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Science and the stock market: Investors' recognition of unburnable carbon

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ABSTRACT

This paper documents the stock market's reaction to a 2009 paper in the *Nature* journal of science, which concluded that only a fraction of the world's existing oil, gas, and coal reserves could be emitted if global warming by 2050 were not to exceed 2 °C above pre-industrial levels. This *Nature* article is now one of the most cited environmental science studies in recent years. Our analysis indicates that this publication prompted an average stock price drop of 1.5% to 2% for our sample of the 63 largest U.S. oil and gas firms. Later, in 2012–2013, the press "discovered" this article, writing hundreds of stories on the grim consequences of unburnable carbon for fossil fuel companies. We show only a small negative reaction to these later stories, mostly in the two weeks following their publication. This limited market response contrasts with the predictions of some analysts and commentators of a substantial decline in the shareholder value of fossil fuel companies from a carbon bubble. Our paper discusses possible reasons for this discrepancy.

1. Introduction

On April 29, 2009, 17:15 GMT, Richard Black (2009), writing for the BBC, broke the headline "About three-quarters of the world's fossil fuel reserves must be left unused if society is to avoid dangerous climate change, scientists warn." That headline referred to two papers in the April 30, 2009 issue of *Nature* – Allen et al. (2009) and Meinshausen et al. (2009) – both of which concluded that if global warming by 2050 were not to exceed 2 °C above pre-industrial levels, then strict limits on the total carbon budget through that date would be required. The latter study went one step further and predicted that to meet such goal, less than one-half of the world's proved economically recoverable oil, gas, and coal reserves could be emitted during 2007–2050. What these studies meant, especially Meinshausen et al. (2009), was that without major changes in business practices and government policy much of the world's fossil fuel would be stranded and, therefore, potentially worthless under the climate change scenarios examined. At the time, however, the scientists and the media[1] seemingly ignored a key implication, namely, that if the burning of fossil fuel were greatly limited under a 2 °C climate solution, this could trigger a sharp reduction in energy firms' valuations because their financial statement reserves make up a significant part of that value (Harris and Ohlson, 1987; Qurin et al., 2000). Following the initial BBC story, however, both *Nature* papers drew little attention from the financial media and, otherwise, stayed in relative obscurity.[2]

In the passage of time since, however, a very different situation has emerged. Thomson Reuters' *Web of Science* now ranks Meinshausen et al. (2009) as one of the most cited environmental studies in recent years, placing it in the top 0.1% of science papers published in 2009; and the results and implications are now also well known to a much

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[1] For listing of media reports coincident with the April 30, 2009 issue of *Nature*, see sites.google.com/a/primap.org /www/nature/nature_presscoverage.
[2] For example, of the 741 Google Scholar cites for Meinshausen et al. (2009) through September 30, 2013, only 64 occurred in 2009, and of these most were made by fellow scientists.

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larger audience due, in part, to reports by Leaton (2011), Spedding et al. (2013), Redmond and Wilkins (2013), and popular press articles such as McKibben (2012) and *The Economist* (2013). Leaton et al. (2013) have updated the remaining carbon budget from 2007–2050 to 2013–2050 and paint an even gloomier picture for the energy industry. For example, the updated data indicate that the world's listed fossil fuel (oil, gas, and coal) firms have the equivalent of 1541 gigatons of CO_2 in their proved and potential reserves, but their customers can burn safely only 269 (225) gigatons for temperatures to have a 50% (80%) chance of not rising by more than 2 °C above pre-industrial levels (Leaton et al., 2013, 15); and, with present trends, this remaining carbon budget will be spent well before 2050.[3] These more recent figures imply that 82% (1-(269÷1541)) of firms' proved fossil fuel reserves could eventually be unburnable.[4] In financial terms, and assuming accurate data, the potential cost is daunting. According to Spedding et al. (2013), the combination of reduced oil and gas prices (from lower demand) and unburnable fossil fuel reserves places at risk some 40% to 60% of the market capitalization of the world's top 200 energy companies. With a total year end 2012 market capitalization of about $4 trillion (Leaton et al., 2013), this could translate to a substantial wealth loss for these firms' shareholders, thereby bursting what some analysts and commentators have termed a carbon bubble from the mispricing of fossil fuel reserves. The Spedding et al. (2013) report, however, cautions that investors "have yet to price in such a risk, perhaps because it seems so long term."[5]

This paper examines when and whether the stock market might have recognized the potential loss of value to energy company shareholders due to unburnable carbon, which, in this paper, we define as the economic value of the excess of a firm's prove economically recoverable oil, gas, and coal reserves over those reserves consistent with stabilizing global temperature increases at an acceptable level, such as less than 2 °C.[6] On the one hand, we might expect investors to respond rationally to all available information in pricing their securities, including significant results from science, in our case, the aforementioned *Nature* publication. Under such rational response hypothesis, we predict a negative price reaction as early as April 29, 2009, when the BBC first published its story about Allen et al. (2009) and Meinshausen et al. (2009). On the other hand, financial experts offer various explanations of why capital markets might respond biasedly and slowly to adverse news about future returns, for example, based on media inattention (Dyck and Zingales, 2003), investor bias (Bernhardt et al., 2006; Hirshleifer, 2001; Welch, 2000), hard-to-process information (Kumar, 2009), proprietary cost (Healy and Palepu, 2001; Verrecchia, 2001), and poor communication by scientists (Revell, 2013). These and other explanations offer an alternative view, which we call the lagged response hypothesis, which predicts an additional and possibly more negative (and delayed) response to news stories following the *Nature* articles. We reason this could occur if the financial and popular media increasingly publicize the earlier scientific results as newsworthy and/or investors respond to the updated scientific evidence, which might place more relevance on the earlier results, in this case, the possibility that unburnable carbon could adversely affect the share value of energy firms.[7] In discussing the earlier *Nature* articles, the media may have also contributed to the public's understanding of the science by introducing "unburnable carbon" as an easy-to-understand metaphor for the fossil fuel carbon on company balance sheets that would threaten their market value under policies to limit global temperature increases to less than 2 °C. Both the rational response and lagged response hypotheses also encompass the null hypothesis of no response; that is, we might observe no systematic response to unburnable carbon regardless of the sequence of the news or events, possibly because of the uncertain and long-term nature of the increased investment risk or from offsetting benefits ignored or underemphasized by the news media.[8]

[3] More recent estimates by the IPCC's Fifth Assessment Report (IPCC, 2013) suggest a world carbon budget of 1119 gigatons of CO_2 for a greater than 50% chance of temperatures rising to less than 2 °C (including reductions for non-CO_2 radiative forcings). We calculate this number for the 50% scenario as follows: IPCC (2013, 1113) indicates a total carbon budget of 1210 gigatons since 1870. Net of non-CO_2 radiative forcings over the same period, this results in a total carbon budget of 820 gigatons. But 515 gigatons of carbon were emitted in 1870–2011. This leaves 305 gigatons of carbon or 1119 (305×3.67) gigatons of CO_2 remaining to be emitted after 2011. Since only about 27% of the remaining amount would be burnable as oil, gas, or coal (Leaton, et al., 2013), this amount is much less than the proved and potential fossil fuel reserves sitting on firms' balance sheets of 1541 gigatons of CO_2. For similar data on the CO_2 budget, see IEA (2014).

[4] This 82% estimate, however, applies to oil, gas, and coal firms. An analysis of the distribution of fossil fuel reserves by McGlade and Ekins (2015, 189) suggests unburnable reserves of 33% and 49% of total reserves for oil and gas, respectively. Moreover, the overall percentage for U.S. oil and gas firms is generally lower given the proximity of their reserves to demand centers. For example, based on Exxon-Mobil's 2013 disclosures of proved developed and undeveloped oil reserves (2013 Form 10-K Part 1, Item 2), the combined percentage of unburnable reserves given the percentages in McGlade and Ekins (Table 1, p. 189) is 17% for 2 °C without Carbon capture and sequestration (CCS).

[5] Amid these stories about how unburnable carbon might affect oil and gas companies' valuations, over the same time period, public interest continued to grow around topics such as the role of anthropogenic (man-made) carbon emissions in the stabilization of radiative forcing from global temperature increases. Discussions often centered on a desirable target level of global emission concentration (e.g., CO_2 stabilization at 450 ppm) and/or international actions to meet the target such as cap-and-trade, carbon capture, use of negative emission investments, and clean technology. If covered by the media from an investor standpoint, those discussions often focused on (a) which sectors, notably energy, might be most exposed to carbon regulation such as cap-and-trade and (b) the nature of the transformation of the energy sector worldwide under a global agreement to cap carbon emissions. One early press report (March 11, 2008) used the term "unburnable" as a reserve category, although this was primarily in the context of proposals to reduce carbon use consistent with a desired level of global CO_2 concentration to limit global warming (e.g., news.bbc.co.uk/2/hi/science/nature/7287572.stm). On the other hand, the scientific literature on climate change has mostly ignored the term, until quite recently (e.g., McGlade and Ekins, 2015; also note 4). For example, a search of the term "unburnable carbon" in the many hundreds of published climate change research papers between 2007 and 2013 supported by the Tyndall Centre for Climate Change Research produces the result "no items found" (www.tyndall.ac.uk/biblio). In addition, while Spedding et al. (2013) raise unburnable carbon as a significant energy company valuation issue, Spedding et al. (2008), which pre-dates the 2009 *Nature* articles, makes no reference to the term or similar phrase.

[6] While few scientific articles use the term "unburnable" or "stranded" carbon (note 5), Meinshausen et al. (2009, p. 1158) clearly imply such a concept by referring to (a) budgeted GHG emissions consistent with policies to stabilize global temperature increases to an acceptable level, such as less than 2 °C, and (b) the GHG emissions in "proven economically recoverable oil, gas and coal reserves." A precise definition of "unburnable carbon" requires further specification, however; in particular, a statement of (i) the time horizon of the GHG emission budget, at least initially, (ii) whether the concept shall be viewed as an emission quantity or a measure of economic value, (iii) an emission policy objective, (iv) the emissions that would be produced, such as from proved economically recoverable reserves or from proved and provable reserves, within the stated time horizon in the absence of a policy objective, and (v) the level of disaggregation, such as at the company, industry, or economy-wide level. For the present analysis, we assume that rational investors would have anchored their response on the *Nature* article, as it was in the public domain at the time. That article considered a budget horizon of 2050 relative to proved economically recoverable oil, gas, and coal reserves and a 2 °C policy objective. While not discussed in the 2009 *Nature* articles, rational investors, also, would have considered the potential loss of shareholder value of unburnable carbon (rather than the physical residual carbon) at the company level by discounting the future net value of residual carbon to the present, conditional on their expectations of future firm performance, governmental policies, efforts to mitigate, and technological change. We recognize, however, that investors' response to the subsequent news stories could have been affected by firm-related analyses (e.g., Leaton, 2011), new results such as those based on an extended budget horizon to 2100 (IPCC, 2001; McCollum et al., 2014), an evolving definition of fossil fuel reserves, and possible future short- and long-term policy changes within the horizon that could change the emission budget (and mix of fossil fuels) to meet the temperature change policy objective (Bauer et al., 2013, 2015).

[7] As a possible example of the lagged response hypothesis, Huberman and Regev (2001) document a small positive response to a *Nature* article of November 27, 1997 about a scientific advance in cancer therapy, but it was not until a May 3, 2008 story in the *New York Times* that the breakthrough garnered widespread attention, prompting a much more significant reaction in the next few days.

[8] By potentially affecting the future demand for fossil fuel, unburnable carbon news could increase oil price uncertainty, thereby inducing firms to postpone current investment, which could negatively affect firm value. Effects on firm value from oil price uncertainty, however, can depend on whether future oil prices and firms' output increase or decrease in response to governments' and others' actions to constrain carbon emissions in the fossil fuel sector (Elder and Serletis, 2010; Rahman and Serletis, 2011).