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Weather profits: Weather derivatives and the commercialization of meteorology

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Abstract

While many scholars researching the commercialization of science focus on biomedicine, this paper explores the changing commercial frameworks for meteorology in the UK and the US. The organization of meteorology in both countries increasingly reflects a political–economic approach that treats science as an economic entity in which market-based criteria can be used to allocate scientific resources. The differences are equally significant in terms of the production and dissemination of meteorological forecasts and other data to public and private services. Alongside this commercialization has been the emergence of weather derivatives markets – financial products that enable trading on weather indices in a way similar to oil or gas futures – which have re-shaped how some businesses interact with meteorologists. This paper explores how weather derivatives traders engage with, shape, and are frustrated by a commercialized approach to funding meteorological data and forecasts. It highlights how commercial imperatives raise questions about the collection and quality of meteorological data, and how forecasting and weather modelling is being adopted within the private sector to enable trading strategies in the weather derivatives market. The consequences for commercial actors are highly variable, suggesting that any account of commercialization of science, while recognizing extant policy shifts, must be sufficiently nuanced in its interpretation of such effects.

Keywords

commercialization, meteorology, neoliberalism, state funding of science, weather derivatives

On 23 May 2006, representatives of the UK Meteorological Office, which is funded by both the Ministry of Defence and its own commercial activities, were brought before the regular meeting of a UK parliamentary committee to account for how they had lost at least £1.5 million of public money in a failed business venture. The business, weatherX-change, had been established in 2001 as a joint venture with a financial broker (Umbrella

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Brokers) to provide data and forecasts to the nascent weather derivatives market. At the committee hearings Peter Ewins, chief executive of the Meteorological Office (hereafter Met Office) from 1997 to 2004, blamed the demise of weatherXchange on a number of factors, including a loss of confidence between the partners. He also admitted that once the Met Office staff realized how lucrative providing information for weather derivatives traders could turn out to be, they deliberately undercut business from their joint venture to take a larger share of the market themselves. Though Mark Hutchinson, chief executive of the Met Office at the time of the hearings, subsequently denied this admission, sufficient damage had been done to provoke a Labour member of parliament to say that, 'if you had done that in local government, you'd have been shot'.[1]

WeatherXchange was supposed to be a shining example of the potential earning power of a Met Office released from the shackles of exclusively public funding. Instead, it put Met Office executives in the uncomfortable position of defending the organization against accusations of loss of public money, lack of experience in the private sector and staff being paid a salary from each organization. Was this simply a misstep on the path to a burgeoning and prosperous Met Office? Or was this symptomatic of broader problems with the growing commercialization of meteorological activities?

This paper investigates these questions by exploring the use and development of meteorology by weather derivatives traders in the UK and the US. My research included 26 interviews with weather traders in energy companies, banks and insurance companies, and meteorologists who had involvement with the industry and other industry service providers (consultancy, pricing software, brokers). The semi-structured interviews were conducted between 2003 and 2005 using a combination of note-taken and recorded interviews appropriate to interviewees' confidentiality requirements. During that time, I also attended industry conferences and had numerous informal conversations with market participants. I also collected detailed secondary data, including newspaper and Internet resources, and other media coverage of the industry, as well as patent filings, conference proceedings, and electronically available letters and other documents. This enabled familiarity with the research material to be attained, in order to establish the reliability of the interviews, all of which were fully transcribed and assessed.

All names and companies have been anonymized in this paper, but a significant number of the companies that publicly disclosed their weather derivatives trading in this period were interviewed.[2] I begin with a concise examination of some of the literature on commercialization of science before situating meteorology within its historical context. I then introduce weather derivatives before exploring how weather derivatives traders engage with meteorological data and forecasts. The conclusions suggest some possible implications for research on the development of commercial science.

Commercializing science

There has been a rapid growth in science and technology studies (STS) research on the commercialization of science, with much of it on biotechnology or medicine (for example, Fisher, 2009; Krimsky, 2003; Mirowski and Van Horn, 2005; Sunder Rajan, 2006; Rasmussen, 2004; Sismondo, 2009). These studies have illuminated how scientists engage in commercial projects (Sunder Rajan, 2009), the implications of legal and regulatory developments (Mirowski and Van Horn, 2005), the consequences of these developments for science (Krimsky, 2003) and the publics embroiled in them (Fisher, 2009). Less has been written about commercialization in the geophysical sciences. What studies exist tend to examine effects of government, especially military, funding upon these fields (Doel, 2003; Miller, 2001; Mukerji, 1989). This absence could suggest that what has been called a neoliberal approach to science funding is not widespread in these fields, but it could equally point to the diverse ways in which these policies are enacted amidst competing interests.

The relevance of scientific research to society and economy has become an important rationale for the commercialization of science (Slaughter and Rhoades, 2004; Varma, 2000). Science has become increasingly organized by reference to supply and demand (Mirowski, 2004) and governments have supported structural arrangements that enable scientists (and their projects) to compete for commercial consumption. Indeed, Varma (2000) argues that in corporate laboratories primary research has given way to mission-oriented research that prioritizes short-term business interests. Mirowski and Sent (2008) suggest that commercial imperatives emanating from corporate laboratories have spread to universities and other publicly funded research organizations.

Mirowski (2009, 2010) has argued that such developments represent a neoliberal philosophy that places faith in the ability of markets to process information, relies upon the state to establish markets, promotes an economic theory of democracy, stresses the necessity for a free flow of capital, and excuses corporations from blame when things go wrong (also see Lave et al., 2010). The marketplace of ideas becomes a key trope for placing scientific expertise in a competitive framework in which success is judged in terms of meeting consumer goals (whether in the public or private sectors). The regulatory frameworks required to implement these ideals have been standardized in many developed countries through changes in government funding policies and the development of for-profit education systems (Mirowski and Sent, 2008).

Responses to commercialization in STS have fallen into two primary categories according to Mirowski and Van Horn (2005). The ‘Mertonian Tories’ emphasize threats to an ideal scientific community from corrupting private monies, while the ‘Economic Whigs’ debate how best to engage in technology transfer. Treading between these extremes requires a provisional agnosticism in favour of detailed studies of corporate science and a broader analysis of changing scientific activities that attempts to explain how sciences become privatized, how exactly private funding influences scientific process and what the consequences are for other types of commercial activities.

The policies and practices that are labelled neoliberal are always located in specific times and places (Castree, 2006; Ong, 2006; Sunder Rajan, 2006). Sunder Rajan’s (2006) study of biotechnology companies in India and the US distinguishes how they transact business in different contexts while attempting to develop an Americanized image to access global markets. Neoliberalism in India is not a universal principle, but instead refers to the work of actors who engage with a set of processes or ideals that have been ‘universalized’ by American companies, but realized in all kinds of incongruous ways by Indian companies (Sunder Rajan, 2006). At the national level, governments implement intellectual property regulations, pass laws encouraging (certain forms of) labour and capital movement, and attempt to privatize public services in order to provide (de)regulatory spaces and opportunities for companies to compete internationally (Ong, 2006; Sunder Rajan, 2006).

These contextual differences are important for considering how different state funding regimes in the UK and US produce qualitatively different commercialization regimes for meteorology. The extent to which these regimes might be classified as neoliberal is a question I do not attempt to resolve in this paper. Rather I focus on contradictions in the weather traders' interactions with these regimes as they try to work out how to meet their own goals.

Context

Connections between meteorology and commerce began well before the late 20th century. With the expansion of instrumental data collection and growing attempts to predict the weather in the 19th century, prospects developed for a commercially viable meteorology, especially in agriculture, fisheries and shipping – fields in which forecasts could make a significant difference for productivity and safety (Anderson, 2005; Burton, 1983; 1984; Craft, 1999; Fleming, 1990). Meteorology was important for other industries too, such as telegraphy, in which mutually beneficial relationships developed, as telegraph companies needed business and meteorologists needed reduced rates for their telegrams (Burton, 1984; Fleming, 1990). In the US, meteorological networks also provided a means for monitoring Native American and worker uprisings (Fleming, 2005). The predecessor of the US Weather Bureau was established through the Army, particularly through Signal Service and Colonel Albert Myer, whose disciplined weather observers provided a useful rationale for retaining control of telegraph networks (Dupree, 1986). From the late 1860s until 1890, the Weather Bureau effectively was a military agency, but in 1891 the Weather Bureau was taken over by the civilian Department of Agriculture, though the Signal Corps, still retained a meteorology section (Dupree, 1986; Harper, 2008). The Weather Bureau, however, was the main employer of meteorologists, though the number of professionally trained meteorologists remained small. Its primary functions were to provide forecasts for the public as well as for agricultural, aviation, insurance and marine interests.

The position of the Weather Bureau remained relatively unchanged until 1940 when the demand for meteorologists expanded rapidly during the war, especially for aviation. Importantly, meteorologists during this period also established a technical journal (*Journal of Meteorology*). Further opportunities arose for teaching mathematics- and physics-based meteorology, inspired by European geophysicists (Harper, 2008). In other words, meteorology was becoming professionalized as an academic discipline. The number of professional meteorologists increased tenfold to 6000 by the end of the war (Harper, 2003). In 1940 the Weather Bureau was officially integrated into the Department of Commerce, but producing freely available forecasts for public safety remained a primary goal. The question of how forecasts should be provided for commercial use was, however, open to debate. Tensions arose about how the enhanced need for professional standards could be met without drawing awkward boundaries between academics, Weather Bureau professionals and the increasing number of private meteorologists (Harper, 2003).

Likewise, in the UK meteorological pursuits also focused on public safety through the late 19th and early 20th century. The Met Office was formed in 1867 from the ashes of the Meteorological Department, which had been set up in 1854 but closed in 1865 after Robert Fitzroy's suicide (Burton, 1983). Both organizations were part of the Board of Trade and responded to commercial demand for a meteorological information system, especially in fisheries. Mining and agriculture also had interests in such information, especially as the government budgets for science increased during the 1870s and 1880s (MacLeod, 1971). In 1920 the Met Office became part of the Air Ministry in response to the rise of aviation and the growing military significance of meteorology. Aerial warfare and developments in meteorological theories and forecasting practice enhanced the scientific status of the profession (Friedman, 1989). The Europeans at this point advanced their meteorological research capabilities beyond those of their US counterparts (Harper, 2008). What is interesting about the UK is that the military retained control of the Met Office through its absorption into the Ministry of Defence from 1967 and to the present day.

From the 1940s, however, both in the UK and the US, commercial meteorology became more prominent. Mergen (2008) dates the first commercial meteorology to the 1920s, when meteorological consultants (such as Irving Krick who made predictions for Hollywood studios) would advise weather sensitive industries, but it was not until the glut of post-war meteorologists that private sector meteorology began to expand. The National Association of Industrial Meteorologists was formed in the US in 1948 and supported moves towards separating public and commercial interests, with the former served by the Weather Bureau and the latter by private sector meteorologists (Mergen, 2008). After the Weather Bureau was renamed the National Weather Service (NWS) in 1970 (and placed within the newly created National Oceanic and Atmospheric Administration [NOAA]), private meteorologists also re-organized with a new trade association, the National Council of Industrial Meteorologists (Mergen, 2008). Commercial and applied meteorology grew in stature with the rise of university courses such as the University of Birmingham's (UK) MSc in Applied Meteorology and Climatology (established in 1963) and the publication of books such as Maunder's (1970) classic *The Value of the Weather*. Mergen (2008) suggests that there was growing acrimony between public and private sector meteorologists through this period, which was prompted by a series of disputes about certification, the extent of public–private co-operation and, perhaps most famously, frequent attacks on the NWS by AccuWeather (a company established in 1962 by Joel Myers). In attempts to avoid irresolvable conflicts, both the UK and the US developed regulatory frameworks to separate areas of public and commercial interest.

The US presently allocates public money to the NWS for data collection, basic research, forecast database services (that are not tailored to specific industries or businesses) and emergency forecasts, while the private sector operates all commercial forecasting and other services that can realistically be sold (Fine, 2007). In the UK, by contrast, it was only in 1996 that the Met Office became a trading fund as well as continuing to be part-owned by the Ministry of Defence. Although private companies have slowly developed to compete in areas such as forecasting, the Met Office operates across, what in the US would be classified as, public and private services. The Met Office is effectively split, with staff, costs and services being placed in the private or public block depending upon whether they are considered to be addressing public needs. The public part is similar to the NWS, except that data do not have to be freely accessible, particularly for commercial uses. This is a critical difference between the US and UK regimes.

Ellig (1989: 14) summarizes it as follows: ‘The British policy attempts to make a government bureau function more like a private business, while the US policy restrains a government bureau so that private businesses can enter the field.’ The US government legislates to protect private interests under the assumption that the NWS otherwise would become an inefficient bureaucracy. In both cases, the pursuit of cost-effective, preferably profitable, approaches to funding scientific services leads to meteorological systems that deliver best value for money in relation to the demands placed upon them.

During the 1980s, proposals were made to fully privatize the largely public meteorological system. This was quite different from earlier commercial activities, as it turned the entire set of activities from data collection to forecasting into a marketplace. In 1983, the Reagan administration proposed to sell five weather and land-sensing satellites to private corporations (Ellig, 1989). Although this particular initiative failed due to public criticism, private companies continued to question the government’s commitment to a public weather service, especially in relation to the perceived poor quality of NWS forecasts. This argument, however, did not just apply to commercial uses of meteorological expertise. Ellig (1989) argued that not only should forecasting and other products be subject to private competition, but the process of data collection should be included too. After all, he opined, a meteorological office such as the one in the UK could inflate the price of data to prevent private enterprises from creating new services with those data. Since the state enterprise could block access to public data to protect its competitive interests, data collection should no longer be seen as constituting a public good. Privatization, Ellig (1989) reasoned, would not lead to poorer services, because data to be exchanged would have to be of good quality and available at a reasonable price. Thus the US model with commercial enterprises developing products with public data differs from the UK’s partial privatization of both data and value-added services (Freebairn and Zillman, 2002a).

These different systems produce different working environments for commercial meteorologists (as Table 1 highlights). In Europe, because of difficulties with working across language differences and through national meteorological offices, a company called Ecomet was established that would provide data to any company in Europe for a fee. It became impractical, however, for many companies to pursue this route, due to the continual increases in prices and the lack of people willing to pay for access to the data (Interviewee 4 was particularly strident on this point). In the US, a significant amount of commercial meteorology is built upon forecasting and business services, whereas in Europe difficulties with data access have restricted the development of commercial activities. In one sense, data in the US appear more ‘neutral’ in that the NWS has less interest invested in what it collects than its European counterparts.

The development of commercial meteorology has implications for employment. In 2006, 40 percent of atmospheric and space scientists in the US were employed by the federal government, but this is predicted to decline to 34 percent by 2016, with a corresponding rise in professional services, with technical consulting employment predicted to rise by 5 percent (US Department of Labor, 2009). Pay and working conditions vary for private sector workers, with some employees considered to be drones operating machines, while others attract better salaries than their public sector equivalents (Fine, 2007).[3] Likewise, in the UK, the Met Office’s partly-public, partly-private status encourages staff time and research capability to be charged to its public or private accounts,

Table 1. The value of private meteorological services in the US and Europe in 2002, showing that the US system leads to greater value of commercial meteorology (Weiss, 2002)

	US	Europe
Gross receipts (US$)	400–700 million	30–50 million
Number of firms	400	30
Number of employees	4000	300

Note that this is separate from the $2.7 billion spent by the US government, of which $745 million went to the NWS to collect data (National Research Council, 2003). European meteorological offices operate on a national public basis (as in the UK) with commercial activities limited to areas of business interests.

respectively. Indeed, personal communications with former employees of the Met Office suggest that staff become frustrated with juggling the kinds of services they provide to customers and with rules that inhibit synergy among divisions. One of the commercial arm's most notable (and notorious) creations was the data and service provider weatherXchange, which spawned accusations about staff time and debates about the extent to which private interests should drive the Met Office.

These kinds of figures and debates have promoted discussion about what the relationship between commercial activities and meteorology should be. Morss and Hooke's (2005) commentary on commercialization in meteorology suggests that the processes in the late 20th century differ from those in earlier eras, as patenting and data-sharing, to take two examples, become caught between public or private interests. Smith (2002) suggests that some academic resistance to commercial meteorology is based on a poor understanding of how commercial weather companies provide more public benefit from applied science than public sector meteorologists. He further suggests that some commercial lobbying of Congress stems from the fear that university-sponsored corporations with insider access to research journals (through institutional subscriptions funded with public money) and public funds for technology have financial advantages over commercial meteorologists. Commercial meteorologists cannot conduct as much 'basic' research, because they depend on market relations to justify their budgets. Although these issues remain intractable, the example of weather derivatives traders sheds some light on how commercial interests interact with, shape and are resisted by commercialized meteorological offices. In the following section, the example of weather derivatives will be briefly contextualized. I then examine how weather traders try to shape commercialized meteorology.

Weather derivatives

Weather derivatives are financial contracts that enable companies to trade upon weather indices (such as temperature, precipitation, snowfall, wind velocity or frost) to manage their weather-sensitive costs or simply to speculate. They function like oil or corn futures, but because weather is not physically deliverable (at least not consistently with projects such as cloud seeding) contracts are settled with cash. Weather derivatives emerged within the US energy sector in the mid-1990s with Enron, Aquila and Koch Industries. These companies were leaders in the re-regulation of the energy industry towards market-based pricing and trading (the term re-regulation is preferred to deregulation for the reasons set out by Pryke (2007)). Aquila was a US natural gas distributor and trader established to take advantage of the regulatory changes, but which suffered serious financial damage after Enron's collapse and was subsequently merged. Koch Industries were (and still are) involved in a wide range of industries, but entered the weather market through their gas and financial trading interests. Enron, however, was the 'celebrity firm' of this group (Rindova et al., 2006) attracting publicity for a range of new products, of which weather derivatives was just one example. They yearned to be seen as a highly innovative company. Lynda Clemmons, Mike Corbally and their colleagues within Enron's Environmental Trading group prepared the ground for establishing a weather derivatives market when insurance companies were unwilling to insure the company against non-extreme weather risks. These risks included reduced gas pipeline use during warm winters. Insurers claimed insufficient expertise in pricing such risks, and so Enron employees resorted to inventing a new market based on something that they were very familiar with: energy futures trading. Consequently, the new weather product became derivatives (rather than insurance), because energy companies could more readily adopt financial products than the more heavily regulated and licensed insurance products. This also meant that weather derivatives paid out as soon as the weather parameter was triggered in the contract, regardless of whether damage occurred or not.[4] Subsequently, Enron, along with Koch and Aquila, enrolled more energy companies into the market, and companies in Europe, and later Asia, followed (often via Enron employees in other countries). Companies in other economic sectors also participated in the market (agriculture, golf courses, wine bars, and so on).[5] Nevertheless the market was constructed around energy companies' specific needs for temperature protection. Heating Degree Days (HDDs) and Cooling Degree Days (CDDs)[6] thus became key loci in the market, as both were derived from energy industry understandings of how energy demand was related to temperature.

From these initial experiments, weather derivatives expanded to become a US$32 billion notional value market in 2007–8 (Figure 1).[7] There has been significant growth in end-user demand by companies buying contracts to mitigate their weather risks, with

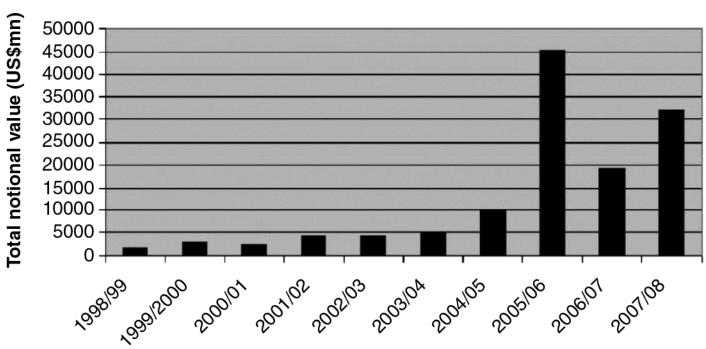

Figure 1. Total notional value (in millions of US Dollars) of the weather derivatives market over time, as recorded in the surveys completed for the Weather Risk Management Association (WRMA). (Derived from PricewaterhouseCoopers (2008) and previous years' surveys)

even more significant growth in speculative trading, particularly during the hedge fund boom in 2005–6. This was enabled by the Chicago Mercantile Exchange's (CME) weather contracts, which have been traded since the turn of the 21st century. There is not space in this paper to discuss every aspect of weather derivatives in terms of the companies using them and prospects for the future, the kinds of contracts being negotiated and the financial aspects of those deals. There is a small, but growing literature on these topics (for example, Banks, 2002; Changnon, 2007; Pollard et al. 2008; Pryke, 2007; Thornes, 2003; Zeng, 2000). The important point in relation to the emergence of weather derivatives is that they rely on meteorological indices for their datasets, contract settlement and pricing, and that forecasting changes in those indices becomes a financially remunerative activity for trading.

Somewhat different from cases discussed in other papers in this special issue, then, weather derivatives did not emerge through a direct commercialization of science. The government-administered meteorological organizations were already being encouraged to commercialize, and weather traders encountered these commercializing imperatives when requesting data and forecasts from those organizations. The following sections explore these interactions in more detail. By focusing on data and forecasts, it is possible to examine how commercial actors experience commercialized science and then try to re-shape the existing system to suit their own interests.

Weather traders and commercial meteorology

Data

Systems for weather data collection and sale are compelling examples of the implications of commercialization. Unlike forecasts or other 'value-added services', data are more frequently perceived as free, public goods that are not influenced by social, political or economic interests. Data for the weather market are predominantly collected by publicly funded national meteorological offices, such as the Met Office in the UK or the NWS in the US. There are three main ways in which weather derivatives traders have interacted with the provision and use of data, first in debates over the quality of data, second in the access to data, and third in the privatization of data.

For weather traders, timely and accurate data provide a coherent and commensurable set of indices for the marketplace. The indices of HDDs, for example, rely upon a meteorological dataset (in this case, of temperature) usually derived from an airport meteorological station close to a major city (New York La Guardia, London Heathrow, and so on). Airport stations are the primary data inputs for trading, because they are considered highly reliable, with regular observations, stable historical records and strong security. In the US, these data are available for 'free', though there are costs for processing, while in the UK access to such data is through a central organizing body such as the Met Office or companies such as MDA (formerly EarthSat). As mentioned earlier, privatization has been much more systematic in the UK than in the US, where much of the data are conceived as a public, environmental good. Weather traders are forced to purchase data in the UK at the commercial rate, while in the US the nominal costs of the data make them more readily accessible to traders.

Although European and US traders have tried to work pro-actively with meteorological organizations, this was not easy because these organizations 'weren't set up to provide data for the financial market and, because they had other priorities, there had to be some kind of pro-active approach to actually get things set up for the financial market. It's very, very difficult … ' (Interviewee 3). One reason for this difficulty is that meteorological offices have not been accustomed to producing data on demand (in contrast to forecasts) for private companies. The weather traders had very specific needs in relation to the quality of such data, and public sector meteorologists were not always attuned to those needs. Indeed NOAA and the Weather Risk Management Association (WRMA) arranged joint workshops in the US precisely to enable better communication between weather traders and data providers (Dutton, 2002; Kelly, 2001; Murnane et al., 2002). Undoubtedly, there is some circularity in defining what is meant by good quality meteorological data (see Chang, 2004). Within weather trading, debates centre on the reliability and accuracy of observations for establishing the commensurability of indices in the market and establishing contract payouts. These map onto two uses: the pricing of contracts, where continuity becomes important, and contract settlement, where instrument anomalies are immediately represented in financial consequences.

For pricing contracts, it is critical that data display continuity and reliability over a significant time period (30 years for the climatological average). Historical metadata records are strewn with discontinuities (abrupt or gradual statistical deviations) for which there are no documented changes to station practices, procedures or instruments, although some may simply result from poor record-keeping (Murnane et al., 2002). These data, however, can be 'cleaned' in a relatively straightforwardly way (at least for statistical purposes), and significant work has gone into addressing this need for weather traders. The important point in terms of commercialization is that for some stations the data and data record are now crucial, because of the increased value placed upon them by the weather derivatives community. Indeed weather traders complained that the Met Office, having realized this, chose to maintain or increase charges rather than to promote the fledgling weather derivatives industry.[8] This is not a new complaint. Ellig (1989) collated numerous complaints in the UK during the late 1980s by private meteorologists who felt that the Met Office withheld data or prices so that its competitors would fail. All commercial users, and not just weather traders, had to contend with the cost of these data.

If data are going to be sold, then they must meet the demands of the purchasers who increasingly scrutinize the quality of the data. When data are used for settling derivative contracts, there must be no sudden deviations or changes. Contracts have back-up stations when no data are recorded, but if the data are 'wrong' there is no time in the fast-paced settlement of weather derivative contracts to correct them. Though meteorologists may be less concerned with such immediate accuracy, as they can remedy any faults when the data are cleaned, their purchasers have less flexibility. Weather derivatives may be agreed over a multi-year period, so that changing instruments halfway through a contract might not be acceptable, particularly when no warning is given or insufficient overlap is provided between two sets of instruments (a frequent problem). Upsetting the data stream during the period of a contract can have significant economic consequences, so that meteorologists may find that they must confer with private interests when considering changes to their data network.

For example, traders who knew that a thermometer had been moved at Houston, resulting in a rise of about one-degree in minimum temperature measurements, reaped considerable benefit from this knowledge. Blame is laid at the door of the meteorologists who:

> make such a hash of making the measurements. They've got a thermometer and they just move it and the meteorologist actually made an announcement that 'this will not affect the measured temperatures' ... but when you look at the measured temperatures there's a huge effect, but the meteorologists are just really naive about this and partly because they think that the change of 1 or 2 degrees is a small effect, whereas for weather derivatives that's a huge effect. (Interviewee 5)[9]

This interviewee contrasts the meteorologists' assumption that moving the thermometer would have no effect with the precision demanded by the weather derivatives market. For weather forecasters, the move might have little effect, as one or two degrees is not seen as a significant change, and in any case forecasters are becoming more reliant on synthetic data (Brettle, 2006; Edwards, 1999, 2001). This is especially true with global general circulation models (GCMs), because, as Edwards (2001) points out, the data from land and ocean points require correction, gridding and interpolation by intermediate models before they can be used in GCMs. Models will correct any 'unusual' dataset readings. For weather traders, however, a one or two degree change could influence whether a weather derivative contract would pay out and what the 'fair' price for such a contract could be. As one interviewee (10) noted with regard to different valuations of datasets:

> [t]he observations are probably at a level which is adequate for inputting into a weather forecasting model … whereas for a weather derivative … the impact of that weather station is very high. So there's opposing needs.

Weather traders thus claim that more money should be devoted to generating accurate observations rather than developing better models or synthetic data: a plea for reorganizing meteorological priorities (a plea also made by some meteorologists such as Brettle (2006)). Despite such claims, as Fine's (2007: 108) ethnographic research reveals, many meteorologists *are* concerned about data accuracy in connection with radar technology, the move away from mercury for recording temperatures, and the problems of infrequent calibration of automatic observation instruments (with the Automatic Surface Observing System that has been rolled out across US airport stations to record temperature, wind, precipitation and fog, among other things). These points are important, given that data for weather derivatives contracts are taken from automatic machines rather than human observers, because of greater reliability and security attributed to the mechanical systems.[10]

Not all weather traders are so concerned about accuracy. For some traders, data quality is not even an issue, as long as there are none of the trading (dis)advantages illustrated by the Houston thermometer example. As Porter (1995: 28) suggests, accuracy is not as important as an 'adequate quantification', that 'everyone is measuring and reporting … the same way' and 'it is possible to combine and manipulate data'. As one weather trader, a trained meteorologist, stated, 'you know, as long as we are where the market is, once, you know, we've got the same averages and standard deviations as the rest of the market has, we're OK' (Interviewee 3). Data become facts by virtue of being accepted by prominent actors within the weather derivatives community. This accords with the notion that deciding which data are acceptable is done through social and economic interactions, and not through a purely rational scientific process. Of course, not all opinions count in this process. As long as the relevant gatekeepers accept the data, every trader can use them. These gatekeepers include both the risk-pricing software companies and, in the past, companies such as weatherXchange in the UK that provided data for the weather derivatives market. These gatekeepers have more experience with data and hence should be able to make better-informed judgements about their reliability. This does not mean that each of the gatekeepers will make the same judgement, as other interests can intervene. WeatherXchange was an interesting example, because it was a joint venture between the Met Office and Umbrella Brokers. The Met Office provided data to WeatherXchange to sell on the market, but at the same time assisted with brokering contracts based on those data. Surprisingly, no interviewee raised concerns about the threat to the perceived neutrality of meteorological data. As long as every trader is the same (the level playing field) there is less concern for strict accuracy. Or to put it another way, as long as more people accept the measurement scheme in preference to other schemes, then it becomes objective through consensus as much as reliability (Cronon, 1991; Porter, 1995: 96). In this case, the marketplace adjudicates the quality of certain datasets used in the specification of the contract. For end-users the data need to be reliably consistent with the hedged risk such that the contract pays a suitable compensation for lost sales. In speculative activities, companies may be prepared to turn a blind eye to questions of quality as long as traders meet their profit expectations.

Weather traders are concerned with access to data as well as their quality. Lynda Clemmons, then President of WRMA, wrote to the Deputy Secretary of Commerce Samuel W. Bodman at the US Department of Commerce in 2002 to thank him for NOAA's attempts to help promote the weather risk management industry. These are discussed in a report of a workshop between NOAA and WRMA (Murnane et al., 2002). Clemmons wrote:

> Data issues are critical to sustain our industry, not only in the US, but globally as well. Other governments are not as enlightened as our own, and see data as a way to take taxpayer funded information and effectively auction it off. We believe the access to global weather data is in fact a trade issue, and we hope through your efforts, you can assist in raising awareness of this important anti-competitive stance.[11]

Here the industry association, in an effort to open up international trading, presses the US Department of Commerce to take a position against the sale of weather data. By appealing to the concept of free trade on a level playing field, Clemmons strengthens her arguments. It becomes less disputable, because it is an economic issue. The politics of the US weather traders can also be seen here. For European-based traders the data *have* to be bought to engage in primary trading. For the US operators who want to engage in speculative or secondary trading in the European markets, however, the data costs restrict this involvement. WRMA have subsequently been lobbying the European Parliament in Strasbourg to liberalize access to weather data and the rules for re-using such data. Currently, such data are licensed, and buyers and sellers must purchase them to check contracts, as re-use is not permitted.[12]

There is little wonder that US traders in particular get frustrated with this system, as they are accustomed to having environmental data freely available. Within Europe, data costs and access have been blamed for the slow development of the market, compared with the US where no company has high purchase costs (Interviewees 3, 4 and 5, who discussed this in depth, were all involved with establishing the market in the UK; see Weiss (2002)). The US should not, however, be held up as the nirvana of weather data. A couple of interviewees (in the UK) suggested that US data were in difficult-to-read formats or required editing (Interviewees 3, 4).[13] For traders with limited meteorological expertise, it can be expensive to purchase the necessary knowledge to reliably use these data. In the UK, data are cleaned and packaged, but at a cost.

Interestingly, Fine (2007) points out that private forecasting firms in the US have asked for weather data to be removed from the public sphere, because of fears that these raw materials of their trade are too easily available for others to undercut their forecasting operations. At the same time, data collection is an arena in which private firms are reluctant to work, given the high costs of the infrastructure (Fine, 2007). The public sector in effect subsidizes the private sector. However, Smith (cited in Ellig (1989: 15)) suggests that the problem is rather that the NWS' regulatory set-up and various re-definitions of what is in the public interest mean that private companies are never sure of what a future government will decide should be free. For some commentators (for example, Jones, 2003), weather derivatives provide the NWS with further commercial reasons for requesting government funds to support and expand the collection of meteorological data. As the value of data rises, governments pursuing cost-effectiveness will be more likely to support such commercial use of data. The NWS tries to stabilize its employees' jobs, under pressure from government and private weather companies, by emphasizing its ability to partner with private companies to provide meteorological services (Fine, 2007).

On the other hand, UK weather traders purchasing data that are also used for public forecasts may be privately subsidizing data collection for public services. Ellig (1989: 27) suggests that a private system actually may produce more useful weather information that is 'needed to accomplish well-identified public purposes' thus providing 'taxpayers [with] better value for their money'. This system, however, requires a range of regulations and procedures to be in place to protect public and private 'interests' and delineate between them. If data activities are privatized, it raises questions about what types of data to collect and how to interpret them. Nobody would claim that meteorologists manipulate instruments, but their decisions about labelling storms (watch/warning/advisory) in order to control social reactions (for example by portraying elevated levels of danger) attests to the political nature of their work (Fine, 2007). As discussed earlier, what defines quality of data in a commercial audience is highly variable.

An example of private data in Europe illustrates potential problems with privatization. In recent years, weather traders have conversed with renewable energy financiers about funding strategies for small-scale renewable energy projects in areas of unreliable weather (as evidenced for example by numerous industry presentations on this topic since 2004). These commercial opportunities gave rise to one of the most infamous disputes in the weather derivatives market over an effort to patent wind power indices (WPI) by Entergy Koch Trading (EKT) in 2003.[14] This patent would provide, 'a method and system of generating wind index values for a facility'.[15] The problem with wind derivatives is that the wind can vary between the location of the meteorological station and the wind farm. EKT's product addressed this problem by compiling regional wind indices that could be used by any individual site within an entire area. Areal averaging would decrease the risk premiums that companies paid by packaging the risks much more effectively for the seller, thereby collateralizing the risk (this was discussed in depth by interviewee 21 who had a particular interest in this market).

However, wind power was gaining political and economic currency. EKT was not the only company aiming to profit from the UK government's drive to meet renewable energy targets. Several bankers contested the patent filing, as they wanted to use wind derivatives to finance wind farms, but without being forced to use EKT's indices. A vociferous argument at a risk management conference in Autumn 2003 concerned this filing (Interviewee 21). Nonetheless the patent application was successful, and EKT secured a key passage point within the market. At the present time, it is unknown how lucrative the patent will be, as it is possible traders will find ways to avoid buying EKT's indices. This example has implications for wind trading and renewable energy policies, and demonstrates how the Met Office's privatization of data by licensing it and charging end-user fees has encouraged further privatization. EKT is not the only company to have filed a patent relating to weather derivatives, and there are at least five more patents in the weather market on weather data indices and pricing software. Data therefore are not just used or contested by weather traders; datasets are actively moulded for commercial interests to become private property.

Data have been re-valued in a variety of ways. Principally, greater commercial value is now attached to data, because businesses use them to make financial decisions. In many ways, the UK example reflects a more complete commercialization of meteorology in its focus on data as well as forecasts as profit opportunities. In both the UK and US new strategies are promoted by states and companies to create foundations for a 'free' market for data and, while doing so, to subtly alter how meteorological data are justified. From being a public good or product of nature, such data are now being negotiated in terms of cost-effectiveness and value. Instead of making decisions on which projects to fund, scientists are now leaving it to the market to determine 'quality' for corporate use and more importantly to assess expertise in terms of usefulness rather than any external criteria. That is, the network of data users would be produced through an 'ignorant' market as much as through a 'wise' one (Mirowski, 2010). This case highlights the wide-ranging, and sometimes confusing, repercussions for all kinds of scientific and commercial activities.

Forecasts

Forecasting has been a significant commercial activity, ever since it became reliable enough to attract interested constituents rather than gamblers. It has been incorporated into many business activities, to their considerable economic advantage (Changnon et al., 1999; Dutton, 2002; Freebairn and Zillman, 2002b). Although weather forecasts are commercially available at reasonable cost for companies to aid their planning and decision-making processes, the forecaster provides no financial compensation for losses due to weather events, regardless of how well or poorly they were forecast. To a certain extent, weather derivatives make forecasts less valuable, because the contract pays a prior agreed amount based on the weather index, rather than the actual loss. Derivatives provide more complete protection than simply reacting to a forecast and they minimize some of the moral hazard of failing to protect ones goods in the expectation of compensation (it is not paying out on the actual loss incurred so it makes sense to minimize that loss). Speculative trading, on the other hand, is driven by preferences for particular types of forecasts or interpretations of them. Economic value can be extracted from the information in a weather forecast. To explore this, it is first important to understand how short-term, seasonal and multi-year forecasts are commercially useful, before examining how weather traders have developed new forms of forecast. It is also possible to assess how traders respond to meteorological offices' efforts to market products, in this case as probabilistic forecasts. Finally, it is possible to ask whether, with all the expertise flowing into the weather derivatives market, the prices of weather contracts reflect a grand ensemble forecast.[16]

Short-term forecasting produces important information for speculative contracts and for contracts that spread risks in a similar way to re-insurance. For a trader, short-term forecasts have a number of implications. When buying or selling contracts, traders require 'accurate' forecasts. Most companies buy a minimum of ten forecasts from different companies, as well as produce their own in-house forecasts. This has resulted in a raft of investment opportunities for private forecasting and meteorological consultancy. The forecast is enrolled within the trader's 'box of tools' to assess the viability of trades at particular prices. It is vital for a trader to know which forecasts to use and how to judge their accuracy, and when in April 2001 one UK energy company employed a meteorologist in a trading position other companies swiftly followed.

Short-term forecasts are important for setting the prices of weather derivatives contracts. Interviewee 23, a market maker, explained the fair value for a monthly temperature contract with the equation: 'FV (fair value) = month to date amount + forecasted amount (for the next 12 days) + 10 year average (for remaining days of the month)'. These fair values are generally calculated from proprietary forecasts or from widely used paid services such as those provided by MDA. When setting their prices, traders likewise purchase significant numbers of forecasts from a variety of sources. As with data, it is less important for a forecast to be considered completely accurate than for it to be reputable as a 'reasonable' source within the weather market (several interviewees admitted to doing little or no forecast verification). The CME's risk pricing software calculations therefore become proxies for the fair value of contracts, obviating the need for each trader to calculate them for themselves. With as much as 80 percent of the market based on speculative trading, it is clear why forecasts are so economically important and why some companies employ meteorologists to produce their own in-house forecasts. Short-term weather forecasts may be no less reliable than forecasts in other financial markets; indeed, one interviewee (3) avowed that they are better than 'Greenspan on the interest rate markets'.

Seasonal forecasting is generally regarded as a less reliable art within the atmospheric sciences, and in the past was considered too unreliable for decision-making (Agrawala et al., 2001). Season-ahead trading involves buying a contract, often several months before the start of the coverage period, in order to mitigate risk over a 5-month period (winter trading in the northern hemisphere covers November to March). Detailed forecasts are not available, and the concern is with probable trends in average temperature through the coming season. Such trends are then used to estimate the fair value of the seasonal contracts. Weather traders use commercially available forecasts from both the Met Office and private companies for season-ahead trading/pricing. Companies also invest in attracting the brightest young atmospheric physicists, most with PhDs in related fields, to create in-house seasonal forecasts (Interviewees 19, 20 and 26 are examples). These forecasts must outperform publicly available forecasts for the investment to be worthwhile for advancing the companies' trading positions.

Although multi-year forecasting is particularly difficult, one energy company claimed that their models were far more sophisticated than anything in the public or academic sectors (Interviewee 20). Another private forecaster (Interviewee 17) stated that he had been particularly successful at predicting the cool winters in New York in 2002–4 by sidelining global warming and looking at other indicators, such as the North Atlantic Oscillation (NAO).[17] This interviewee clearly believed that public forecasters used global warming excessively in their predictions. This sort of claim is a matter of corporate identity creation and marketing, but also hints at continuing discord between public meteorologists and commercial meteorologists. Evans and Shackley (1997) note that there are some common differences between models produced by public scientists and those used within the private sector. They argue that public models are much more open to public scrutiny and also far more complex. This is because they seek holistic scientific understandings, whereas the commercial models are more restricted and instrumental:

> the persuasiveness of specific numerical outcomes to very specific users and customers is what matters here. Such business users are not overly concerned about 'research' per se, and their own modellers are much less part of, or constrained by, the peer community than in publicly-funded research domains. Hence, their identity as the 'expert' goes relatively uncontested. (Evans and Shackley, 1997: 8)

Yet as they go on to point out, the increasing complexity of academic models actually makes policymaking more difficult and these models less useful. Seasonal forecasting may be developing rapidly outside the public domain in ways that enhance profitability rather than producing better predictions of season-ahead weather. Simplistic though business models may be, they are at least readily useable within commercial and other contexts, which leads many traders to advocate their advantages.

Indeed, the commercial imperatives for using forecasts can be highlighted with the example of probabilistic forecasting. The Met Office invested significant sums of money in probabilistic forecasting, guided by the theory that businesses and other users will be able to use these forecasts more readily. Weather traders are frequently interested in these forecasts, but have difficulties integrating them into their business practices.

> Probabilistic forecasting is a more advanced way of forecasting for sure. It relies on people that are using that forecast a) believing that other people are using it and b) being able to price a bimodal distribution of the two-week forecast into their pricing models. (Interviewee 10)

Traders will use probabilistic forecasts if other people do even though they might accept that it is more 'advanced'. It can be difficult to agree the price of contracts when one trader uses deterministic forecasts while another uses the probabilistic type, producing radically different results. Here again, the argument is not about whether probabilistic forecasting is better, but whether it is the accepted procedure for commercial use. The Met Office could thus devote significant time and research expense to produce a product with little commercial rationale. This highlights that commercial interests do not necessarily evoke 'better' or more 'complex' science, but rather science that fits particular needs.

Can private sector organizations go beyond using meteorological science to actually leading its development? Evans and Shackley (1997) suggest that commercial models are kept private, but not necessarily because they are inferior or only do a particular job; rather, they are a source of financial competitiveness. In the case of weather derivatives, this includes both forecasting and pricing software models. Companies primarily employ mathematicians or physicists (not specifically meteorologists) who have completed the PhD. Their models can be divided into two types along a continuum. The first is based upon the physics of predictive-chaos: a way of seeing the world as ultimately unpredictable but somewhat directional, so that nothing that happens is completely random. Such models describe the atmosphere and are processual in form. The corporate experts who develop these models are usually physicists. The second type of model is based in statistics and is used extensively by some traders and companies that develop pricing-software. The world here can be understood numerically and many of the producers of these knowledges have backgrounds in mathematics or finance. For statistical approaches it is about finding the best fits; for physics-based approaches it is about creating better models. Weather traders fall into either camp and, of course, they create a trading environment by their different valuations based on those understandings. The boundaries of acceptability of these knowledges are often defined by deference to corporate 'reasonableness'. One example is that of trading correlations between weather in one place and weather in another. This is a common part of market practice, but beyond a few hundred miles it becomes dubious (unreasonable).[18] The key point here is that commercial science doesn't necessarily distinguish between different types or qualities of understandings of meteorology, rather preferring models that provide the best information for a justifiable financial strategy to meet the needs of the trader/company.

How might one know if these private models are superior? Ultimately, if weather traders are developing the best expertise and if private funding is producing useful knowledge, then this should be evidenced in the prices of weather derivatives contracts. This is because the weather market should act as an ensemble of both public and private forecasts *if* traders use information perfectly in their trading behaviour. If this is the case, then the market comes to reward those forecasters and traders who are most accurate, such that the scientific expertise is literally judged within a 'marketplace of ideas'. In an interesting post on the Wilmott Message Boards[19] one 'Paul (senior member)' writes:

> People are so fond of 'calibrating to the market' that I imagine I can tell if it is raining outside by looking at the prices of weather derivatives. (That was meant to be sarcastic!). P.

This quote suggests that people have genuinely considered the idea of weather derivatives as an information processor, yet in response to this question posed to interviewees, traders would find the idea interesting, but not what they considered themselves to be doing. There is an implicit trust, regardless, in the weather prices to reflect to a certain degree likely probabilities of particular weather events occurring. Given the in-house company expertise devoted to developing or using forecasting in novel ways this should not be surprising. Although it may be easy for meteorologists to deride the weather traders' (untested) claims that their models are better at seasonal predictions, an area which the Met Office has considered experimental even while extracting profit out of them,[20] nonetheless the quantity of experts now flowing within the corporate sphere and the willingness of these people to use their models for trading suggests that there might be some substance to their statements.[21]

These models or forecasts, however, may be predominantly instrumental (Evans and Shackley, 1997) and might predict the weather derivatives market's weather indices. While proponents of alternative methodologies may stake their claim, whether this produces 'better' science is far less clear, given the ways in which these markets are established around energy companies' interests, certain types of forecasting and, not least, the fact that different strategies of trading muddy the waters. The knowledgeable trader can take advantage of a 'bad' public forecast if the market prices are changing in line with that forecast, but one knows that it is a bad forecast. Markets can be viewed as useful limited information processors or producers of ignorance (Mirowski, 2010), but it requires methodologically difficult in-depth examination of prices and forecasts to make more detailed claims about them in particular cases.[22]

Weather traders are voracious consumers of weather forecasts and significant producers too, at least within the space of their own corporations. Unlike weather data, commercial weather forecasts date back at least to the 1920s, but distinguishing instrumental, but scientifically less well referenced, outputs from public, scientifically credible, but often difficult to apply forecasts is made harder as the two are brought into alignment (in theory, if not always in practice). The idea of the weather market as a grand information processor that producers the best meta-forecast derived from traders' individual sensibilities and insights would help establish the value of such claims. Unfortunately there are insufficient data to support or confirm this idea, but given the points made earlier about how data can be contested, or how forecast models can be developed to serve instrumental ends, it seems odd to trust that the market would produce optimal scientific expertise. Nevertheless there clearly is diversity, and that is not intrinsically bad. A more practical question is how to distinguish the quality of these different products, given the specificity, in many cases, of the product to the user community.

Conclusions

Weather derivatives traders are a small group among the many interested actors that meteorological organizations must respond to, but in this paper I focused on them to highlight important repercussions of the commercialization of meteorology. With common goals for cost-effectiveness, the UK and US governments have instituted distinct funding regimes that delineate public and private meteorological services. The science may be for a purpose or profit, but exactly what that means is open to contestation. Weather derivatives traders encounter these regimes through their requests for data, forecasts and other services to create and sustain a financial market based upon weather indices. By translating the needs of the weather derivatives community within the meteorological data and services industries, meteorological products are being reframed in relation to quality, economic need and availability. Yet this is far from a coherent story of the ways commercial entities engage with a commercial science.

Weather traders attempt to enrol a wide variety of actors to support their claims. Different traders value data differently. For some, meteorology is too driven by forecasting, where data quality is less of an issue than for weather derivatives settled at one station. Others deny any real concern with the quality of data, choosing instead to focus on laissez-faire arguments. As long as everyone uses the same data, any faults with them are not the important issue. Others attempt to enrol trade organizations to protest against European charges for data as discriminatory acts that should be made the subject of free trade laws. A few try to involve the legal system to protect their models and indices in a privatization of meteorological knowledge. Still others implore the Met Office to stop ‘wasting’ time on mid-range, probabilistic climate forecasts, which are of ‘no use to any business’, and to invest instead in providing timely and accurate data. Meanwhile, other firms invest large amounts of money to create expertise in climate forecasts for pricing future contracts. This is especially the case with seasonal forecasts, which the Met Office says are experimental, but which weather traders use to make multi-million pound decisions. These models, however, may be instrumental and less concerned with modelling weather per se than adequately predicting future prices and trends in the weather market. It is not what is ‘good’ that is enrolled, but what is *good enough* to suit a particular purpose. There is thus no singular thread to the weather derivatives community’s engagement with meteorology. When asking questions about the repercussions of commercializing science, it is important to remain sensitive to the differential impact of these policies on different constituents. Likewise, it is important to note the regional variation in these policies.

The UK and US governments have adopted policies for organizing meteorological science in order to realize commercial benefits through cost-effective collection and dissemination of meteorological data, forecasts and expertise. Both systems share common features in their drives for commercialization, including a policy of separating public services from specialist services provided under business contracts. However, there are significant differences between the UK and US. Most significant is the fact that the US NWS provides a core of public data and forecast services that is supplemented by a large commercial sector, while the UK’s partly privatized Met Office has stifled competition in its much smaller commercial sector. In the US, businesses run most of the value-added services, but the tools of the trade, meteorological data, are freely available to any user. In the UK, commercial meteorology has been muted, especially given the ability of the Met Office to charge for data.

The NWS system seems to offer greater access to participants in the weather derivatives market to generate their own forecasts with publicly available data, but there is far less incentive to improve the quality of data collection in areas that are of particular interest to companies. In contrast, the Met Office, especially with weatherXchange, made access to the market much easier for UK companies, especially for non-specialists. There are more incentives to improve quality, but the system is compromised by the ability of the Met Office to protect its business through high data or service charges. This suggests that the part-private, part-public system for data and forecasts in the UK hinders the development of a more commercially oriented meteorology (with its associated business services). The problem can be attributed to insufficient privatization, where the Met Office accrues value for its private operations from public funding that other companies do not have. Would complete privatization be the answer? The diversity of knowledge produced through a competitive weather derivatives market does not necessarily imply a better quality of meteorological science. Producing what is 'good enough' to assure a 'level playing field', or what out-performs other forecasts, actually may override any concern with improving understanding of meteorology by focusing on successful applications or fairness in the delivery of services. A fully privatized system also seems unlikely to occur, because data operations are expensive, and while certain stations in the weather derivatives market become important, many others are unlikely to find similar sources of funding, even though they may be vital to other public interests.

It is clear, however, that meteorological offices increasingly will need to justify the costs of their operations in terms of public needs and private services. This is where debates about the quality of service will bite. Weather traders have complaints similar to those made by earlier generations of commercial meteorologists about the quality of service provided by public-funded organizations (Mergen, 2008). These complaints highlight how data are constructed and raise possibilities for constructing them differently – in human versus automated recordings, in choice of station sites, and in the reliability of stations versus the ability to clean data in the historical records. In the UK, unlike the US, this is important because data services are sold to companies, resulting in higher expectations, especially by data producers to listen to their consumers. Private weather services must justify their services to their private clients. In the end, perhaps the ultimate goal for this system would be Block's (2006) vision of a private weather sphere that protects the most well-funded constituents from the worst consequences of the elements.

Returning to debates about commercialization, this case study has highlighted the importance of national context upon the ways in which governments pursue projects to make science more cost-effective. Ironically, however, approaches to the privatization and commercialization of science have not left all commercial actors feeling so positive. If anything, commercialized science involves complex nuances and disagreements about how to organize public science. It is unlikely to be efficient for all users. When discussing a 'neoliberal' approach to science, we must stress that understanding these contingencies is critical for opening up commercialization as an historicized process. Such accounts also enable us to identify potential levers for re-shaping scientific funding and justifying alternative directions. Regardless of the political conclusions, turbulence should be expected. After all, a science of weather could hardly be otherwise.

Appendix. List of interviewees directly referenced in the text

Interviewee number	Position, type of company	Location*
1	Product Manager, Exchange A	UK
2	Weather Trader, Energy Company A	UK
3	Managing Director, Service Provider A	UK
4	Chief Executive, Service Provider B	UK
5	Director, Service Provider C	UK
6	Analyst, Energy Company B	UK
7	Trader, Energy Company B	UK
8	Seller, Broker	UK
9	Analyst, Energy Company C	UK
10	Vice President, Seller A	UK
11	Seller, Bank A	UK
12	Partner, Law Firm	UK
13	Analyst, Energy Company D	US
14	Analyst, Energy Company E	US
15	Project Manager, Exchange B	US
16	Executive Vice President, Seller B	US
17	Meteorologist, Consultancy	US
18	Managing Director, Seller C	US
19	Managing Director, Seller D	US
20	Meteorologist, Seller D	US
21	Independent Consultant	US
22	Consultant, International Institution	US
23	Market-maker	US
24	Seller, Bank B	UK
25	Business Manager, Energy Company F	UK
26	Former Meteorologist, Seller E	UK

*Sellers are banks, insurance companies or, as in many of the cases, companies that combine both functions.
The interview numbers here give the order in which the interviews were conducted.

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Notes

1. Uncorrected transcript of oral evidence later published as HC 823-ii, UK Parliament. Claims of the lucrative nature of the business seem to be based as much on market potential as actual profits.
2. This claim is based on the companies listed as members of the Weather Risk Management Association in 2005, but it is impossible to provide an exact percentage, because some companies entered and left the market quickly, while the traders also moved between companies throughout the research period. This figure is biased towards banks, insurance companies and energy companies that sell weather contracts, because end-users often do not publicly declare these contracts.
3. The UK Met Office starting salary for a minimum-graduate trained meteorologist in 2005 was £17,837 with an average of £23,674 (this was formerly advertised on the Met Office website, www.met-office.gov.uk. Copies available from the author). As an example, one meteorological expert working in weather derivatives (who had completed a PhD) started on a £38,000 salary (personal communication). In the US, a starting Federal meteorologist would earn just over $35,000 compared with a private firm's $20,000, though top salaries in the private sector would be higher (Fine, 2007: 226). Note that Fine does not provide the educational levels for these salaries). The average salary for US atmospheric scientists is $77,000 (US Department of Labor, 2009).
4. Unlike insurance, derivatives must not include an insurable interest or proof of loss. Poorly structured contracts can lead to insufficient compensation being collected or to cash bonus when losses fail to meet 'expectations'.
5. Golf courses and bars with outdoor seating are affected by declining demand during wet weather.
6. HDDs are used in winter and the index is calculated as 18°C minus the daily average temperature for a specified period (day, month, season). Thus, the colder the given period, the higher the HDD index. CDDs are the reverse (daily average temperature minus 18°C) and are used in summer. 18°C is chosen as the temperature for which no heating or cooling is usually required for buildings to maintain a comfortable temperature.
7. Notional value is the underlying value of the total assets with all trading positions, though these are hypothetical values which tend to overestimate the value of such assets, and hence of the market.
8. Data charges are often between €0.5 and €10 per data point, depending on the amount of processing involved (Pollard et al., 2008). WeatherXchange charged £350 per dataset for daily updates on core weather sites for 1 year (non-core site prices were individually negotiated). Historical datasets were charged at £400 for up to 40 years.
9. In the context of the interview it is probable that Fahrenheit is meant rather than Celsius.
10. There are exceptions to this, however, in the kinds of contracts the World Bank has offered through micro insurers in Ethiopia, India and Malawi, where it can be important to have local rain gauges that rely on human observation and are potentially alterable (Syroka and Wilcox, 2006).
11. Letter from Lynda Clemmons to Samuel Bodman, 2002, previously available from: www.wrma.com.
12. Mirowski (2004: 138–141) suggests that these re-use clauses in data licences and agreements are symptomatic of the extent to which industries have moved to protect their scientific interests downstream (also see Mirowski and Van Horn, 2005).
13. It is worth noting that these interviewees had close connections with Met Office data provision and may simply have been unfamiliar with the US system.
14. Société Générale subsequently bought Entergy Koch Trading.
15. UK Patent Application: GB 2 389 930 A.

16. An ensemble forecast provides representative future states of the atmospheric system, given differences in initial conditions and model uncertainties. Numerical predictions are thus products of a series of model runs and often are used to assign probabilities to particular precipitation or temperature forecasts.
17. The NAO is a proxy index for climate circulation between the Azores High and Iceland Low atmospheric masses. This circulation influences weather patterns in North East America and North West Europe accounting for one-third of the surface temperature variation in these regions (Hurrell, 1995).
18. An example would be trading a UK gas book's weather risk on temperatures at Schiphol airport (Amsterdam) knowing that the correlation between these two datasets generally holds in certain months. Interviewee 6 discussed this in depth saying that 'it's a very brave person that trades correlations ... blocking patterns are something that really you can't predict, well *some think* they can but good luck to them ... Seattle and the UK is a Rossby Wave pattern that's often set up that gives some strong positive correlations between Seattle and the UK. No way would I ever trade Seattle [even] if it happened to be a liquid centre.'
19. These message boards operated for a short time at www.wilmott.com, an early participant in the weather derivatives market.
20. The Met Office cautioned that its 4-week and seasonal forecasts should be considered 'indications'. At the end of 2005, the public 4-week forecasts were removed and replaced with 2-week forecasts. Anyone requiring the 4-week forecast had to buy the Met Office's Monthly Outlook product based on the logic that businesses extract more value than the general public from the relatively limited information (reports previously available from www.met-office.gov.uk. Copies available from the author). Internally, such forecasts would have to be classified as a commercial product rather than a public need. Interestingly in 2010 the Met Office scrapped public seasonal forecasts in favour of a 'new' monthly outlook product.
21. Nevertheless if one company predicts the weather better than everyone else, it is likely that prices will move in line with that company's trading pattern. This is why traders create noise by making bluffing trades in the opposite direction.
22. These data are not easily accessible, as they involve CME real-time price records, company trading records and weather forecast information.

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