PhDs in physics and maths, "toiled to develop new products and trading ideas. New terms – 'duration', dvo1' (dollar value of one basis point), OAS (option adjusted spread), spread warrants', 'yield curve swaps'…" (Das 2006, 184) began to appear.

> Gradually, quants became a fixture in trading rooms. They proved themselves useful in pricing and modelling new instruments, especially derivatives. Some became integral to trading and managing the risk of complex portfolios, others became

> invaluable as marketing assets and would be wheeled out in front of impressionable clients. Quants increased their understanding of markets, traders understood what they could contribute. A key to this symbiotic relationship was the almost total dependence on computers in trading. Quants held the key to maintaining the technological infrastructure that supported trading – they were now indispensable
>
> (2006, 1867)

Quantitative techniques offer sophisticated, mathematically based, ways to play with numbers to produce amongst other things new financial products. Yet the wish to play with the numbers is not something that is exclusive to the quants. Traders and financial product designers for example need to be able to relate to the 'numerical flux', the cubes of data. This type of judgement is as Zaloom notes 'far from strict calculation' (2003, 258). While nowadays solving a Black-Scholes equation, for instance, may be run-of-mill, to be effective say in designing a new financial product, the cube of data (the output of the numerical process) needs to be displayed in visually innovative ways which allow the numbers to be reflected upon in order for their full meaning and potential better to be judged. As the following example illustrates, the assessment of volatility is as much a qualitative activity as it is about the precise and correct application of the sometimes involved and formulaic techniques of quantitative finance. This, and the examples that follow, help to demonstrate the pressing need to unearth meaning in the markets, whether this be judging volatility (viewing, evaluating interrelationships and identifying trends amongst variables); or as in the case of the second example, judging meaning (seeing the 'spread', the bids and offers, and how others in the market view the future); or third, refining market information, reflecting on market movements, gaining a peripheral edge.

…re-enter the qualitative: the need to see the 'solution'

As one visualisation developer acknowledged, financial market agents already have their own visualisation systems, systems they are used to, with which they have trained themselves to interpret data. As this example highlights, the successful introduction of new ways of seeing is to demonstrate how the new software enables market participants to see things – the emergent 'shapes' and 'patterns' – that previously they could not spot, particularly in relation to the interaction of market variables and understanding the correlations and interactions amongst them and their effects.

The example focuses on the first relates to the need to see the numbers, to 'represent the abstractions' (Zaloom 2003, 2006) of quantitative finance, and centres on the performance of the Black Scholes option pricing model. The equation can be solved by using a numerical solution (provided by specialist companies such as NAG Ltd that are able to supply routines to aid derivative pricing and specific Black-Scholes 'solvers' (see NAG brochure undated)) which calculates the price and derivatives (the so-called Greeks). (Here I am referring to swaptions rather than standard options.) The Black-Scholes model produces values for option volatility as a function of underlying maturity of the swap and the expiry time of the option. The relationships that are of interest are between volatility, maturity and expiry (the latter two being independent variables). However seeing the solution is not so straightforward as the value of a derivative may be discontinuous (for example where there are discrete dividends). What this means is that the value of the option goes down, vertically, at such moments when the dividend is paid. The existing software can provide a representation of the solution, it cannot cope with discontinuities; in a sense it cannot adequately visually convey the temporalities of the instrument.

Yet the important point here is that the value of a derivative can be discontinuous (in the case for example where there are discrete dividends). This means that the value of the option goes

down, vertically, at such moments when the dividend is paid. Here there is a strange situation of software in a sense correcting (the established) software. Excel software has a limitation 'built deep into it': it 'cannot handle discontinuities' – it cannot display a step; it can only show a slope. And this is thus not helping the quants and others 'see what the solution [say a 100 * 100 data set] looks like', and as noted earlier to be able to manipulate the outcome with precision.

This is of interest not just to the quants but to the financial product managers in charge of design, packaging and selling financial instruments. By seeing the solution they can see how it might be shaped in away that will allow the innovation to be sold; they can reflect on the representations and engage in 'what if' analysis. This is an important part of market judgement as with fierce competition for market share and the accompanying higher margins and boost to a financial organisation's reputation that comes with the successful financial innovation, the 'quants', the derivatives traders and the product managers need to be able to be sure of what they are seeing as they swiftly group around the visualisation of data in an effort to spot, if not create, a 'need' for a particular market instrument, 'testing it for the desk' and getting it to market as soon as possible. The process of generating the visualisation is thus crucial.

So, returning to the above example (of an option on a swap agreement) the Excel representation of the solution shows the expiry line as equal jumps when they are not (0.25, 1…5, 15 – all shown as equal). As time is inadequately represented this means that the 'interesting things' that happen at the low end of the expiry time (where closer analysis may thus be beneficial) are missed. The problem is that the generative software reads in the labels and treats them as labels and does not use the information to space the axes correctly. For example, the same distance separates time 1–2, 9–10, and 10–15. The slope changes at around year 10 but in fact this is not what the numbers suggest should be happening; the software has introduced this misrepresentation. What is missing is the 'qualitative and quantitative information about what the surface is doing'. Significantly the emphasis is placed on seeing correctly which is linked to trading profitably: trading at the top/bottom of the ridge is the best place/time to trade, for example. Financial practitioners are interested in the qualitative shape; they are seeking to 're-cognise- features in the surface (and thus there's a need to separate out the features that are (really) there and those that have been put in by the software).

The other attractive side to this type of visualisation software revolves around the ability to see relationships between key parts of the data. In particular the software allows the data cube (that is, the solution arrived at through quantitative techniques) to be sliced through in any number of ways; ideally those wishing to see the market want to see the interrelationship between three variables –the maturity, strike and price. Practitioners are interested in seeing the irregularities, the spacing, the components of the solution; they wish to see the 'real' shape of the surface. With this software it is possible to see the irregular spacing, to slice the cube in many ways, to jump from one plot and the accompanying visualisation, to another. The process works by setting up the equation, coding it, using a routine to solve it; a data file (say 15*15*15 array of numbers) is then produced; this still means that no-one is clear what the solution looks, like and how volatility depends on the variables, for instance. To be able to slice through the data and see the shapes interact with them means that these questions can be answered and the answers made visually digestible. By viewing slices of data in this way it is possible to reveal the characteristics of the surfaces and the all important 'volatility smile'[10]. The shape of the smile aids better judgement of in this case the relationship between strike values and the expiry time.

Alternatively, it is possible to use techniques such as isosurfacing to view the same data cube. With such a technique it is possible to see how volatility changes through the box of data. Like contours, the surfaces connect all those points in the box (the solution data) where volatility is say 10%, 12% …or whatever particular threshold value is of interest. It is then

possible to group these isosurfaces, where volatility has been calculated as a function of strike, maturity and expiry time, for further analysis.

Again the idea is for market participants to be able to interact with the data, to explore the implications of the 'folds', for instance, and the interrelationships between say volatility and the strike value. Those viewing the visualisation can then ask say 'Is this is what we should be seeing?', 'Should the volatility be changing in this way as we move through the data?' The ability to see and interact with the numbers arguably helps in the preparation of a market for a new instrument (and how it is marketed and sold).

Visualising US Treasuries: 'Getting closer to the market…to an actionable event'

The US Treasuries securities market is a key global financial market[11]. This pivotal position revolves around their centrality to other major markets which use Treasury yields as a benchmark price for judging and pricing a range of other debt securities. Additionally US Treasuries act as a conduit for US and thus global economic information. US government macroeconomic policy and monetary policy, the repercussions of international geopolitical events, and the tremors from 'distant' financial market crises, for example, turn up as number in New York as the practices of Treasuries trading reinterpret news and events and incorporate them in prices. Given their market significance it is hardly surprising that Treasuries are "analyzed for the *information they might reveal* about market participants' expectations about the future path of the [US and the world] economy and monetary policy (Dupont and Sack 1999, 785; emphasis added). As was explained to me, traders in these markets are 'position centric': a market participant's expectations revolve around the question of 'where can I get in and out of a trade?' (interview). Whereas with say equities the analysis focuses or whether a stock is over- or undervalued and relative performance, hence another set of meanings are looked for in the data (as the next section suggests).

Yet the task of analyzing, making sense of what's going on, being sure about what price shifts mean immediately and in the 'near future', judging when it is best to trade…are all market practices that are swiftly complicated in fast moving, real-time where the volume and frequency of trades are staggering. Five year notes for example, the most frequently traded of US Treasury Securities, had a mean of 687 daily trades per day between 1996 and 2000. The volume of trades may of course vary depending on broader economic conditions both within the USA and abroad, and the mood and expectations of those within the global financial markets. Over the same time period, the mean daily volume of trades in the two-year note was US$6.8bn; the volume of trades in this note reached just over US$12bn in the autumn of 1998, the year which saw the Russian financial crisis and the bail-out of LTCM (which had substantial positions in US Treasuries) (Fleming 2003, 87-89; Dupont and Sack 1999)[12] reverberate through the Treasuries markets.

In the all of these markets – from primary and secondary markets through to derivatives based on the price of securities – one significant problem arises in the interpretation of market movements, the nature and quality, that is, of the bid or the offer, and relatedly, judging the factors that contribute to liquidity at any one time. To understand what contributes to liquidity is simultaneously to gain a better insight into price formation. For the different types of Treasury securities markets, considered above, all of the factors highlighted here – trading volume and frequency, bid-ask spreads, quote sizes, trade sizes, on and off-the-run yields spreads – need to seen more clearly, as it were, although they each may contribute to a greater degree (in the case of the bid-ask spread) or to a lesser extent (in the case of trade size, for instance) to understanding the liquidity of the market at any point in real-time[13]. The information may well be in the numbers but the task is to pull it out and turn it into market knowledge in ways that help market participants more fully to sense the markets'

developments in real-time and to act, to intervene, appropriately by executing a buy or sell decision.

The attractiveness of software that re-presents the board prices in a clearer visual form is suggested in the wording of the earlier quote where the emphasis was placed on the 'analysis of yields' to "garner information hidden in them" about "market participants' expectations about the future". Visualisation software for this market has been designed to aid market participants to judge how others view the future, what bids and offers might mean, in brief to help them "act intuitively" to get "closer to the market, to an achievable event" that is unfolding as number across their screens.

Conventionally, participants see the market represented as a 'quote board'. This is a box of numbers arranged in columns and rows and labelled accordingly, which is still the dominant way that prices are seen. The latest software in this market transforms the flat data into colourful representations of market movements and features. The colours and shapes of the columns or stacks change like a carousel as market action changes. The software provides a choice of views; it is possible to focus on all Treasury instruments (from the 2 year to the 30 year) or just focus on one instrument. The re-presentation of numbers helps participants see more exactly where the market is and what the market patterns are; the best bid/offer can be viewed and 'moused-over' to see market depth behind the bid or stack.

For instance, it is possible to see the make-up of the 'stack' or total bid of say US$117m (the screen will show up to say the top five bids making up the total). The design enables both interaction and the ability to 'see through bids and offers'. The screen may show where other market participants are – the flashing screen will reveal the number of people putting in an offer at any one price – and the type of bid or offer. In the words of a representative of the software developer, the visualisation enables someone to

> See numbers flashing and turn…to see depth, bias, where there is support …positions behind best bid/offer. Is there active market support in the stacks? You can see there's a waiting gap…there's more bias on offer side…waiting to see there's US$250m [bid/offer] but [you can see that] nobody else is there. On the [price] board you would really have to look at the numbers…18 +, 18 ¾…work at it…to see someone in the stack who is just trying to offload or someone putting in a bogus bid…but you can see this using the visualisation techniques. A lot is happening and trying to process that in your head, trying to see the bias, is difficult. See what the market is doing trying to anticipate your next move…[The software helps to visualise the] same prices [as are shown on the board] but [offers a] different way of looking at them…particularly [useful] to a trader who is say in equities but needs to see quickly what is going on in Ts. See last ten trades…thus get better idea of what market is doing. As a lot more markets move to electronic rather than voice, then have to get an edge somewhere
>
> (interview)

This suggests that this form of visualisation is one stage on from that used by Zaloom's futures traders where 'The numbers consolidate the image of the market on a trading screen; in those numbers, traders confront only the aggregate market they receive through their computers, not an image of the human competitors' (2006, 174–175). This software goes along way to see around the numbers precisely to sketch the competitor and their likely intentions and motives and the consequent impact on market prices. As another software developer involved in this market put it: "Visualisation techniques assist in the task of making inferences – which in many ways is what it's all about" (interview).

And getting an edge means being able to manipulate in an effort to reveal meaning. For instance, so-called handles are available to turn the market as it were and to move it around the screen; it is possible to enlarge the dedicated screen when prices on the quote board

(shown on another screen) signal the need to look at what's causing the prices to change rapidly. This feature may be of use to those dealing directly in Treasuries or equally to those who hold instruments, other debt say, the price of which may be influenced by what happens in Treasuries. The screen display uses colour as well as changing shape to indicate market action; when there is activity, for example, the inside stacks will get darker when there is a hit or a take, indicating a trade; changing colours and moving stacks aid faster and easier processing of market developments. Other features aim to help make important calculations visible. The '3x3' bonds for example are normalized against each other. In sum what is offered is felt to be a 'truer representation of the market'. The software offers other views relating to futures and options in US Treasuries. The data are passed straight through straight from CBOT to the software application.

With Treasuries futures, market participants are interested in slightly different features of the market than is the case in the secondary market. What the participants in futures want to see in particular is the basis spread and although there is no actual trade state to be seen (as was the case with say the on-the-runs, above) they will also still want to see positions and stacks, an intraday chart, a ticker strip.

The visualisation software is again a way of displaying market depth as well as expressing important relationships; it's possible say to chart 2 year futures against the 10 year futures, or the 2yr future versus the cash. The significant thing is that once prices are turned into picture then it makes it easier to "keep an eye on them to see how they are running against each other" (interview). Moreover, because of the interactive nature of the software, there is choice as to what is seen and which instruments are calculated against each other to show whatever spreads are of interest: switch say into a spread view to see basis spread then click (the brown or grey slab) and see 10 year cash basis spread, and so on.

Viewed through the type of visualisation software discussed in the section, suggest that the market, as an actionable event achieved through the interaction of many changing components, is prepared by a process of addition and looking, manipulation and seeing, as the user desires. Significantly, the market participant is "not left with numbers alone"; all key aspects of the market can be shown on one screen; full vision of the market is achievable. Moreover, each representation is open to closer scrutiny by a simply click.

'It's all about market watching - but not losing peripheral vision'

The last example focuses on software that aims to help market participants refine and reflect on market movement and the associated data. The software focuses on enabling the judgement of relative performance and 'value' and risks. As noted in the introduction, the main issue today is not access to data but what to do with them. As was remarked by one interviewee, in the past twelve months (to Autumn 2006) there has been a significant change in clients' expressing a wish to move from having vast silos of data (complied using business intelligence software) to a wish to be able to filter data and to ask questions of the data rather than simply be presented with a mass of numbers. Visualisation software allows questions that might not have previously been posed, to be posed.

> Financial firms wish to mine data. They need to do so quickly; the Excel presentation of data meant that it was a slow process of finding out what is going on within a firm, where the risks are, how market movements may develop and affect a firms' profits. Time is important.
>
> (interview)

This visualisation software can be used in any kind of financial trading. To date the market making use of the software are equities, fixed income, and foreign exchange. The area where

the software is most used is in risk management – chiefly market, credit and operational risk management. What is emphasised in relation to all of these applications is the refinement of market information.

The software enables data relating say to global equities to be broken down or 'drilled through' to allow analysis of individual component companies within an index, within a sector and sub-sector, and for the related numbers showing performance (such volume of trades in the company's stock, latest bid price, price/earnings ratios…) to be seen; pictures and the numbers to which they relate sit side by side on the screen. The software breaks the world into three main regions: Europe, Pacific Rim, and N/S America. By moving a computer mouse the display closes-in on an index, for example the IBEX 35; then click again to get to a sector, all the way through to individual stock and its contribution to the sector's performance and the index. The technique assists the viewer to see how much of this particular company's stock is held by say an investment bank. The attraction is that the screen works through colour and shapes but also gives the user instant access to the data, the numbers. So it is possible say for the bank to see that although the IBEX 35 may be doing well, the relative buoyancy is actually being driven by the non-cyclical consumer sector. Similarly, if say the Nikkei is doing badly it is possible to drill down to see that within it the energy sector is bucking the trend: "It's all about market watching…being able to see the market". The software is designed so that the investment maps can be set to show in colour what happens as the market moves from say –3% to +3% and enables a bank to see real time trades and their effect on an investor's portfolio. It is also possible to move amongst the market data and to alter what is seen according to other criteria (or linking in other secondary market data feeds or other internal feeds in cases where the visualisation has been embedded into organisation's operations). For example, a bank may wish to see medians, means …the data then are 're-cubed', that is recalculated, and the new criteria/ criterion, in effect, the new market, is displayed.

What is felt important and has been designed into the software is the ability to "see what is just around the corner that may affect a bank's profits" (interview) in ways that do not obscure important data. This is well illustrated in the use of this software by one leading global investment bank to help it cope with its equity risk management at a global level. The problem is that to work effectively a bank may set limits on the percentage of funds in x, y and z sectors or regions, for example, yet in order to make profits the bank has to allow its traders to take risks – quite obviously that's how they make their money. Contributing to the problem is the criss-crossing of financial markets, noted in the introduction, which means that in the process of trading, traders increasingly may be buying complicated products that run across many different risk categories and profiles. The maps help those in charge of risk management to 'see through' trades to work out the risks, their nature, and potential impact on the whole bank's operations, and to do this on an ongoing basis. This is not possible in real time as to attempt this would simply too complicated. Thus at the end of the trading day data are collected centrally by the bank and calculations are run overnight. The bank will run 'scenarios' – such as what happens if certain markets go up by 1%, while others go down by 2%? What happens if the Fed hikes interest rates – what will this do to holdings in SE Asia? So, what is being calculated is the original data set multiplied by say six different scenarios. What the software allows is for the risk associated with each scenario – for example, if rates rise by 3% – to be seen and identified: "the problem is here" (interview). The data can be updated during the day so that for instance the head of the equities desk in Europe can see where s/he is and what his / her traders must do in the markets so as to get back within risk limits. Although it may be possible to spot the 'numbers that will hurt' if the data are looked at in more traditional grid form, the search for these data and a market's hidden meanings is both much swifter and easier where visual cues, in the form in this case of coloured discs, are displayed on screen. Significantly, the way the visualisation software interprets the data enables market participants to anticipate, to spot where a problem may arise, which then provides time to act in the market to avert the danger.

Conclusion

> The world is not square, or so we learn at school, but on the brink of the third millennium it is not round either. I do not know which geometrical figure best presents the world in its present state but in an era of digital communication, we could see it as a gigantic screen – one of those screens you can program to display several pictures at the same time, one inside the other. In our global world the pictures come from all over the planet – but some are missing. Not because there is not enough room on the screen but because someone up there selected these pictures rather than others
>
> (Subcomandante Marcos 2000 'Do not forget that ideas are also weapons' *Le Monde Diplomatique* http://mondediplo.com/2000/10/13marcos accessed November 12th 2004)

Five brief points will be made by way of conclusion. They are made in a speculative manner and are an attempt to make sense of the latest visualisation software, its impact on financial markets and some possible wider consequences.

First, it seems clear (as Karin Knorr Cetina has pointed out previously (2005, 22)) that there is a need to look beyond the financial institutions to the 'secondary economy', where the software developers and designers are to be found, if modern finance and its markets are to be understood and the wider consequences of financial practices are to be fully appreciated.

Second, following on this point, what also seems apparent and often overlooked perhaps because of its obviousness, is the range of markets within global finance. The requirements of each, what the participants wish to 'see', to review, to understand more clearly…all vary considerably, as the examples in this paper highlight.

Third, there is a case for examining more closely the design and thinking contained within the software. And this should not be limited to the types of software companies spoken to for this research; there's a need to be aware of the research undertaken in universities, for example, that feed the possibilities of such software development. Significantly it appears to be the exception rather than the rule that the techniques of visualisation software (of which there are many) have been adapted for use within the financial world, rather than having been designed specifically for the 'needs' of finance. Yet what seems common – from geology[14] to derivatives – is a desire to 'see', a growing need (manufactured or 'real') to transform number into picture in an effort to explore and exploit the surfeit of data, for meaning. The addition of such software may well change how we understand the 'economics' of financial markets.

Fourth, and relatedly, there is a range of issues relating to the how the technical artefact – visualisation software – is moved and absorbed into new cultural contexts, such as financial markets, and the effects on the hybrid collective that is each of these markets.

Fifth, there is the issue of how visualisation software transforms raw data, price information and the like, into financial knowledge, and how in turn this impacts the operation of certain key financial markets, and the wider consequences. It might be contended that the manner in which visualisation software facilitates the capture of data and visually to be re-cognised afresh according to a range of criteria chosen by market participants, and the way it provides possibilities for discovering new angles and niche market opportunities, suggests that it stands to produce new (consequential) financial topologies that express the latest ability of finance to spatialise. As Zaloom has noted (see the opening quote) technology here in the form of visualisation software is foundational in the shaping of financial knowledge. The introduction of such software as a way of knowing the world arguably means that some places are made visible while others, as the Subcomandante notes, 'go missing'. The varied topologies of modern finance have their source in the software and the criteria embedded in it. The way the software works with the data potentially makes visual a series of coordinates that are of the

world as it were yet do not map precisely in the world (for example, making adjacent what in Euclidean terms are distant space-times, while simultaneously pushing away financially less attractive spaces). When acted upon, however, when that is they influence economic judgement and lead for example to 'market executions' informed by previously unimaginable financial topologies, then they may have effects, real consequences, in the world from which they have been drawn.

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[1] The paper draws on a growing literature on 'cultural economy' see for example du Gay and Pryke (2002), and Amin and Thrift (2004).

[2] So-called rainbow options are examples of such instruments. In the pricing of such options mathematical finance techniques will use the visualisation of the 'skew' in an effort to get as much information of the likely evolution of the skew as possible (see Ouwehend and West 2006, 79).

[3] Interest in the formation and workings of financial markets is growing rapidly. There has been considerable work by those working within the social studies of finance, such as that by Donald Mackenzie Knorr-Cetina, Alex Preda, David Stark and Daniel Buenza, Fabian Muniesa and Yuval Millo, for example. Social anthropologists led by Bill Maurer, Annelise Riles and Hiro Miyazaki, and Caitlin Zaloom have produced fascinating ethnographies of key aspects of how financial markets work; political economists such as Dick Bryan and Michael Rafferty have turned their attention to derivatives in particular, while sociologists in the UK such as Geoff Ingham and Nigel Dodd, and economic sociologists in the US such as Mitchel Abolafia, Neil Fligstein and Bill Carruthers, and Jocelyn Pixley (in Australia) have all engaged money and finance in a long list of publications. Within geography the work of Gordon Clark, Andrew Leyshon and Nigel Thrift are obvious examples of this discipline's interest in matters financial, just as Marieke de Goede's research signals an interesting take on finance from with international politics.

[4] Visualization software and screens are understood in this paper as technical artefacts. As Kroes and Maijers helpfully clarify, such artefacts differ from physical or natural objects as they are "intentionally produced by human beings to realize certain goals". As they go on to refine their definition, these artefacts are "produced in the sense that it is only in relation to human intentionality that physical objects become technical artefacts…they are objects to be used for doing things and are characterized by a certain '*for-ness*'. It is this teleological element that sets technical artefacts apart from physical objects" (2006, 1, emphasis added). The introduction and application within financial organisations of the types of visualisation software discussed here (often developed originally in fields as distant as geology and medical research) is where and how it acquires its 'for-ness'. The software gains for-ness through integration into the forms of sociation characteristics of each financial market and the various socio-cultural-technical practices that continually make-it-up.

[5] Thrift's summary of recent writings on changing 'sensings' of space and time helps in understanding how the design and use of visualisation software may be interpreted as a new power to 'spatio-temporalise' (2004, 592).

[6] Software, as Thrift and French (2002, 310) have noted, too often sits in the background, as it were, unnoticed (see also Thrift 2004a; Knorr Cetina (2003, 9).

[7] In an interesting paper Klamer goes back to Schumpeter to remind us that 'Economic theorizing begins with a vision'. The way Klamer develops this is to link the constitutive metaphors and narratives of economics, to visions. Following Rorty, he argues that vision "informs and is represented by the metaphors that constitute a conversation, the so-called constitutive metaphors" which "underlie all thinking to such an extent that thinking without them is inconceivable" (2004, 259). Metaphors reflect visions held by economists; and like metaphors, visions are constitutive of conversations (see Klamer 2004) about how for instance the workings of financial markets and 'the world' are / should be talked and the consequent acts that follow. Visualisation techniques allow those conversing to be surer of their ground. Note how Knorr Cetina refers to markets in foreign exchange, the first screen based financial market (2003, 14-15), as a "large, globally distributed conversation" (2002a, 914).

[8] Knorr Cetina and Bruegger (2002b) argue the screen world is a flow world made this way by technologies; what is the 'material' of a system that is located entirely in the symbolic space of an electronically mediated reality, they ask? (As they note elsewhere, the screens do not, in their core elements, represent a reality 'out there', but are "constitutive of it" (2000, 166).) Knorr Cetina and Bruegger emphasise the 'textual' character of this world; writing…on the screen. This they argue leads to the identification of the secondary economy of 'hardware developments and writing (news etc.) that is also a form of 'world-making'. Other traders provide the writing….prices, gossip …as they 'perform the market on screen'; the representational part of screens brings the world electronically on to screens…they emphasise news (rather than 'confirmed correspondence with world'), *information is the materiality of the screen world*. (See also Knorr Cetina and Bruegger 2002c; 2000).

[9] "In the phenomenon of screen, seeing is not merely being aware of a surface. The very watching of the screen as screen implies an already present ontological agreement about the nature of the world; a world that is relevant (and true) to us who share it, in and through the screening of the screen" (Introna and Ilharco 2006, 69-70). This is part of an "an already implied and agreed way of being" (ibid, 71).

[10] The smile can be thought of " as a pattern of option prices in which the graph of the relationship between strike price and implied volatility is not a straight line, as it should be on the Black-Scholes model (or the analogous surface is not a plane, if we are dealing with more complicated options)" (Donald MacKenzie, personal communication 08.01.07).

[11] In 1999 the amount of Treasury debt held in non-federal government accounts stood at around US$36 trillion (more or less the total for outstanding debt securities issued by all US corporations at that time (Dupont and Sack 1999)).

[12] This period saw a so-called 'flight to quality' as investor 'sentiment' saw a rapid move away from risky and potentially highly illiquid investment media such as emerging market bonds and into Treasury securities (see Dupont and Sack 1999, 796-7). The effect of this flight however pushed down relative yields on particularly short Treasuries leading to some large losses.

[13] See Fleming 2003 for an in-depth analysis of Treasury market liquidity.

[14] See for example *Financial Times* IT Survey 4th July 2001. BP Amaco is using visualisation technology to help geologists "translate seismic data into visual terms, saving vast amounts of money on drilling costs…The greater accuracy of 3-D maps…has dramatically changed the economics of the exploration industry".

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