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

by

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Abstract

This paper documents the stock market's reaction to findings reported in a 2009 article in the prestigious *Nature* journal of science reporting 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^{o}C above pre-industrial levels. The *Nature* article is now one of the most cited environmental science studies in recent years. Our analysis indicates that this publication prompted at most an average drop in stock price of 2% for our sample of the 63 largest U.S. oil and gas companies. Later, in 2012-2013, the press "discovered" this article, and then wrote 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 firms from a carbon bubble. Our paper discusses possible reasons for this discrepency.

1 Introduction

On April 29, 2009, 15:15 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^{o}C above pre-industrial levels, it would mean strict limits on the total carbon budget through that date. The latter study went one step further and predicted that to meet such a 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 fuels would be stranded and, therefore, potentially worthless under the climate change scenarios described. At the time, however, the scientists and the media[1] seemingly ignored a key financial implication, namely, that if the climate change scenarios were valid, this could trigger a sharp reduction in energy firms' market value because the reserves shown in their financial statements make up a significant part of that value (Harris and Ohlson, 1987; Qurin *et al.* 2000). For the next several months, both *Nature* papers drew little attention from the financial media and, otherwise, stayed in relative obscurity.[2]

Four years later, 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 larger audience due, in part, to reports by Carbon Tracker (2011, 2013), Spedding *et al.* (2013) (hereafter, HSBC 2013), Redmond and Wilkins (2013), and popular press articles such as McKibben (2012) and *The Economist* (2013). Additionally, Carbon Tracker (2013) has updated the remaining carbon budget from 2007–2050 to 2013–2050 and paints an even gloomier picture for the energy industry. For example, the updated data indicate that the world's listed fossil fuel firms have the equivalent of 1,541 gigatons of carbon 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^{o}C above pre-industrial levels (Carbon Tracker 2013, p.15); and, with present trends, this remaining carbon budget will be spent well before 2050. These more recent figures imply that as much as 85% (1-(225÷1541)) of these firms' proved fossil fuel reserves could eventually be unburnable.[3] In financial terms, the potential cost is daunting. According to HSBC (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

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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.

[3] More recent estimates by the IPCC's Fifth Assessment Report (2013) indicate a world carbon budget of 1,210 gigatons for a greater than 50% chance of temperatures rising to less than 2^{o}C, which is less than the Carbon Tracker (2013) estimate of 1,541 gigatons. Some estimates of the global carbon budget represent the amounts in CO_2 rather than carbon. For purposes of conversion, we use the formula $1C=3.67CO_2$, determined as follows. The atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44 atomic mass units, because it includes two oxygen atoms that each weighs 16. This generates the formula that one ton of carbon equals 44/12 or 3.67 tons of carbon dioxide. The IPCC's estimates, which are lower than Carbon Tracker, also do not include reductions for non-CO_2 radiative forcings, which if included, would make the global carbon budget even lower.

(Carbon Tracker, 2013), this could translate to a substantial wealth loss for these firms' shareholders. The HSBC (2013) report, however, cautions that investors "have yet to price in such a risk, perhaps because it seems so long term."[4]

The question we ask in this paper is when and whether the stock market might have recognized the potential loss of value to energy company shareholders due to unburnable carbon. On the one hand, we might expect rational investors to use all available information in pricing their securities, including significant results from science, in our case, the aforementioned *Nature* articles. Under a rational response view, we therefore predict a measureable 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 as to why capital markets might respond in a biased fashion to potentially adverse news about future returns, for example, based on media inattention (Dyck and Zingales, 2003), investor bias (Welch, 2000; Hirshleifer, 2001; Bernhardt, *et al.* 2006), disclosure proprietary cost (Healy and Palepu, 2001; Verrecchia 2001), and poor communication by scientists (Revell, 2013). These and other explanations offer an alternative hypothesis, which we call the lagged response hypothesis, which predicts an additional and possibly more negative response to the later events than the earlier *Nature* articles. We reason this could occur if the financial and popular media increasingly publicize the earlier scientific result as a newsworthy story and/or investors respond to 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.[5] Both the rational response and lagged response hypotheses encompass the null hypothesis of no response; that is, we might observe no systematic response

[4] Amid these stories about how unburnable carbon might affect oil and gas companies' valuations, over the same time period, public interest also continued to grow around topics such as the role of anthropogenic (man-made) carbon emission in the stabilization of radiative forcing from global temperature increases. Discussions often centered on a desirable target level of global emissions 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 emissions investments, clean technology, and so forth. 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 (to achieve emissions stabilization) such as cap-and-trade (e.g., Spedding, *et al*., 2008) and (b) the nature of the transformation of the energy sector worldwide under a global agreement to cap carbon emissions (e.g., the annual publications of the International Energy Agency, most recently, *World Energy Outlook*, 2013). Some early press reports also used the term "unburnable carbon", although this was mostly in the context of proposals to reduce carbon use consistent with a desired level of global CO_2 concentration in order to limit global warming (e.g., http://news.bbc.co.uk/2/hi/science/nature/7287572.stm). On the other hand, the term is seldom found in the scientific literature on climate change. 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 produced the result "no items found" (http://www.tyndall.ac.uk/biblio).

[5] 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.

to news and events relating to unburnable carbon regardless of the sequence of the news or events, possibly because of the uncertain and long-term nature of the increased risk or because of offsetting benefits ignored or underemphasized by the news media.

The stock market's possible recognition of unburnable carbon as a valuation factor is important for several reasons. First, it is important to understand how and when significant results from science might eventually be reflected in stock prices, since a delay or miscommunication could suggest profitable arbitrage opportunities. Second, it is important to understand the role of the media regarding unburnable carbon, for while it may be a compelling story with worrisome implications for many, rational investors consider all potential future scenarios, some of which would have offsetting effects on company value; for instance, those resulting from governments' energy policies to lower the costs of carbon capture and sequestration and CO_2 enhanced oil recovery and/or require firms to internalize the costs of carbon in other ways. Changes in firms' plans and strategies designed to mitigate the risks associated with unburnable carbon, such as by investing in more profitable alternative energy sources with lower emissions and/or adopting more informative risk disclosures, could also have offsetting effects. In addition, rational investors would consider the potential for, and possibly exploit, any significant media bias. Should our results contradict the arguably dire predictions in the popular press, this suggests that findings of a stock price reaction might offer an evidence-based counterbalance to some media scenarios that infuse more emotion and politics into climate change findings than perhaps is appropriate or reasonable.[6]

To test our hypotheses, we examine oil and gas firms composing the *Datastream Energy Index*. This index consists of 72 U.S. firms in the Global Industry Classification Standard code 10120 (comprising the sub-codes Integrated Oil and Gas, and Oil and Gas Exploration and Production). The constraint that we require stock price data from CRSP for the study period reduces this sample to 63 oil and gas firms whose stocks trade on the major U.S. exchanges. Our data show that these firms are the largest oil and gas firms in the United States, and most disclose significant oil and gas reserves in their financial statements. Of all U.S. oil and gas firms, these should be the most exposed to redundant reserves and, hence, to the risk of

[6] For example, McKibben (2012) writes: "We know how much we can burn, and we know who's planning to burn more. Climate change operates on a geological scale and time frame, but it's not an impersonal force of nature; the more carefully you do the math, the more thoroughly you realize that this is, at bottom, a moral issue; we have met the enemy and they is [sic.] Shell."

unburnable carbon. Based on this sample, we test our hypotheses by focusing on the relationship between energy firms' daily excess stock returns and news stories about unburnable carbon.[7]

We start with the BBC's April 29, 2009 story about the *Nature* studies (also reported on the same day as a Dow Jones News Service environmental capital blog) and then use Factiva to identify all news items through May 31, 2013 that might reasonably relate to unburnable carbon based on key words and phrases (listed in section 3).[8] We identify numerous other events and factors that might help us calibrate investors' response to news about unburnable carbon, such as earnings announcements, SEC filings, and news about a proposed carbon tax. As additional factors, we further control for changes in crude oil prices and use the number of energy industry news stories unrelated to unburnable carbon on the same day as an overall measure of information intensity. As discussed in section 3, our event study approach faces some unique challenges, in particular, the feature that we study news stories (e.g., the *Nature* articles) common to all energy firms; so when we control for changes in crude oil prices and energy news in general we may be removing some of the effects we seek to detect. With too few controls, we may incorrectly attribute a price response to events about unburnable carbon when none in fact occurred (type 1 error); and with too many controls, we may incorrectly conclude a lack of response to unburnable carbon events when one in fact may have occurred but is obscured by the controls (type 2 error).

Our analysis produces the following key results. First, we find a statistically significant negative abnormal stock price response in the three-day window around the *Nature* publication date. Because we control for oil price changes and observe a low intensity of other crude oil and natural gas stories in the same three-day window, this event should reflect a low type 2 error, namely, that information unrelated to the *Nature* publication might explain the result. However, we also find positive abnormal stock returns over days -1 to 10, so that the apparent initial negative reaction to the *Nature* article is not sustained over the next two weeks, although such a lagged response could be due to unrelated information. Second, while we do not find a statistically significant negative abnormal stock price response in the three-day window around all subsequent news stories about unburnable carbon, the mean excess return in response to these

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[7] We compute excess returns based on the Fama and French (1993) model, which adjusts daily raw stock returns for risk premia from the market as a whole (*Mkt-RF*), company size (*SML*), and expected earnings growth (*HML*).

[8] We choose the cutoff date of May 31, 2013 as it follows the end of the first quarter of 2013 by two months, by which time most of the popular press stories tied to the original *Nature* articles had been written. While additional stories appeared after that date, these were mostly follow-ons to those appearing one or two years earlier. Section 3 provides more detail.

subsequent media stories is significantly negative over days -1 to 10, and such delayed negative reaction decreases further for firms with proved reserve disclosures in their financial statements. This is what we would expect because proved reserves store much of the unburnable carbon.

The three-day price reactions to unburnable carbon news are limited economically, however. For example, based on the coefficients from a regression analysis, the price reactions aggregate to a shareholder loss of $27 billion or 2.48% of total market capitalization of our sample of 63 large U.S. oil and gas firms. This small but detectable market response stands in contrast with the prediction of some analysts and commentators of a substantial decline in the shareholder value of fossil fuel firms from stranded carbon (e.g., HSBC, 2013). We also find it interesting that one of the most cited environmental science studies in recent years seems to have had only limited sway with energy company investors, at least those who invest in U.S. oil and gas stocks, and regulators tasked with improving company disclosures about the risks of climate change for balance sheet valuations (e.g., SEC, 2010). Later sections discuss explanations for this result.[9]

Our paper proceeds as follows. Section 2 identifies the prior literature and develops the main testable predictions for analysis. Section 3 describes the sample and data. Sections 4 and 5 summarize the results and sensitivity tests, respectively. Section 6 concludes and discusses limitations. An appendix defines the variables used in the analysis and states the data sources.

2 Prior literature and research hypotheses

Despite a plethora of stock market studies on a wide range of news events and announcements (see Beyer *et al*., 2010 for a review), surprisingly absent are findings on investors' reaction to breakthrough publications in science. Some scientific journals document major discoveries with important implications for capital allocation and investors' returns. Yet the market's response could be quite limited if science does not communicate well, perhaps because the researchers have few incentives to do so or wish to keep the results confidential. In addition, results-oriented investors may have little interest in discoveries that have uncertain payoffs, as the present value of the distant and uncertain cash flows from (optional) future investments would be small relative to the present value of current operations. For example, Huberman

[9] An alternative analysis would consider the overall effect on oil and gas companies' stock prices of unburnable carbon under assumed climate change scenarios; and several studies take that approach (e.g., Ansar, *et al*. 2013). We do not take that approach in this paper as our focus is on the, arguably, lethargic propagation of the unburnable carbon finding, initially in the 2009 *Nature* publication, to its later more widespread, public recognition in 2012-2013.

and Regev (2001) document a relatively limited three-day increase (of $3.375) in Entremed's stock price around November 28, 1997, when *Nature* published an article on the discovery of a cancer-curing drug by that company. It was not until May 4, 1998 that the stock price jumped dramatically, over a few days. by $39.75 (from $12.06 to $51.81) following a *New York Times* story, which then triggered considerable additional media attention. Huberman and Regev (2001) conclude that this later response was an overreaction, as the *New York Times* article used the same information as in the original *Nature* article.[10] That study, therefore, documents an initial response, which the authors describe as rational, followed by an overreaction from increased media attention.[11] On the other hand, the stock market might overreact to an initial scientific result, perhaps with the help of the media, and correct itself later based on a more rational and complete assessment of the evidence. For instance, Hill *et al.* (1991) document that a Utah university news conference on March 23, 1989 announcing that scientists had produced sustainable energy from cold fusion increased palladium prices by 25% over announcment days -2 to 14 following a worldwide media frenzy. Those prices, however, dropped to pre-announcement levels in the next few months as the impossibility of limitless energy from low temperature nuclear fusion became evident through additional and more credible channels. In other words, with the cold fusion announcement, we observe the opposite of the prior study, that is, an initial overreaction to the science news (spurred in this case by unprecedented media attention) followed by a more reasoned analysis of an expanded array of evidence.

Given these studies, what might we expect about investors' response to the *Nature* articles on unburnable carbon? Since Factiva shows that the initial articles triggered only limited attention in the popular press, this might suggest the rational response hypothesis (H1), namely, that we should observe a limited but negative investor reaction, and not a biased one or an overreaction potentially inspired by media attention. On the other hand, because of increasing interest in unburnable carbon by the financial and popular media beginning in 2012, much of which predicted dire consequences for the fossil fuel industry, we might expect a stronger media-driven negative response to these later stories, even though they might have added little new information to the basic results from science. Such a response would be consistent with the delayed response hypothesis (H2) and the results reported in Huberman and Regev (2001) and Tetlock (2007). However, the delayed response hypothesis assumes myopic behavior on the part of

[10] Entremed's stock price eventually dropped to $24.875 on November 12, 1998, when it became known that other laboratories could not replicate the original *Nature* result.

[11] See, Dyck and Zingales (2003), Tetlock (2007), Barber and Odean (2008) and Fang and Peress (2009) for studies that document evidence of media bias in pricing stocks.

investors, as they focus on news stories only (which tend to be highly correlated) rather than a broad array of information, including information from firms and governments regarding their actions and policies undertaken or intended to be undertaken, in this case, to mitigate the impact of unburnable carbon. For example, rational investors might consider not only governments' possible policies that provide for carbon capture and sequestration or require firms to internalize the costs of carbon but, also, the effects of changes in firms' plans and strategies designed to mitigate the risks associated with unburnable carbon, such as by investing in more profitable alternative energy sources with lower emissions or by expanding the information set, for instance, through more informative risk disclosures in published financial reports.[12] To the extent that these plans, strategies, and government actions have offsetting effects on shareholder value, we would expect a less negative response under the delayed response hypothesis, although media bias (Groseclose and Milyo, 2005; Green, *et al.* 2012) suggests that we would not expect the press to discuss the full array of offsetting factors, so some bias may still occur. Finally, we entertain a third possibility of no reaction to either the initial publication or the later news stories, which essentially is the null hypothesis for H1 or H2. It could be entirely rational, for example, for investors to register no reaction to the initial and later news about the effects of unburnable carbon if they were to expect full mitigation from future governmental policy and/or by corporate action.

3 Sample and data

Table 1 summarizes the sample and news stories. We start with 72 oil and gas firms comprising the *Datastream Energy Index* and then select firms registered with the SEC and with stock price and financial data available from Datastream and Compustat, respectively (63 firms). Next, we use Factiva to identify 246 print media stories on 142 days relating to unburnable carbon by using the following search terms: unburnable and bubble, two degrees celsius (2ºC), 560 or 450 ppm (parts per million), 565 gigatons, 2,795 gigatons, Meinshausen, Carbon Tracker, and HSBC and carbon bubble. We then eliminate stories on weekends since we cannot ascribe a daily stock price reaction to those days. This produces a final sample of 88 unburnable carbon news stories by 59 different print media sources. Apart from the initial *Nature* publication in April 2009, all but one of the remaining stories occurs between March 23, 2012 and March 5,

[12] For example, with carbon capture and sequestration (CCS), energy firms could benefit in at least two ways by recycling their captured emissions from current production: (1) by lowering the current cost of enhanced oil recovery (National Energy Technology Laboratory 2010, pp. 13-20) and (2) by exploiting tax benefits for CCS as part of a national energy policy (Global CCS Institute, 2013).

2013 (our cutoff date). Because much else could be disclosed each of those days, we control for other information in our formal tests of the investor response hypotheses (section 4).

[insert table 1 here.]

As an initial descriptive analysis, figure 1 compares the distribution of unburnable carbon news stories with all news stories over days -1 to 1 around the event dates relating to crude oil and natural gas markets, also extracted from Factiva (search details available on request). Other than a large spike on April 11, 2011 (840 news stories), this figure shows that most media interest in unburnable carbon occurred after March 2012 and increased through early 2013. While the April 11 spike appears to relate primarily to oil and gas company or energy industry news in general, this newsday was also dominated by worldwide attention to an unpopular proposal by the Australian government for a corporate carbon tax (116 stories on April 11), which could swamp any negative effects of references to unburnable carbon on the same day.[13] So, hereafter, for convenience, we refer to April 11, 2011 as a carbon tax news story rather than an unburnable carbon story. On the other hand, unlike the unburnable carbon stories, which increase in frequency, figure 1 shows that crude oil and natural gas news stories reflect a more stable pattern. Note, also, the small number of crude oil and natural gas stories around the date of the initial *Nature* publication, which means that this event should have low potential for contamination by other oil and gas stories on the same day (low type 2 error).[14]

[insert figure 1 here.]

Table 2 provides additional summary statistics for the sample based on quarterly observations over fiscal years 2008-2012. As expected, our sample consists of large (mean total assets = $18.6 billion), profitable (mean earnings per share = $1.00), and productive firms (mean sales to total assets = 0.18). Investors also view these firms as riskier than most because of higher market risk (mean beta from Research Insight =1.44) and financial leverage (mean debt to equity ratio = 0.82). Additionally, we observe that the sample appears well governed (mean governance score = 73.20%) but ranks low on environmental performance (mean environmental score = 32.57%). Clearly, we study a non-random

[13] We include this highly newsworthy and negative news event in the regression analysis as it helps us benchmark the impact of the more focused unburnable carbon stories occurring in 2012-2013.

[14] We also used directEDGAR to conduct a search of the SEC filings of our 63-firm sample based on the same search terms used to search Factiva for news stories. Interestingly, this search indicated that no companies had such disclosures. As such, we are reasonably certain that despite a possible risk of unburnable carbon for oil and gas firm asset values on the balance sheet or in supplemental disclosures, these companies assumedly deemed that the implications of unburnable carbon did not rise to the level of a material disclosure.

sample, in this case, a set of large U.S. oil and gas firms with higher than average market risk. However, as we indicated at the outset, these firms should disclose significant uptapped oil and gas reserves in their financial statements, and this means a higher likelihood that company stock price might be affected by investors' perceptions of the likely consequences of unburnble carbon and not other factors (reduces type 2 error). We also test the notion that the stock price reaction to the events we study differs for firms with disclosed reserves versus undisclosed reserves (e.g., energy firms not involved in oil and gas exploration activities).

[insert table 2 here.]

4 Results

Table 3 summarizes the excess returns from a cross-sectional regression of R_j on *RF*, *Mkt-RF*, *SMB*, *HML* (Fama and French, 1993), and percentage change in the spot price for crude oil (Chen, *et al.* 1986) over event days -10 to 10, where day 0 is one of three news story publication dates: April 30, 2009 (*Nature* publication date), April 11, 2011 (first post-*Nature* unburnable carbon mention but dominated by carbon tax news), and all unburnable carbon news stories in 2012-2013 as described in section 3.[15] We also show the same data in figure 2, except that here we cumulate the excess returns from day -1 to t, where t runs from day -1 to 10. Under the rational response hypothesis, we expect a negative stock price reaction coincident with the news event after controlling for those channels (e.g., print media) that might have accompanied dissemination of that news event to investors. First, we observe mostly negative mean excess returns on days 0 and 1 for all three events. Second, except for the *Nature* publication, the cumulation of day -1 to t mean excess returns for the 2012-2013 stories is more negative for firms with reserve disclosures, which is what we would expect given that this news relates to unburnable carbon over a broad cross-section of event days. In other words, descriptively, the data suggest that a possible negative market reaction related to unburnable carbon occurs on days 0 and 1. However, in the case of the *Nature* publication and the April 11, 2011 carbon tax event, much other information could be affecting the excess returns, especially over days 3 to 10. Recall that these are one-off events and our research design does not randomize the effects of these news items. We correct for this aspect of our research design by introducing additional controls into the excess returns calculation, which we do in two ways.

[insert table 3 here.]

[15] This regression is shown as equation 1 in the appendix.

The first way conducts a cross-sectional regression in event time (time *t* is relative to an event date), where we focus on two narrow windows, namely, day 0 and days -1 to 1, and control for energy company news on those same days, as such factors might also drive investors' returns. Specifically, for each sample company, we select four proxies for the intensity of other information available to investors based on the number of Dow Jones newswire stories from Factiva relating to (a) crude oil and natural gas markets, (b) corporate news generally, (c) earnings, and (d) analysts'comments and recommendations. While this is not a complete set of other information, these data cover arguably several significant drivers of stock price, especially earnings and analysts' news. Our basic model also controls for changes in oil prices, another driver of energy company stock returns.[16]

Table 4 presents the results under the event-time approach, which we summarize as follows. Each of the Fama-French factors (*RF*, *Mkt-RF*, *SMB*, *HML*) and *PercentageChangeOilPric*e significantly explain daily stock returns. For example, regression 1 shows an average *Mkt-RF* coefficent of 1.31, which is approximately the same as mean *RBETA* in table 2 (of 1.44); and regressions 1-6 show sensitivities of stock return to oil price changes (oil price "beta") of about 18 to 24%, which are also highly significant. In addition, regressions 3 and 6 of table 4 mostly show that energy company stock returns relate in a very minor way to the intensity of news stories in each of the four Factiva news categories. Moreover, the nine contol variables in those regressions capture as much as 30% of the variation in energy company stock returns (apart from the potential effects of news about unburnable carbon).

[insert table 4 here.]

We now comment on the test variables. First, we observe significantly negative coefficients for the *Nature* publication variable (*NaturePublicationDum*), which range from -0.0147 (regression 1) to -0.0202 (regression 6) with p-values of less than 0.001. As this is a dummy variable, the coefficient represents the incremental percentage change in energy company stock price (from -1.47 to -2.02%) after controlling for all other factors, including coincident news. Second, the news stories on April 11, 2011 – which are almost exclusively about the possibility of a corporate carbon tax – show significantly negative coefficients for (*CarbonTaxDum*), which range from -0.0050 (regression 3) to -0.0097 (regression 6) with p-values of less than 0.001 Thus, our regression analysis confirms that an event which we would expect to negatively affect energy company stock prices does that. Third, focusing on the three-day window, we find negative

[16] This regression is shown as equation 2 in the appendix.

coefficients for firms with proved reserve disclosures (*ProvedReserveDum*) (regressions 5 and 6); and when we interact the April 11, 2011 news stories with a dummy variable, which equals 1 for firms with reserve disclosure and 0 otherwise (*CarbonTaxDum*ProvedReserveDum*), the coefficient for this interaction effect is also significantly negative (regression 6). This is consistent with the notion that the negative effects of unburnable carbon and a possible carbon tax increase the effects further for firms with proved reserve disclosure versus those without. Fourth, we show mostly negative but insignificant intercept coefficients. This is a residual effect over all unburnable carbon event days not explained by the regressor variables. However, to the extent that we capture the effects of unburnable carbon and other price sensitive news with our regressor variables, we would not expect this to be significant. Finally, we note the number of observations for regressions 1–3 derives from the sample of 63 firms times 85 event dates. The numbers are smaller for regressions 4–6 due to missing observations for some variables.

Table 5 presents the results under the calendar-time approach (time *t* is a calendar day), which is our second way to analyze the unburnable carbon events.[17] Here we widen the window to include all trading days from December 16, 2008 (90 trading days prior to the Nature publication) to March 5, 2013 (end of the study period) and include dummy variables to indicate the presence of an event on calendar day *t* potentially related to unburnable carbon, which can be common for all sample firms (e.g., the events in table 4) or unique at the company level and/or for subsets of the sample. This approach also includes the Fama-French factors (*RF*, *Mkt-RF*, *SMB*, *HML*) and *PercentageChangeOilPric*e as common factors that may affect firms differentially on each trading day. This approach also allows us to include several other test or control variables, such as earnings announcements and analysts' comments (different days for each company), longer window responses to unburnable carbon news (days -1 to 5 and days -1 to 10), and company characteristics that differ over time and across firms (size, environmental performance, SEC filing dates, etc.) that otherwise might influence the market's response to unburnable carbon news. This approach also has the advantage that the statistical tests of whether an unburnable carbon event has a significant impact on stock prices use the entire time series to infer the regression coefficients rather than only those days on which an event occurred.

[insert table 5 here.]

[17] This regression is shown as equation 3 in the appendix.

Table 5 offers several observations. First, the Fama-French coefficients are broadly similar to those in table 4. For example, the coefficients on *Mkt-RF* approximate 1.25 (versus 1.12 to 1.45 in table 4); and the oil price betas for *PercentageChangeOilPrice* approximate 0.25 (versus 0.19 to 0.24 in table 4). Second, several of the control variables are significant in the expected direction. The coefficient for *LOGTA* is significantly negative (larger firms reflect lower returns); the coefficient for the intensity of earnings news (*QE-1to1*) is significantly positive (higher intensity of earnings reports associates with positive news); and the coefficient for *ENVSC* is also significantly positive (better environmental performance associates with positive stock returns). Third, similar to table 4, the April 11, 2011 event (*CarbonTaxDum*) is significantly negative but the interaction with *ProvedReserveDum* is not. Fourth, we observe significantly negative coefficients for *NaturePublicationDum*, which exceed negatively the coefficients for *CarbonTaxDum*. These coefficients are less than those in table 4, however, because of the additional controls in the model. We also find negative coefficients for *OtherNewsDays-1to5* and *ProvedReserveDum*, but these are not significant. However, when we extend the news event period to -1 to 10 days, the coefficients for both *OtherNewsDays-1to10* and *OtherNewsDays-1to10*ProvedReserveDum* are significantly negative. For example, regressions 4, 5, and 6 show that the combined effect on stock price of *OtherNewsDays-1to10* and *OtherNewsDays-1to10*ProvedReserveDum* is -0.29%, which while statistically significant is economically quite small. Hence, rather than an immediate response to the 2012-2013 news stories, these results suggest a small, delayed response to the 2012-213 news stories that mainly occurs over 10 days following publication. This response is also predictably more negative for firms with disclosed reserves. Panel C of figure 2 shows the same result based on Fama-French excess returns without adjustment for the control variables in the regression model.

[insert figure 2 here.]

In sum, as with the previous table, table 5 shows a significant negative reaction to the *Nature* story but no similar initial response to the later (2012-2013) unburnable carbon news stories. However, we do find evidence of a statistically significant delayed reaction to the 2012-2013 stories in the next two weeks following their publication (*OtherNewsDays-1to10*), although that delayed response is economically quite small. In other words, while the evidence supports the delayed response hypothesis (H2), we also find relatively small negative excess returns over days -1 to 10; and these negative returns differ predictably on the basis of disclosure of proved reserves in the financial statements (*OtherNewsDays-1to10*ProvedReservesDum*).

Our last table summarizes the economic significance of these results. Specifically, table 6 shows the aggregate and per company change in market capitalization at the time of the unburnable carbon news stories based on the mean excess returns over days -1 to 1 or days -1 to 10 from a market model (columns 1 and 2) and a Fama-French model including daily percentage change in oil prices (columns 3 and 4), calculated as market capitalization times the excess return percentage.[18] The table also splits firms by those with and without oil and gas reserve disclosures. Panel A uses the data from table 3. For example, we find mean three-day Fama-French excess stock returns of -2.81% and -0.54% around the *Nature* publication, -3.24% and -2.66% around the carbon tax story, and -0.80% and -0.66% around other news stories for non-reserve and reserve disclosure firms, respectively (panel A). Panel B summarizes the percentage change in the total market capitalization for the 63-company sample. Aggregate market capitalization drops by $7.1 billion, $29.2 billion, and $7.3 billion around the *Nature* publication, the carbon tax news, and the other 2012-2013 unburnable carbon news stories, respectively; so that based on the Fama-French excess returns from table 3, our energy company sample loses about $43.6 billion of market capitalization. However, the amounts in table 3 could overstate the shareholder loss because the excess returns shown do not remove the effects of other information. When we use the equivalent measures from the regression analysis in table 4 (based on regression 6), panel D shows an equivalent loss of market value of $27.1 billion (or $429 million per company based on the sample average). This shareholder loss represents 2.48% ($27.1 billion÷$1,088.6 billion) of the total market capitalization of these firms; and as shown in figure 3, this relates primarily to the *Nature* news event ($22.0 billion).

[insert table 6 and figure 3 here.]

5 Additional analyses

Because we analyze all media stories about unburnable carbon (identified through Factiva) over the 2009–2013 period, we essentially examine the entire population of news stories potentially relevant to investors' assessments of energy firms' market value. This means that the regression coefficients show the average response coefficients for this sample over the study period, and do not generalize to other

[18] Because each media release essentially views the original *Nature* publication as the genesis of its story, we treat each release in statistical terms as a separate "drawing" about the potential economic effects of unburnable carbon on energy company stock prices, rather than treating each media story as adding new information.

industries or sectors. However, from the perspective of studying a population, some contend that researchers should refine their analysis when they study common events, because company A's response to an event on day t may not be independent of company B's response on event day t, especially if A and B operate in the same industry. When events cluster on common dates, this can reduce the number of independent residuals in the regression, which is an assumption of the test statistics we use. At the extreme, even though we might observe 63 different stock price responses on 85 different days (63 x 85 = 5,355 observations), that could also equate to one response for 63 related firms on 85 days. As a sensitivity test, we estimate the regressions in tables 4 and 5 based on standard errors for coefficient significance that adjust for clustering. Untabulated analysis shows that when we cluster at the company level (extreme clustering), none of the test statistics for the unburnable carbon news stories is significant at $p<.05$, although we would expect this given that the effective number of excess return observations for each event date is one (not 63). However, when we cluster by asset quintile or reserve disclosure quintile (which is a less extreme way to partition the excess return observations into potentially unrelated groups), the coefficients for *NaturePublicationDum* in tables 4 and 5 and *OtherNewsDays-1to10* in table 5 continue to be negative and significant (at $p<.05$).

We also face a design issue when some events cluster in time, namely, day t could be day 0 for event X and, say, day -2 for event Y for the same company. With overlapping days, under the event day or calendar day approaches, this creates spatial correlation in the regression residuals, which can also influence the regression standard errors. To avoid overlap, we make an assumption about an event a particular day might relate to. Given an overlap, we could assign the minimum event day to day t (day -2 in the example above) or the maximum event day to day t (day 0 in the example above). The regressions in table 5 adopt the minimum event day assumption. However, we obtain similar results for our regression test variables when we adopt the maximum event day assumption (details available on request). The results in table 5 are also robust to the inclusion of additional event dates, such as 8-K and 10-K filings, company attributes such as corporate governance, and different classifications of media news intensity based on filters available through Factiva. We also estimate the regressions in tables 4 and 5 after replacing the interaction variable *CarbonTaxDum*ProvedReserveDum* with *NaturePublicationDum*ProvedReserveDum*. Untabulated results show that while the coefficient sign for this variable is positive, it is not significant. Hence, unlike *CarbonTaxDum* (and *OtherNewsDays-1to10*), the negative coefficient for *NaturePublicationDum* in tables 4 and 5 is not statistically more negative for firms with disclosed reserves.

6 Conclusions and discussion

The news stories in the popular and financial press about the effects of unburnable carbon on fossil fuel firms that began in 2012 and peaked in the first quarter of 2013 paint a grim picture by contending that a significant portion of energy companies' proved oil and gas reserves – one of the largest components of their market value – could be stranded as unburnable and, hence, potentially worthless. However, as alarming as some of these reports may be, they only suggest but do not use market-based evidence to demonstrate an impact on energy company shareholder value. Most refer to one or both scientific articles published in *Nature* in April 2009 (Allen, *et al.* 2009; Meinshausen *et al.* 2009), which used climate change simulations to predict how much remaining carbon could be burned so that the average global temperature increase would not exceed a threshold such as 2^{o}C above pre-industrial levels (measured over the 1861-1880 period). Whereas, at the time, these articles drew little notice in the public media and garnered few citations by fellow scientists, four years later, Meinshausen *et al.* (2009) now rates as one of the most influential science articles in recent years, according to Thomson Reuters' *Web of Science*.

This paper studies whether the stock market recognized the significance of the Meinshausen findings contemporaneous with the *Nature* publication and/or whether the market might have responded later, and perhaps biasedly, in conjunction with heightened media attention. For the *Nature* publication, we show results more consistent with the rational response hypothesis (H1), namely, that despite the relative obscurity of the *Nature* article, stock prices declined by 1.5% to 2.0% (depending on the model to estimate expected stock returns) over days -1 to 1 around the April 30, 2009 publication date. This change, while negative, stands in contrast to the claims of some of a substantial potential loss of energy companies' shareholder value. As one report surmised "the value at risk from unburnable reserves would be equivalent to 40-60% of the market capitalization of affected companies." HSBC (2013). From a research design standpoint, the relatively small number of news releases around April 30, 2009 also means that we can more likely link the -1.5% to -2.0% stock price response to information in the publication rather than media bias. Such bias, if any, would have been predictably small, as research indicates that the least media bias occurs for low visibility events relating to firms with high public information availability (Dyck and Zingales, 2003).

We then test for a reaction around the dates of the news reports in 2012-2013, which could be biased, as the later press stories introduced little new information beyond the *Nature* article; or an unbiased rational response to new information, for example, because new analysis made it clearer which energy firms faced stranded carbon assets and/or updated the global carbon budget for certain levels of temperature change. Our results for the press stories are more consistent with the former view of the reaction, as they show no stock price movement – positive or negative – in days -1 to 1 but, rather, a delayed negative reaction over the next 10 trading days. We tested for a reaction on day 0, days -1 to 1, and days -1 to 10 (allowing for a multi-day response) and whether the reaction might be more negative for firms with significant reserves and found a systematic negative relation that increased in signifiance for the longer event window. However, while negative, this evidence does not support the predictions of many that recognition of unburnable carbon might prompt a significant and substantial reduction in the shareholder value of fossil fuel firms, although it does suggest that the media may have contributed to a limited negative reaction over the next two weeks.

Thus, unlike the cold fusion announcment, which prompted substantial media-inspired initial overreaction followed by rational correction (Hill, *et al.* 1991), or the Entremed reaction, of an initial rational response followed by a substantial media-inspired reaction to essentially no new information (Huberman and Regev 2001), our evidence is most consistent with a rational investor response around the *Nature* event followed by a small delayed reaction around the later news stories. As a way to benchmark these results, we also analyzed separately a large number of Factiva mentions on April 11, 2011 about proposals for a corporate carbon tax, which occurred prior to the spate of unburnable carbon stories in 2012-2013. Regarding this event, we expected and found a significant negative reaction of about -0.5% to -0.97% to this news (depending on the model), which also associated significantly negatively in firms' disclosure of oil and gas reserves (premised on the view that the greater those reserves the higher the expected carbon taxes).

Why might we have observed only a limited negative stock price reaction to the scientific results that McKibben (2012) concludes "add up to global catastrophe" and that, also, have sparked considerable interest in campaigns for institutions to divest themselves of fossil fuel companies (e.g., Ansar, *et al.* 2103)? Many others have issued similar ominous assertions, such as "fossil-fuel investments are destined to lose their economic value."[19] We offer several explanations for this result. While none is entirely new, the collective views of energy company shareholders and investors as expressed through stock price changes provide an important counterbalance to the mostly one-sided predictions of the popular and financial press, in particular, those that espouse a carbon pricing bubble.

First, investors would consider alternatives such as the use of carbon capture and sequestration (CCS) (Global CCS Institute, 2013) and CO2 enhanced oil recovery (EOR) (National Energy Laboratory, 2010) which could be beneficial for unburnable carbon (e.g., assuming sufficient prices for carbon and oil and gas) by allowing fossil fuel use (e.g., by power companies) to continue by removing and storing carbon emissions from the extraction process (CCS) (Elliot and Celia, 2012) or by injecting the carbon underground as a well stimulation technique (EOR). While these technologies increase the costs of extraction, the added production expense is generally immaterial to profitability on the basis of net present per barrel value except under very low oil price scenarios. The oil industry itself remains optimistic that it will be able to continue to extract its reserves profitably using CCS technologies.[20] There are also indications that some governments could share a proportion of the cost for CCS. In Canada, for example, which would not like to see its massive oil sands reserves wind up as stranded assets, government subsidies may cover up to 65% of the $1.35 billion costs to add CCS regarding a Royal Dutch Shell, Chevron, and Marathon Oil joint oil sands production project.[21] Similarly, investors would consider the potential for energy firms to invest profitably in alternative, less carbon producing forms of energy production, such as wind, solar, and improved fossil fuel technologies.

Second, investors would anticipate governments' national energy policies, which might provide economic incentives in the form of tax reductions and rebates for firms to internalize the cost externalities

[19] http://online.wsj.com/news/articles/SB10001424052702304655104579163663464339836.

[20] In its 2010 World Energy Outlook, the International Energy Agency (2010) notes that "cutting emissions sufficiently to meet the 2 degrees C goal would require a far-reaching transformation of the global energy system." However, the agency forecasts that "carbon capture and storage (CCS) plays an important role…" in such scenarios, especially in the power generation sector. Specifically, under its 2 degrees scenario, the IEA estimates that CCS will provide 14 % of cumulative emissions reductions between 2015 and 2050 compared to a business as usual scenario. Under the 2 degrees IEA scenario, CCS represents one-sixth of the required reduction in emissions from fossil fuels in 2050. Globally, approximately $23.5 billion in public support has been made available for CCS demonstration. Finally, Vuuren et al. (2010) include CCS as one of several mitigation options that play an important role in reducing the probability of temperatures from rising more than 2^{o}C.

[21] Royal Dutch Shell, Chevron Corp. and Marathon Oil have announced a $1.35 billion Quest CCS project that will gather carbon dioxide emissions from an oil sands upgrading project in Canada and pipe the carbon to a site 80 kilometers away for storage underground. Government subsidies will cover the majority of the project cost, with the industry partners covering only $485 million of the cost of construction of the CCS facilities. Over a 25 year period, Quest will cost $72 a ton for the carbon it stores.

of unburnable carbon; although given the high requirement for mobility and the difficulty of quickly replacing hydrocarbon-based fuels in transportation, the timing of when governments might respond to scientific information about climate change and implement strict carbon restrictions on oil remains uncertain. But regardless of whether governments impose tax costs or offer benefits, the longer it takes governments to organize policies aimed to restrict or replace the use of carbon-based fuels, the smaller the impact such policies would have relative to today's stock prices for oil companies. In pricing energy stocks, rational investors would also generally have difficulty in projecting future energy prices (which can be highly uncertain) and, thus, it is reasonable to suppose that many investors would be reluctant to make substantial portfolio adjustments based on the modeling of uncertain price competition points for various energy commodities. In short, in the presence of future and uncertain net costs or benefits well into the future, the present value of such future amounts can be quite small relative to the present value of current or near term operations.[22]

Third, investors would be skeptical about whether the demand for oil can actually be pared back within an economically meaningful horizon, regardless of the need to lessen carbon emissions; and may be assuming that more carbon reduction or stranding will come from less clean alternatives such as coal. For example, the International Energy Agency (2013) forecasts that oil demand will rise to 99 million barrels per day by 2035, up from 87 million in 2010, with almost all of the net growth coming from the transport sector in emerging economies. Over 90% of all fuel used in the transport sector is petroleum-based. Moreover, to date, there are few commercially available substitutes for petroleum based fuels for vehicles; and those that exist, mainly biomass, electricity, and hydrogen, are not in wide deployment. This reality renders the demand for oil relatively inelastic in both the short and medium term; and a transition to other non-oil fuels would take decades. The EIA, for example, anticpates that road transport for freight and personal mobility will be responsible for 75% of future oil in transportation use, and the global passenger vehicle fleet is expected to double in the coming decades to 1.7 billion by 2035 (International Energy Agency, 2011).

A fourth possible explanation for the limited impact could relate to investors' dearth of information in companies' financial statements. In the United States, the SEC (2010) requires all material risks and

[22] This horizon issue may also explain the limited impact on stock price of divestment campaigns, which research suggests associates with little permanent impact on target company valuations. See Ansar *et al.* (2013) for a review of this literature.

uncertainties to be disclosed about climate change. Yet after taking a comprehensive search of the most recent 10-K filings of the firms in our sample, we could find no mention of unburnable carbon or an equivalent phrase (based on the same search terms used to search for news media articles in Factiva). Proposals by private-sector groups for climate change risk disclosures in financial statements related to stranded assets (e.g., Asset Owners' Disclosure Project, http://aodproject.net, Institutional Investors Group on Climate Change, http://globalinvestorcoalition.org, Carbon Asset Risk Initiatve, http://www.ceres.org), however, may change the present disclosure imbalance.

A final possible explanation for the limited stock price impact relates to the effects of potential media bias, which prior work suggests should be small, as energy stocks are largely held by institutional investors, trade in efficient markets, and their prices reflect a wide range of investment strategies with relatively few constraints. Our results are consistent with this view, as they show a small but detectable delayed reaction.

We cannot rule out the possibility of a carbon bubble, however, as market prices in the past have grossly deviated from the underlying fundamentals, as in the case of the dotcom bubble of 2000 (Olek and Richardson, 2003) and earlier espisodes. Drastic action by governments and regulators such as a prohibition on fossil fuel production on a global basis, or the imposition of a very strict cap on global carbon emissions within the framework of a truly workable carbon market, might be two such long-tail events that could burst this potential bubble.

The results expressed in this paper are not without limitations. First, the effects we document do not extrapolate to global energy markets, as we study only U.S. oil and gas firms, which hold only a fraction of the world's unburnable carbon. The large majority is held in coal reserves or in reserves owned by central governments or national oil companies (up to 80 perecent by some estimates), whose stakeholders and profit incentives differ greatly from those of the U.S. companies we study (Jaffe and Soligo, 2010). In addition, we may have underestimated the impact of unburnable carbon news, as our models of abnormal change in stock price extract the influence of market returns, crude oil price changes, and news events about the crude oil and gas markets generally, all of which could reflect some anticipatory and antecedent impacts about how unburnable carbon might affect shareholder value. Lastly, while we document the average response effects of unburnable carbon on U.S. fossil fuel firms based on past and present events, those effects may not generalize to future news stories, as today's events could change tomorrow's government policies and firms' investment plans in ways that even a crystal ball could not anticipate.

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Appendix

Panel A: Definition and source of variables used in the analyses

Variable	*Description*	*Source*	*Mnemonic*
ANALYST	=1 if analyst comment or recommendation on day t, otherwise 0.	IBES	
CAPTA	Quarterly capital expenditure÷quarterly total assets	Research Institute	CAPXQ/ATQ
CarbonTaxDum	=1 for day 0 (or days -1 to 1) around April 11, 2011, otherwise zero.		
CGVSC	Corporate governance pillar score	Asset 4	CGVSCORE
Corporate/Industrial News	=1 for days -1 to 1 around corporate/industrial news, otherwise 0.	Factiva	
CrudeOil/ NaturalGasProductMarkets	=1 for days -1 to 1 around crude oil market news, otherwise 0.	Factiva	
ECNSC	Economic pillar score	Asset 4	ECNSCORE
ENVSC	Environmental pillar score	Asset 4	ENVSCORE
EPSAR	Quarterly earnings per share as reported	Worldscope	W18193
EPSBA	Quarterly earnings per share including extraordinary items	Research Insight	EPSPIQ
HML	Fama-French earnings growth factor	Ken French web site	
LEVRG	Debt÷common equity	Research Insight	DTQ/CEQQ
LEVRT	Debt÷total equity	Research Insight	DTQ/TEQQ
LGEQY	Natural log of quarterly common equity	Research Insight	CEQQ
LGMKT	Natural log of quarterly market value traded	Research Insight	MKVALQ
LOGTA	Natural log of quarterly total assets	Research Insight	ATQ
Mkt-RF	Market return in excess of risk free rate	Ken French web site	
MKTQR	Market value of stock at quarter end	Research Insight	MKVALQ
MKTVL	Market value of stock at fiscal year end	Research Insight	MKVALF
NaturePublicationDum	=1 for day 0 (or days -1 to 1) around April 30, 2009, otherwise zero.		
OtherNewsDays-1to10	=1 for days -1 to 10 around 2012-2013 unburnable carbon news, otherwise 0.		
OtherNewsDays-1to5	=1 for days -1 to 5 around 2012-2013 unburnable carbon news, otherwise 0.		
PercentageChangeOilPrice	$(COP_t – COP_{t-1})/COP_{t-1}$, where $COP_{t=}$spot price of West Texas Intermediate crude.		
ProvedReserveDum	=1 if Form 10-K contains disclosure of proved reserves, otherwise zero.		
QE-1to1	=1 for days -1 to 1 around quarterly earnings announcement date, otherwise 0.		
RBETA	Beta	Research Insight	BETA
REVTA	Quarterly net sales÷quarterly total assets	Research Insight	SALEQ/ATQ
RF	Risk free rate	Ken French web site	
SHREQ	Quarterly shareholders' equity	Research Insight	TEQQ
SMB	Fama-French size factor	Ken French web site	
TA	Quarterly total assets	Research Insight	ATQ
TOTEQ	Quarterly common equity	Research Insight	CEQQ
VOLAV	Trading volume – 1 year average	Research Insight	CSHTRD1
VOLQT	Trading volume – quarterly	Research Insight	CSHTRQ

Other terms	
CCS	Carbon capture and sequestration.
CIK	Central index key: A number given to an individual or company by the U.S. Securities and Exchange Commission.
CUSIP	A 9-character alphanumeric code that identifies a North American financial security: Allocated by the Committee on Uniform Securities Identification Procedures (CUSIP).
SEC	Securities and Exchange Commission.

Panel B: Regression models

(1) Cumulative daily excess returns around unburnable carbon news stories

To examine the relationship between excess returns and unburnable carbon news stories, we calculate cumulative daily excess returns using a Fama-French model (1993) as shown in equation 1.

$$r_{it} = RF_t + \alpha + \beta_1(Mkt_t - RF_t) + \beta_2\mathrm{SMB}_{it} + \beta_3\mathrm{HML}_{it} \qquad (1)$$

The intercept term, α, reflects the amount that firm U.S. oil and gas firms outperform/under-perform the market on a risk-adjusted basis on the event day (excess returns).

RF is the daily one-month Treasury bill rate. The independent variables are as follows: $Mkt_t - RF_t$= the return on a U.S. market value-weighted equity index (Mkt) in excess of the monthly T-bill rate on day t (RF); SMB_{it} (Small Minus Big) = the average return on the small-cap portfolio minus the average return on the large-cap portfolio (size factor). *SMB* represents a small-cap return premium; HML_{it} (High Minus Low) = the average return on the high book-to-market portfolio minus the average return on the low book-to-market portfolio (earnings growth factor). We also determine excess returns using a market model, $r_{it} = \alpha + \beta_1 Mkt_t + \varepsilon_{it}$.

(2) Stock price response to unburnable carbon news stories: Event day regressions

To examine the stock price response to unburnable carbon news stories, we regress daily stock returns, $\mathrm{r_{it}}$ in event time, for the 63 U.S. oil and gas firms on our test variables, Fama-French factors, and other controls and as shown in equation 2. Not all variables are included in each regression. See table 4 for details.

$$r_{it} = RF_t + \alpha + \beta_1(Mkt_t - RF_t) + \beta_2 SMB_{it} + \beta_3 HML_{it} + \beta_4 PercentageChangeOilPrice_t + \beta_5 CarbonTaxDum_t + \beta_6 NaturePublicationDum_{\mathrm{t}} + \beta_7 ProvedReserveDum_i + \beta_8 CarbonTaxDum_t * ProvedReserveDum_{it} + \beta_9 Corporate/IndustrialNews_t + \beta_{10} CrudeOil/NaturalGasProductMarket_t + \beta_{11} EPSAR_{it} + \beta_{12} ANALYST_{it} + \varepsilon_{it} \qquad (2)$$

Fama French factors are as previously specified. $NaturePublicationDum_t$= one for days -1, 0, and 1 around the Nature article on April 30, 2009, and zero otherwise; $PercentageChangeOilPrice_t$= $(COP_t - COP_{t-1})/COP_{t-1}$, the percentage change in the spot price of West Texas Intermediate crude oil over the event day t, where day 0 is one of three news story publication dates; $CarbonTaxDum_t$= one for days -1, 0, and 1 around the large spike in unburnable carbon new stories on April 11, 2011, and zero otherwise; $NaturePublicationDum_{\mathrm{t}}$= one for days -1, 0, and 1 around the *Nature* article on April 30, 2009, and zero otherwise; $ProvedReserveDum_{it}$ is a binary variable, equal to one when the Form 10-K contains disclosure of proved reserves, and zero otherwise; $CarbonTaxDum_t * ProvedReserveDum_i$= the interaction of carbon tax news and proved reserves; $Corporate/IndustrialNews_t$= one for days -1, 0, and 1 around corporate/industrial news, and zero otherwise; $CrudeOil/NaturalGasProductMarket_t$= one for days -1,0, and 1 around crude oil market news and zero otherwise; $EPSAR_{it}$= quarterly earnings per share as reported by Worldscope; $ANALYST_{it}$= one if an analyst comments or makes a recommendation on firm i on day t and zero otherwise. We expect that $(Mkt_t - RF_t)$ (the equity market factor) to have a positive coefficient to compensate equity investors for bearing systematic risk. Additionally, the Fama-French model considers size (SMB_{it}) and earnings growth (HML_{it}) as underlying risk factors. As $PercentageChangeOilPrice_t$ increases we expect the stock returns of oil and gas companies to increase. On the other hand, carbon tax news and the *Nature* article are expected to have negative impacts on stock price, which should be most severe for firms with proved reserves.

(3) Stock price response to unburnable carbon news stories: Calendar day regressions

We also consider the stock price response to unburnable carbon news stories as calendar day regressions. The general form calendar day regression is applied to calendar day stock returns, r_{it}, for the 63 U.S. oil and gas firms and shown below as equation 3. Not all variables are included in each regression. We also consider different versions of the dependent variables. See table 5 for details.

$$r_{it} = RF_t + \alpha + \beta_1(Mkt_t - RF_t) + \beta_2 SMB_{it} + \beta_3 HML_{it} + \beta_4 PercentageChangeOilPrice_t + \beta_5 CarbonTaxDum_t + \beta_6 NaturePublicationDum_{\mathrm{t}} + \beta_7 ProvedReserveDum_i + \beta_8 CarbonTaxDum_t * ProvedReserveDum_i + \beta_{13} OtherNewsDays - \mathrm{1to5}_{\ t} + \beta_{14} OtherNewsDays - \mathrm{1to10}_t + \beta_{15} OtherNewsDays - \mathrm{1to5}_t * ProvedReserveDum_i + \beta_{16}\mathrm{QE} - \mathrm{1to1}_{it} + \beta_{17} LOGTA_{it} + \beta_{18} ENVSC_{it} + \varepsilon_{it} \quad (3)$$

The newly-introduced independent variables are as follows: $OtherNewsDays - 1to5_{\ t}$= one for days -1 to 5 around 2012-2013 unburnable carbon news, and zero otherwise; $OtherNewsDays - 1to10_t$= one for days -1 to 10 around 2012-2013 unburnable carbon news, and zero otherwise; the interaction between unburnable carbon news and proved reserves; $QE \ - 1to1_{it}$= one for days -1, 0, and 1 around quarterly earnings announcements, and zero otherwise; $LOGTA_{it}$= Natural log of quarterly total assets; $ENVSC_{it}$= environmental pillar score. We expect unburnable carbon news to have a negative impact on stock returns, which should be most severe for firms with proved reserves. Firms with better environmental performance (i.e. higher *ENVSC*) are expected to show a positive coefficient.

Table 1
Sample selection

Firms in the *Datastream Energy Index*		72
Company-years (2008-2013)		432
U.S. firms in the *Datastream Energy Index* with CUSIP and CIK		63
Company-years (2008-2013) with CUSIP and CIK		378
Unburnable carbon print media news stories		
Factiva news stories from key word search, including multiple stories per day		246
New stories on different days, including Sat/Sun		142
New stories on different days, excluding Sat/Sun (Compustat sample)		88
Print media news sources		59
	All obs.	Sample obs.
Distribution of news stories by month		
All stories	246	88
2009/04 *Nature* publication	1	1
2011/04 Carbon tax news	1	1
2012/02 Unburnable carbon news	1	0
2012/03 Unburnable carbon news	2	2
2012/04 Unburnable carbon news	7	5
2012/05 Unburnable carbon news	8	5
2012/06 Unburnable carbon news	5	2
2012/07 Unburnable carbon news	6	5
2012/08 Unburnable carbon news	5	2
2012/09 Unburnable carbon news	18	6
2012/10 Unburnable carbon news	11	8
2012/11 Unburnable carbon news	23	11
2012/12 Unburnable carbon news	22	10
2013/01 Unburnable carbon news	42	15
2013/02 Unburnable carbon news	39	13
2013/03 Unburnable carbon news	29	2
2013/04 Unburnable carbon news	26	0

An appendix defines and states the data source of the variables.

Table 2
Sample descriptive statistics

Variable	Unit	Mean	Median	Percentile 25	Percentile 75	Standard Deviation	No. obs. (min)
LEVRG	Fraction	0.82	0.53	0.29	0.86	4.08	224
LEVRT	Fraction	0.74	0.51	0.25	0.81	4.73	224
REVTA	Fraction	0.18	0.08	0.05	0.13	0.33	224
CAPTA	Fraction	0.16	0.12	0.07	0.18	0.22	224
EPSBA	Dollars	0.14	0.27	-0.12	0.91	2.00	224
EPSAR	Dollars	1.00	0.85	-0.36	3.36	4.84	224
TA	Dollars, millions	18,615	3,505	1,443	9,777	47,073	224
LOGTA	Natural log of TA	8.28	8.16	7.27	9.19	1.74	224
LGMKT	Natural log of market value	8.04	7.87	6.82	9.21	1.75	224
RBETA	Number	1.44	1.32	1.01	1.87	0.62	224
TOTEQ	Dollars, millions	8,921	1,251	514	4,300	23,332	224
SHREQ	Dollars, millions	9,273	1,347	531	4,572	24,448	224
MKTVL	Dollars, millions	17,558	2,951	986	10,409	53,644	224
MKTQR	Dollars, millions	16,751	2,628	915	9,999	52,205	224
CGVSC	Percent (100=100%)	73.20	72.52	62.93	84.25	14.51	224
ECNSC	Percent (100=100%)	50.91	48.60	27.81	71.68	25.71	224
ENVSC	Percent (100=100%)	32.57	16.90	12.31	45.66	27.99	224

An appendix defines and states the data source of the variables.

Table 3
Cumulative daily excess returns around unburnable carbon news stories

News Day	*Nature pub.* No reserve disclosure	*Nature pub.* Reserve disclosure	Carbon tax No reserve disclosure	Carbon tax Reserve disclosure	Other news No reserve disclosure	Other news Reserve disclosure
-10	0.43%	-1.70%	-0.01%	-0.40%	0.01%	-0.10%
-9	2.12%	0.03%	0.31%	0.26%	-0.19%	-0.26%
-8	-1.05%	2.14%	0.99%	0.44%	-0.02%	-0.10%
-7	2.24%	0.30%	-1.10%	-0.23%	0.02%	-0.33%
-6	-1.08%	1.33%	0.01%	-0.68%	-0.06%	0.58%
-5	0.59%	-1.66%	0.90%	-0.38%	-0.07%	-0.30%
-4	-0.61%	0.53%	0.10%	0.12%	0.32%	-0.01%
-3	-0.69%	1.17%	-1.34%	-1.69%	0.37%	-0.05%
-2	-0.22%	-0.61%	-1.17%	0.32%	-0.14%	0.99%
-1	1.22%	0.83%	-1.31%	0.56%	-0.48%	-0.49%
0	-2.74%	-0.22%	-1.45%	-1.68%	-1.17%	-0.64%
1	-1.29%	-1.15%	-0.48%	-1.54%	0.08%	-0.84%
2	0.27%	2.84%	2.96%	0.51%	0.15%	-0.14%
3	3.73%	5.34%	2.90%	0.41%	-0.33%	-0.66%
4	0.53%	1.65%	1.15%	-1.19%	0.10%	0.51%
5	-0.55%	0.59%	3.77%	2.88%	0.83%	1.18%
6	-0.67%	3.98%	0.76%	-0.40%	-1.03%	-1.86%
7	0.12%	-1.07%	-1.81%	-0.69%	1.69%	0.70%
8	-0.90%	0.47%	-0.15%	-0.53%	1.23%	-0.59%
9	0.60%	-2.38%	-3.53%	-0.51%	0.21%	-1.80%
10	0.50%	-0.78%	-0.14%	-0.53%	0.71%	0.10%

This table summarizes the mean Fama-French excess returns around the initial *Nature* publication (4/29/2009), media mention of a carbon tax (4/11/2011), and all other news stories relating to unburnable carbon (from March 23, 2012 to our cutoff date of March 5, 2013). An appendix defines and states the data source of the variables.

Table 4
Stock price response to unburnable carbon news stories: Event day regressions

Response window	Day 0	Day 0	Day 0	Days -1 to 1	Days -1 to 1	Sum of days -1 to 1
Regression	(1)	(2)	(3)	(4)	(5)	(6)
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Intercept	-0.0008	-0.0008	0.0002	-0.0007	-0.0002	0.0138
Prob>|t|	0.7636	0.1019	0.8563	0.0050	0.6201	<.0001
Significance	ns	ns	ns	***	ns	***
RF	131.3288	112.4071	265.9941	197.9654	216.9264	1298.7089
Prob>|t|	0.0762	0.2700	0.0178	0.0076	0.0037	<.0001
Significance	*	ns	**	***	***	***
Mkt-RF	1.3102	1.3086	1.3130	1.4520	1.4511	1.1182
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
SMB	0.2253	0.2642	0.2021	0.1038	0.1014	-0.1463
Prob>|t|	0.0141	0.0033	0.0267	0.1019	0.1102	0.4112
Significance	**	***	**	ns	ns	ns
HML	0.7752	0.7811	0.7344	0.5255	0.5265	0.3049
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	0.0891
Significance	***	***	***	***	***	*
PercentageChangeOilPrice	0.2153	0.2203	0.2210	0.2402	0.2400	0.1864
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
CarbonTaxDum	-0.0057	-0.0057	-0.0050	-0.0052	-0.0052	-0.0097
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
NaturePublicationDum	-0.0147	-0.0152	-0.0154	-0.0151	-0.0151	-0.0202
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	0.0011
Significance	***	***	***	***	***	***
ProvedReserveDum	0.0015	0.0016	0.0005		-0.0009	-0.0046
Prob>|t|	0.0000	0.0162	0.4545		0.0489	0.0009
Significance	***	**	ns		**	***
*CarbonTaxDum*ProvedReserveDum*		-0.0044	-0.0040			-0.0078
Prob>|t|		0.0062	0.0140			0.0131
Significance		***	**			**
Corporate/IndustrialNews			0.00001			-0.00001
Prob>|t|			0.0008			0.7727
Significance			***			ns
CrudeOil/NaturalGasProductMarkets			-0.00002			ns
Prob>|t|			<.0001			<.0001
Significance			***			***
EPSAR			-0.00001			0.00001
Prob>|t|			0.0809			0.1964
Significance			*			ns
ANALYST			-0.00002			0.00001
Prob>|t|			0.0205			0.9435
Significance			**			ns
Adjusted R square	27.59%	27.68%	28.12%	30.31%	30.33%	8.16%
No. observations	5,355	5,355	5,355	10,332	10,332	5,292

This table summarizes ordinary least squares *event day* regressions of day 0 (days -1 to 1) stock return on unburnable carbon news stories, with controls for the Fama-French factors, oil price changes, and information intensity measures for crude oil, earnings, and analyst news. Col. 5 uses days -1 to 1 as three separate observations, whereas col. 5 uses the sum of days -1 to 1 as one observation. An appendix defines and states the data source of the variables. ***=significant at <.001, **=significant at <.05, *=significant at <.1, and ns=not significant using a two–tailed t test.

Table 5
Stock price response to unburnable carbon news stories: Calendar day regressions

Regression	(1)	(2)	(3)	(4)	(5)	(6)
Variable	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
Intercept	0.0006	0.0006	0.0040	0.0010	0.0010	0.0041
Prob>|t|	0.0055	0.006	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
RF	-45.6444	-45.6645	-49.8622	-51.8207	-51.8360	-52.1903
Prob>|t|	0.0214	0.0213	0.0127	0.0093	0.0093	0.0088
Significance	**	**	**	***	***	***
Mkt-RF	1.2512	1.2511	1.2515	1.2504	1.2504	1.2509
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
SMB	0.2979	0.2984	0.2994	0.2968	0.2968	0.2983
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
HML	0.2024	0.2026	0.2015	0.2065	0.2065	0.2041
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
PercentageChangeOilPrice	0.2484	0.2485	0.2482	0.2475	0.2475	0.2476
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
CarbonTaxDum	-0.0065	-0.0067	-0.0064	-0.0056	-0.0056	-0.0056
Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Significance	***	***	***	***	***	***
NaturePublicationDum	-0.0079	-0.0079	-0.0082	-0.0082	-0.0082	-0.0084
Prob>|t|	0.0275	0.0274	0.0218	0.0231	0.0231	0.0193
Significance	**	**	**	**	**	**
ProvedReserveDum	-0.0002	-0.0002	-0.0002	-0.0003	-0.0003	-0.0002
Prob>|t|	0.4314	0.4496	0.5274	0.2996	0.3000	0.4741
Significance	ns	ns	ns	ns	ns	ns
*CarbonTaxDum*ProvedReserveDum*		-0.0014	-0.0014		-0.0002	
Prob>|t|		0.4308	0.4147		0.9322	
Significance		ns	ns		ns	
OtherNewsDays-1to5			-0.0003			
Prob>|t|			0.3401			
Significance			ns			
OtherNewsDays-1to10				-0.0014	-0.0014	-0.0013
Prob>|t|				<.0001	<.0001	<.0001
Significance				***	***	***
*OtherNewsDays-1to10*ProvedReserveDum*				-0.0015	-0.0015	-0.0016
Prob>|t|				0.0096	0.0126	0.0066
Significance				***	**	***
QE -1to1			0.0014			0.0013
Prob>|t|			0.0126			0.0133
Significance			**			**
LOGTA			-0.0004			-0.0004
Prob>|t|			<.0001			<.0001
Significance			***			***
ENVSC			0.00001			0.00001
Prob>|t|			0.0509			0.0707
Significance			*			*
Adjusted R square	36.83%	36.83%	36.87%	36.86%	36.86%	36.90%
No. observations	65,331	65,331	65,331	65,331	65,331	65,331

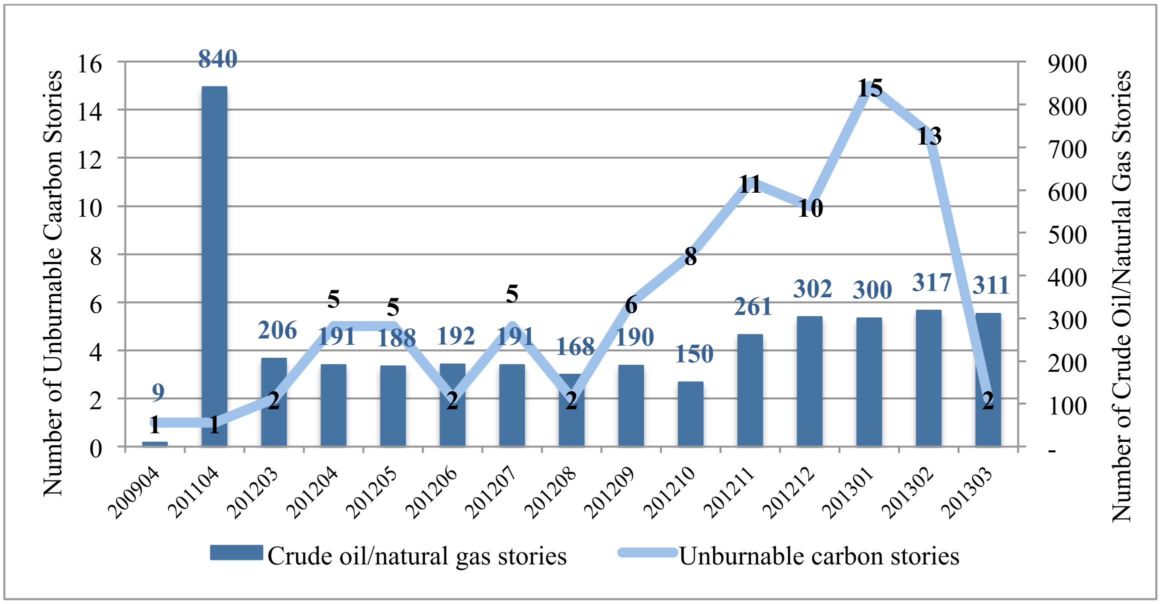
This table summarizes ordinary least squares *calendar day* regressions of stock return on unburnable carbon news stories, with controls for the Fama-French factors, oil price changes, earnings announcements, size, and environmental performance. An appendix defines and states the data source of the variables. ***=significant at <.001, **=significant at <.05, *=significant at <.1, and ns=not significant using a two–tailed t test.

Table 6
Economic significance of unburnable carbon news stories

Excess returns model	Market model excess returns		Fama-French excess returns with oil price changes	
Sample	No reserve disclosure	Reserve disclosure	No reserve disclosure	Reserve disclosure
Dollars in millions	(1)	(2)	(3)	(4)
Panel A: Market capitalization				
Aggregate market capitalization	$54,828	$1,033,786	$54,828	$1,033,786
Average market capitalization per company	$4,218	$20,676	$4,218	$20,676
Days -1 to 1 abnormal price response: *Nature*	-2.2106%	-0.2417%	-2.8128%	-0.5409%
Days -1 to 10 abnormal price response: *Nature*	-0.7788%	7.2628%	0.8112%	10.1027%
Days -1 to 1 abnormal price response: Carbon tax	-4.3373%	-4.4291%	-3.2411%	-2.6555%
Days -1 to 10 abnormal price response: Carbon tax	-1.0698%	-7.0332%	1.4218%	-3.3127%
Days -1 to 1 abnormal price response: Other news	-1.0930%	-2.5001%	-0.8040%	-0.6600%
Days -1 to 10 abnormal price response: Other news	0.0872%	-7.1834%	0.0850%	-1.8411%
Panel B Aggregate change in market capitalization				
Days -1 to 1 abnormal price response: *Nature*	$(1,212)	$(2,499)	$(1,542)	$(5,591)
Days -1 to 10 abnormal price response: *Nature*	$(427)	$75,082	$445	$104,440
Days -1 to 1 abnormal price response: Carbon tax	$(2,378)	$(45,787)	$(1,777)	$(27,452)
Days -1 to 10 abnormal price response: Carbon tax	$(587)	$(72,709)	$780	$(34,246)
Days -1 to 1 abnormal price response: Other news	$(599)	$(25,846)	$(441)	$(6,823)
Days -1 to 10 abnormal price response: Other news	$48	$(74,261)	$47	$(19,033)
Panel C: Average change in market capitalization per company				
Days -1 to 1 abnormal price response: *Nature*	$(93)	$(50)	$(119)	$(112)
Days -1 to 10 abnormal price response: *Nature*	$(33)	$1,502	$34	$2,089
Days -1 to 1 abnormal price response: Carbon tax	$(183)	$(916)	$(137)	$(549)
Days -1 to 10 abnormal price response: Carbon tax	$(45)	$(1,454)	$60	$(685)
Days -1 to 10 abnormal price response: Other news	$(46)	$(517)	$(34)	$(136)
Days -1 to 10 abnormal price response: Other news	$4	$(1,485)	$4	$(381)
Panel D: Change in market capitalization based on table 4, regression 6, coefficients				
Days -1 to 1 abnormal price response coefficient: *Nature*				-2.0248%
Days -1 to 1 abnormal price response coefficient: Other news				-0.4600%
Sum of days -1 to 1 abnormal price response coefficients				-2.4848%
Aggregate change in market capitalization				$(27,050)
Average change in market capitalization per company				$(429)

This table summarizes the aggregate and per company change in market capitalization at the time of the unburnable carbon news stories based on the excess return over days -1 to 1 or days -1 to 10 from a market model and a Fama-French factor model including the daily change in oil prices calculated as market capitalization times abnormal price response percentage. Firms are split into those with oil and gas reserve disclosures and those without oil and gas reserve disclosures (mostly oil and gas services firms). An appendix defines and states the data source of the variables.

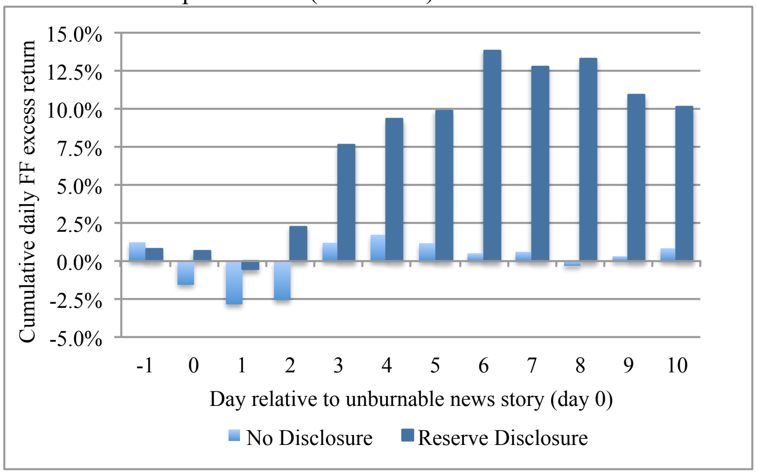
Figure 1
Unburnable carbon and Crude oil/natural gas news story intensity: By month



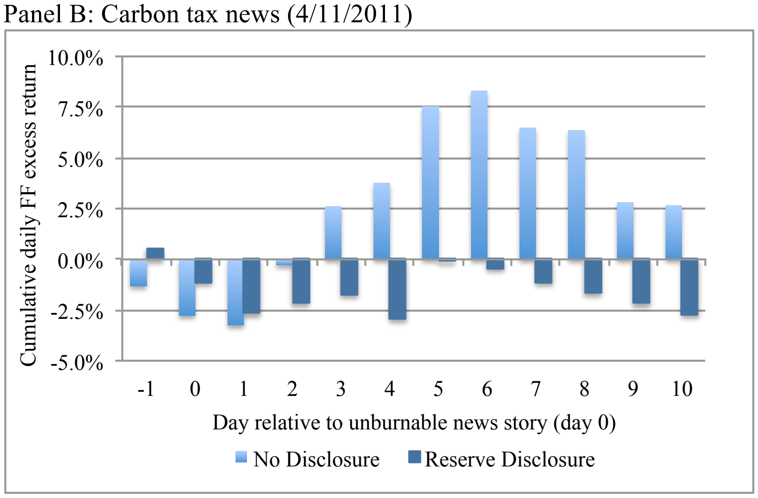
This figure compares the frequency of unburnable carbon and crude oil/natural gas news stories by month. The line represents the number of unburnable carbon new stories, and the bars represent the number of crude oil/natural gas stories by month. Source: Factiva.

Figure 2
Cumulative Fama-French excess returns around unburnable carbon news stories

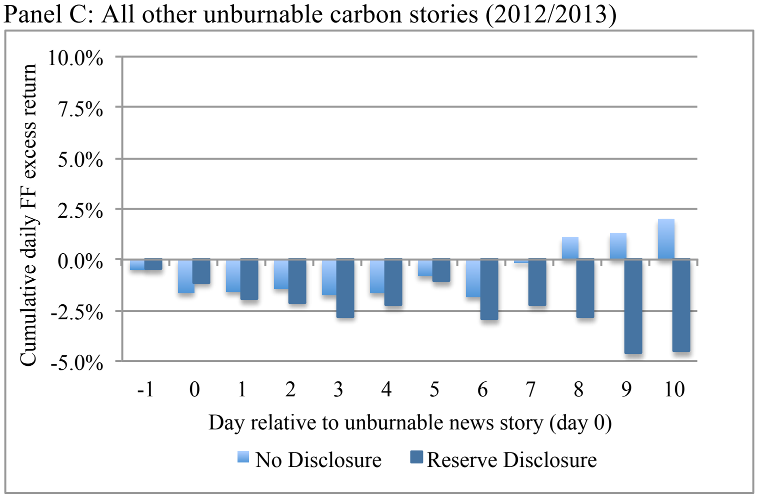
Panel A: *Nature* publication (4/29/2009)



Panel B: Carbon tax news (4/11/2011)



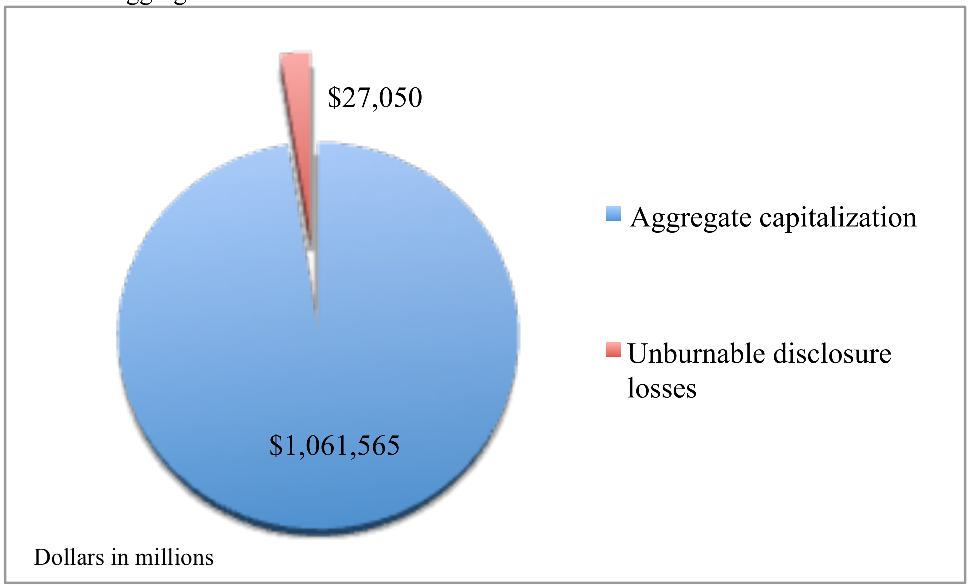
Panel C: All other unburnable carbon stories (2012/2013)



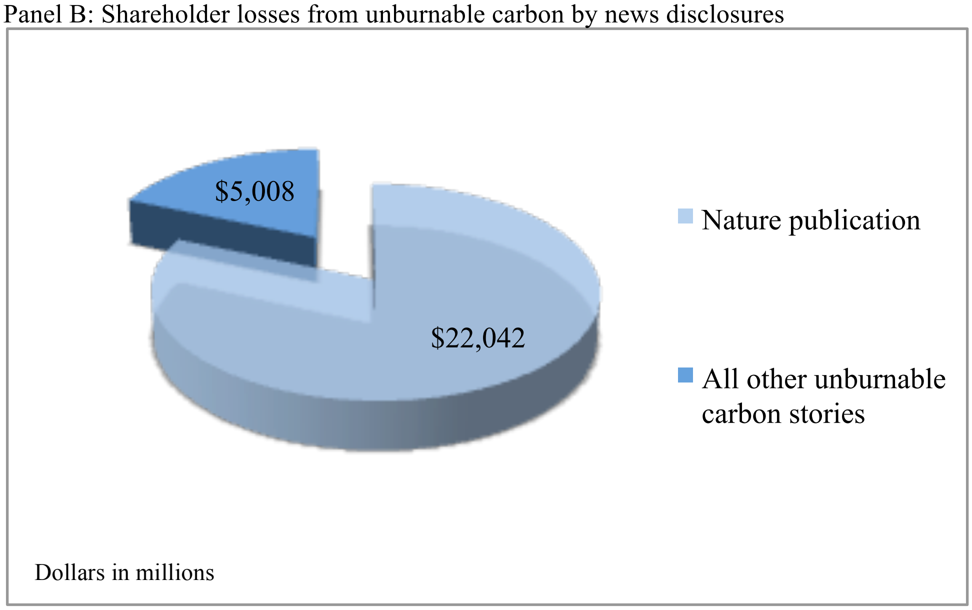
These figures show the cumulative Fama-French excess returns from days -1 to 10 relative to the day of an unburnable news story (day 0). Panels A and B show the mean sample response around a single day. Panel C shows the mean sample response over all unburnable news stories in 2012-2013.

Figure 3
Shareholder losses from unburnable carbon disclosures

Panel A: Aggregate shareholder losses from unburnable carbon disclosures



Panel B: Shareholder losses from unburnable carbon by news disclosures



These figures show that the shareholder losses based on the regression coefficients from table 4, regression 6, equal $27.050 billion, or 2.48% of market capitalization. Equivalent shareholder losses based on market model and Fama-French three factor excess returns including oil price changes for the firms in our sample equal $30.156 billion and 14.397 billion, respectively.