Acceptance by Proxy: Analyzing Perceptions of Hydraulic Fracturing to Better Understand Public Acceptance for Geologic Storage of Carbon Dioxide

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Abstract

Carbon capture and storage (CCS) represents an important pathway for reducing greenhouse gas emissions in order to mitigate climate change. However, there is significant uncertainty about how the technology will be accepted by the public, which is difficult to predict for relatively unknown technologies such as CCS. As such, this thesis explores the use of a similar but better-known technology—hydraulic fracturing—as an analogue for learning lessons about public acceptance of the geologic storage component of CCS. The thesis asks two questions: (1) What factors are associated with public acceptance of geologic storage? And (2) What actions should communities, regulators, and stakeholders take to ensure the safe and efficient deployment of CCS technology?

The thesis investigates these questions using three separate but related analyses. A series of regressions explores links between states' history of fossil fuel extraction and current regulatory attitudes toward hydraulic fracturing. A comparative case study characterizes trends in the development of laws and regulations related to hydraulic fracturing in three states: Pennsylvania, New York State, and Colorado. Finally, a survey identifies factors associated with positive and negative public perceptions of both hydraulic fracturing and CCS. The survey includes an experimental question that measures the extent to which compensation can be used to improve public acceptance for facility siting.

Through these analyses, the thesis reaches several conclusions. States with an extensive history of fossil fuel extraction are more likely to regulate hydraulic fracturing with a moderate level of regulatory stringency, and similar tendencies toward CCS are likely. Municipalities are playing an increasingly significant role in the regulation of hydraulic fracturing, and are likely to be important stakeholders for CCS projects as well. A number of demographic and worldview factors are associated with public acceptance, but none were found to have substantial predictive power. However, the amount of compensation offered to nearby residents was found to have a moderate effect on public acceptance. Developers should therefore consider compensation a tool for increasing the likelihood of acceptance among residents nearby a potential project site. Policymakers should in turn institute market incentives such as robust carbon prices to foster a financial environment that encourages developers to engage with municipalities and residents.

Thesis Supervisor: Howard J. Herzog, Senior Research Engineer, MIT Energy Initiative

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This thesis is largely about the power of communities, and like any large endeavor, it is the product of one as well.

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Chapter 1: Introduction

Carbon capture and storage (CCS) represents an important pathway for reducing greenhouse gas emissions. CCS is a constellation of technologies that capture carbon dioxide (CO_2) emissions from power plants or factories, purify the gas, transport it to a storage site, and inject it underground where it cannot affect the earth's atmosphere (IPCC Special Report on CCS, 2005; CCS Browser, 2013). Sites intended for permanent storage of CO_2 exist at least a half-mile underground and rely on a variety of physical and chemical mechanisms to prevent the gas from reaching the surface. Most climate change models conclude that a mitigation portfolio that does not include CCS will not maintain atmospheric carbon dioxide levels below the dangerous level of 450 parts per million (IPCC AR5, 2013). Moreover, this technology is currently one of the only ways to enable greenhouse gas abatement without threatening the fossil fuel industry's participation in the energy sector (Markusson, 2012). Recent estimates concluded that, by the year 2100, CCS could rescue up to 5,400 exajoules of coal and 3,500 exajoules of natural gas —valued at trillions of dollars—that would otherwise be "stranded" were climate mitigation to move forward without CCS (Clark, Herzog, 2014).

A substantial number of research projects and pilot studies have advanced the development of CCS technologies over the past several decades. Likewise, since the 1970s enhanced oil recovery has served as a commercial-scale validation of CO_2 injection and a source of investment for the requisite technologies. More recently, greenhouse gas emissions regulations promulgated by the U.S. Environmental Protection Agency have been seen as a potential (though controversial) driver for the large-scale implementation of CCS.

As CCS technologies breach the technical, financial, and regulatory barriers to deployment, the question of public acceptance looms increasingly larger. All infrastructure projects face public acceptance challenges, and CCS is no different. While geologic storage sites are located up to a mile below the surface, they may extend underneath a large number of residences and communities, potentially causing anxiety and fear among local populations. Projects can and do fail because of public opposition. For example, local protest led to the 2010 cancellation of a CCS demonstration project outside the town of Barendrecht, costing Shell and the Netherlands tens of millions of euros. Commercial-scale CCS plants can cost billions of dollars to design and construct (MIT CCS Project Database, 2015), and each project is a gamble by investors that local residents will be amenable to development. If too many projects fail because of low public acceptance, commercialization efforts may dwindle.

Nevertheless, low awareness of CCS complicates research aimed at assessing public perceptions of the technology. A survey undertaken as part of this thesis found that less than 10 percent of U.S. residents had heard or read about CCS in the past year, which is a low level of awareness relative to other energy technologies (see Figure 1). This lack of awareness confines rigorous study of public acceptance to the few geographic areas that have experience with CCS, and such studies typically cannot be generalized as representative of the broader U.S. population.

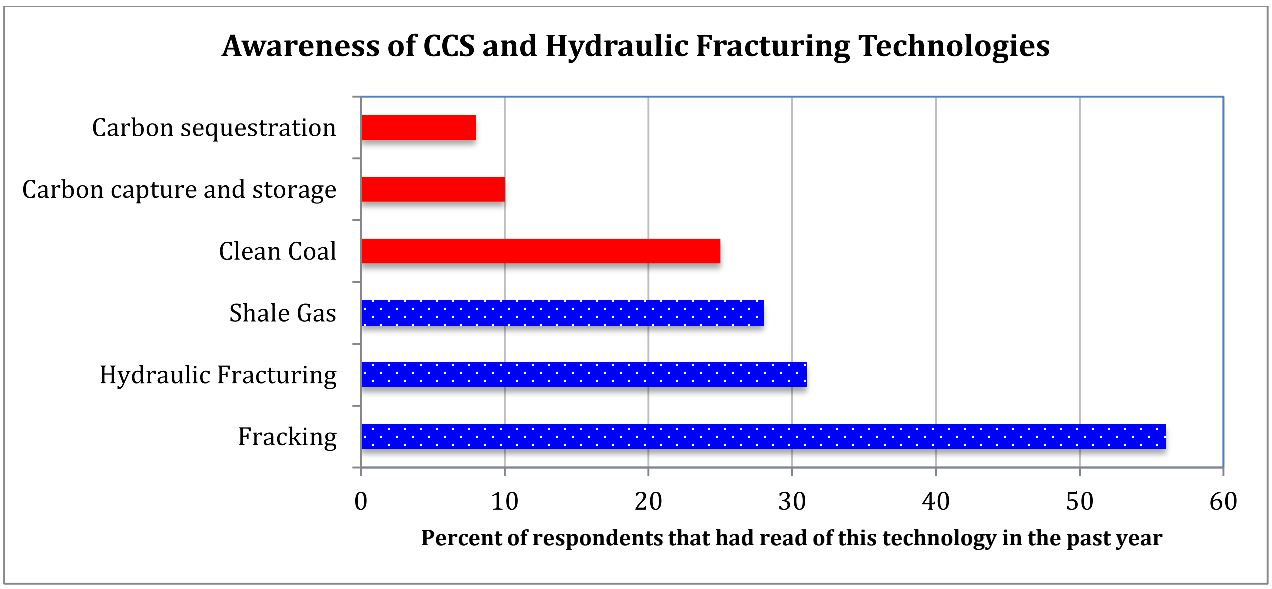


Figure 1: Public awareness of CCS and hydraulic fracturing in the U.S.

To circumvent the lack of awareness, this thesis relies on a novel technique: anticipating public acceptance trends for CCS by studying hydraulic fracturing—a well-known technology that is abundantly similar to CO_2 injection. Hydraulic fracturing technology injects water, chemicals, and sand at higher pressures into deep shale rock formations with the intention of freeing the trapped oil and natural gas. Data from a survey analyzed in chapter 6 indicate that U.S. residents are likely to perceive the local presence of CCS and hydraulic fracturing similarly, and Figure 1 illustrates that U.S. residents are more likely to have heard of hydraulic fracturing than CCS.

This thesis relies on hydraulic fracturing as a technological analogue for CCS in order to meet two objectives:

- Identify and assess the key factors likely to affect public acceptance of CCS.
- Provide insight to communities, regulators, and stakeholders on addressing public acceptance issues related to the injection and storage of CO_2.

To meet those objectives, the thesis is structured into seven chapters:

Chapter 2 presents background on the current state of research on public acceptance for CCS technologies. The chapter focuses on a review of literature related to the perception of risks and benefits of CCS.

Chapter 3 introduces a more comprehensive framework for assessing public acceptance issues. Previous studies have tended to assess acceptance at the community level. The framework employed in this thesis assumes that regulators and stakeholders also influence acceptance of new infrastructure technologies such as CCS. Chapter 3 also provides evidence justifying the use of hydraulic fracturing as a technological proxy for identifying public acceptance issues related to underground injection of CO_2.

Chapter 4 analyzes differences across states in the regulation of hydraulic fracturing. Regression analysis and statistical variance tests are employed to identify correlations between state regulations, experience with fossil fuel extraction, and other factors. This analysis is intended to identify how familiarity with use of underground resources may be associated with future regulations related to geologic storage of CO_2.

Chapter 5 investigates changes in state regulation and community acceptance of hydraulic fracturing over time in three states: New York, Pennsylvania, and Colorado. This qualitative analysis is intended to introduce additional nuance into the understanding of the factors that may impact public acceptance at the regulatory, community, and stakeholder levels.

Chapter 6 analyzes two surveys on hydraulic fracturing and CCS—one from the U.S. and one from the U.K. The goals of this survey analysis are to quantitatively assess the similarities in respondent perception between hydraulic fracturing and CCS, identify the factors relevant to public acceptance of each technology, evaluate compensation as a potential solution for increasing public acceptance, and characterize the extent to which each of these elements vary between the U.S. and the U.K.

Chapter 7 synthesizes the findings from the previous chapters, offering insights for regulators, stakeholders, and communities interested in addressing public acceptance for CCS.

Chapter 2: The Current State of Public Acceptance Research

Acceptance of an emerging energy technology means the propensity to declare approval of the new technology and to act in accordance with those declarations.

Seigo et al. (2014) characterized 42 studies on public acceptance of CCS according to this factor framework. Fourteen of the studies were qualitative, relying on data sources such as interviews, focus groups, and workshops, and methodologies such as thematic analysis. The remaining 28 the studies in the review were quantitative and relied on statistical analysis of surveys and coded interviews, laboratory experiments. The authors' meta-analysis found that perceived risks and benefits are the best predictors for acceptance of CCS.

Seigo et al. (2014) characterized research studies using a simple framework in which individual decisions about acceptance of CCS are based primarily on perceived risks and benefits, which are in turn mediated by an array of secondary factors, including familiarity, trust, values and social narratives, fairness and efficacy, and affect (see Figure 2). This chapter summarizes the current state of CCS using several of the studies introduced in Seigo et al. (2014), as well as some additional studies.

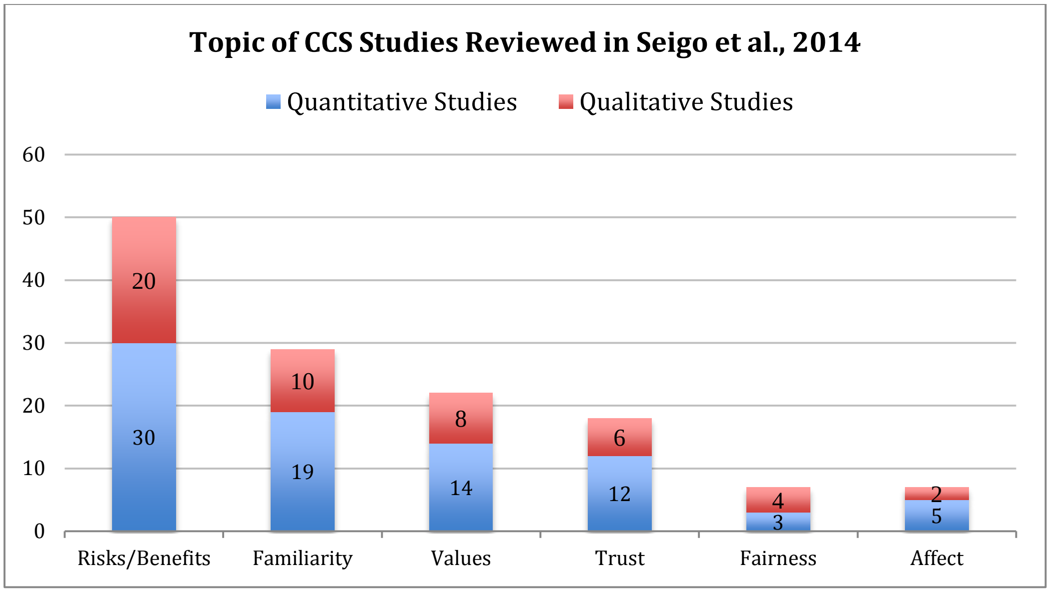


Figure 2: Characterization of previous CCS studies. Based on literature review from Seigo et al., 2014. Studies on perceived risks and benefits of CCS dominate the literature. Seigo et al.'s meta-analysis affirms that this factor is the best predictor of public acceptance for the technology. Note that most studies in the meta-analysis addressed more than one topic area.

2.1 Perceived Benefits and Risks

2.1.1 Benefits

A number of studies have examined the correlation between the perceived benefits of CCS and acceptance of the technology, and several articles explicitly identified the perceived benefits as more relevant than the perceived risks (Kraeusel and Möst, 2012; Terwel and Daamen, 2012; Terwel et al., 2009; Tokushige et al., 2007). Additional studies found that CCS projects were more successful when developers and policymakers stressed local benefits—such as compensation, jobs, and tourism—in addition to the main benefit of climate change mitigation (Upham and Roberts, 2011; Wong-Parodi et al., 2011). Caveating this conclusion, however, are findings that the effects of local benefits on acceptance are context-dependent—for example, benefits such as compensation may be less effective in high-employment areas (Oltra et al., 2012).

Compensation for members of the host community is the most straightforward local benefit of CCS, and it could take several forms: payments to individual members of the community, or public-good compensation such as new schools and libraries for the community at large (ter Mors et al., 2013). Evidence from the nuclear waste disposal industry shows that public-good compensation can be very effective at increasing public acceptance for controversial infrastructure projects, as has been the case with the Waste Isolation Pilot Plant in New Mexico (Jenkins-Smith et al., 2011). Survey experiments have implied that compensation may be effective for increasing public acceptance of geologic carbon storage (Zaal et al., 2014; ter Mors et al., 2012). Yet individual compensation faces challenges, such as the "bribe effect," in which residents perceive compensation as an illicit payoff, and the "crowding out of public spirit" effect, in which compensation primes residents to act more selfishly and abandon values of civic duty (ter Mors et al., 2012).

In addition to compensation, more indirect benefits like increases in community employment levels or influx of money into the local economy may also sway residents toward accepting projects. Residents of coal states place a particularly high value on the economic and employment benefits that CCS may potentially offer (Carley et al., 2013).

2.1.2 Risks

Seigo et al., (2014) also found that the most frequently perceived risk relating to CCS is leakage of sequestered carbon dioxide back into the atmosphere. Earthquakes constitute another often-cited risk, and Seigo et al. note that multiple studies register a perceived association between the risk of earthquakes and the risk of leakage: laypeople wonder whether earthquakes might initiate carbon dioxide leakage. Laypeople have also cited concerns that investments in CCS might reduce investments in renewable energy and thus perpetuate the fossil fuel economy (Gough et al., 2009). Wallquist et al. (2010) surveyed residents in Switzerland and found, in contrast to Seigo et al., that respondents were more concerned with this "perpetuation effect" of CCS than with possible leakage or over pressurization risks. A secondary but significant risk is the high cost and financial uncertainty associated with CCS (Oltra et al., 2012).

Much research has been conducted on the manner in which the public perceives risks more generally. Unsurprisingly, people demand maximum benefits from technologies in return for minimum costs, and therefore society is willing to tolerate higher risks from activities and technologies that are seen as highly beneficial (Starr, 1969). The process that individuals use to calculate these risks and benefits, however, is not necessarily straightforward. While actuaries, engineers, and other risk professionals define risk as an event's probability of occurring multiplied by the consequences an incident (Renn, 1998), laypeople have been shown to judge risks irrationally, based on a set of heuristics and subjective mental models (Kahneman and

Tversky, 1979). A prime example of this is loss aversion, which is the tendency to prefer avoiding loss (or risk) over acquiring equal or even greater gains (Kahneman et al., 1991). The psychometric model attempts to forecast the public's perception of risk and appetite for regulation by analyzing hazards across a small number of "factors," or heuristics (Slovic, 1987). Risk perceptions can be depicted graphically on a psychometric diagram consisting of two factors: dread and "unknown." Dreaded hazards are those that are uncontrollable, irreversible, catastrophic, fatal, or inequitable in their distribution of costs and benefits. Unknown hazards are those that are new, unfamiliar, rare, unobservable, or delayed in their effects. Figure 3 uses the psychometric model of risk to depict several example hazards.

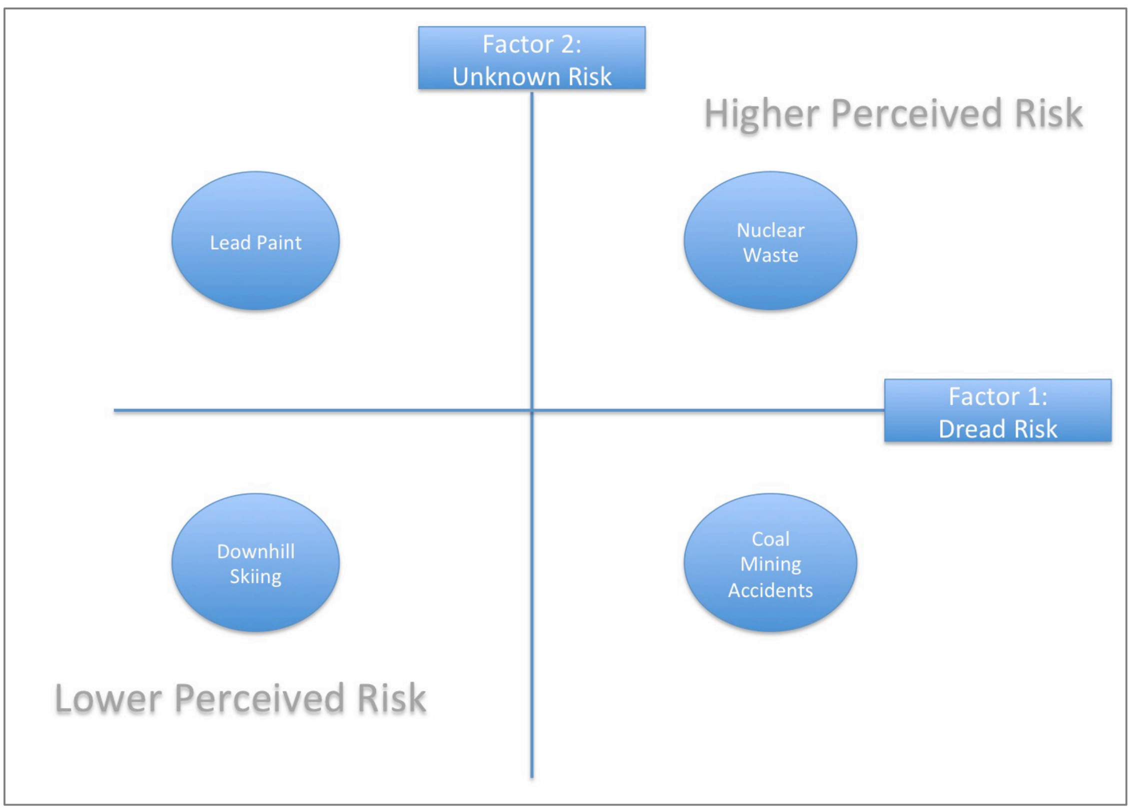


Figure 3: Psychometric risk matrix. Recreated and simplified from Slovic, 1987. Hazards in quadrant I are characterized by effects that are highly dreadful and highly unknown (unobservable or unfamiliar)—e.g., nuclear waste. Conversely, hazards in quadrant III have effects that carry relatively little dread and are directly observable—e.g., downhill skiing.

Additional risks can be located in the two-factor space from Figure 3 by comparing their dread and "knowability" to that of currently ranked risks. Using this method, geologic carbon storage has been hypothesized to occupy a position between fossil fuel combustion and uranium mining in the upper right quadrant (high dread, unknown) of the psychometric risk space (Singleton et al., 2009). Figure 4 depicts carbon storage's location, using arrows to show how it compares to other risks. Slovic (1987) posits that efforts to "educate" the public about risks in this quadrant—so as to better align public risk perception with expert risk assessment—may prove difficult, because the low probability or visibility of mishap for these types of hazards complicates empirical demonstration, and the dreadfulness of the potential hazard ensures that any mishap will be highly publicized.

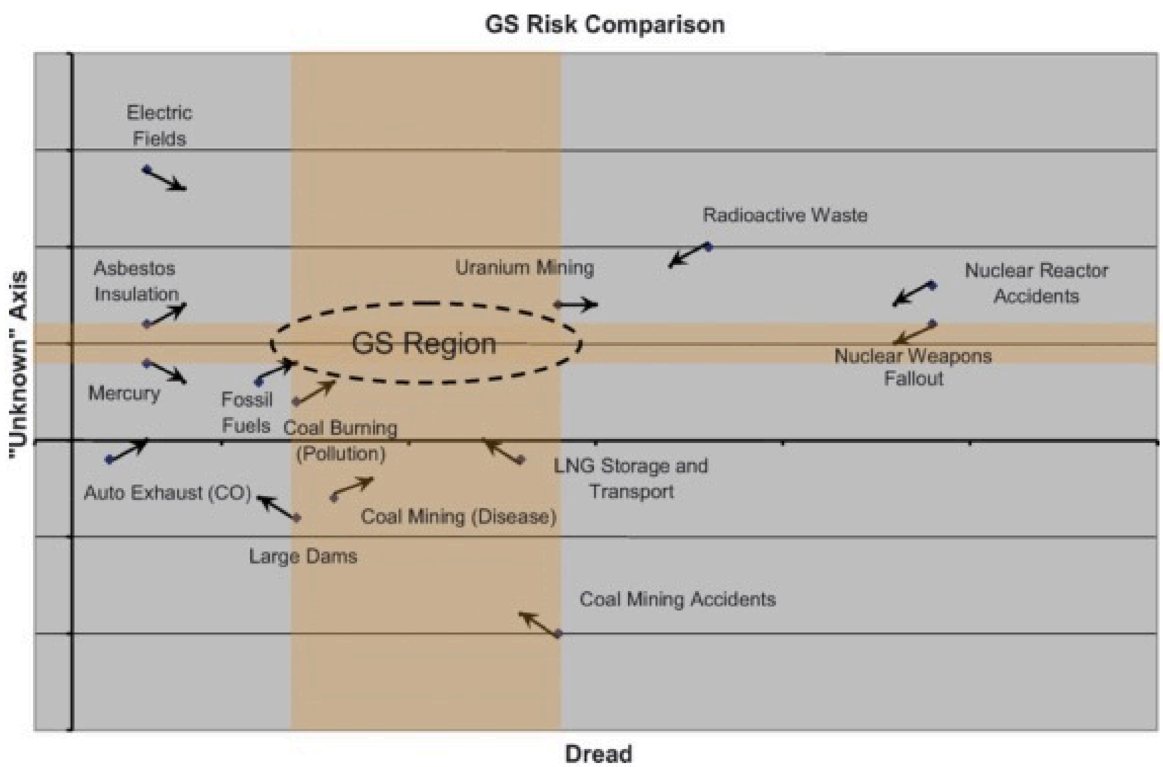


Figure 4: Location of geologic storage in the psychometric risk matrix (Singleton et al., 2009)

Even if laypeople estimate risk distributions inaccurately, however, opposing development of a nearby project may still be a rational choice. First, small as the risk from a NIMBY may be, it likely exceeds a neighbor's share of the global benefits. A neighbor near a carbon storage site, for example, derives very little value from the facility's contribution to climate change mitigation, while facing small but still significant local risks, including groundwater pollution, gas leakage, and induced seismicity. Moreover, because property owners cannot insure against devaluation of their real estate in the face of nearby development, they may rationally focus on upper tail, "worst case scenario" risks (Fischel, 2001). It follows that NIMBY opposition becomes much more likely if property owners compare mean benefits with the upper tail end of the risk distribution, even when compensation exists. See Figure 5.

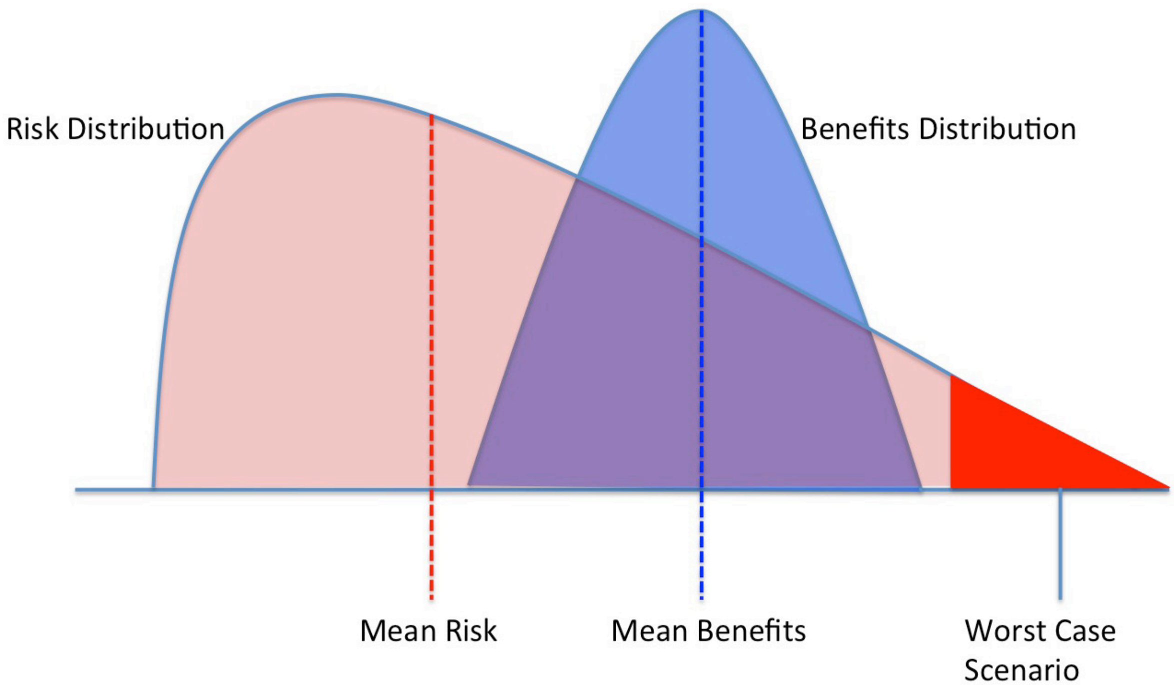


Figure 5: A potential distribution of risks and benefits

2.2 Mediating Factors

2.2.1 Trust

The success of attempts to educate the public about risks depends not only on risk perceptions but also on the degree to which the public trusts the stakeholders and policymakers providing information. Studies investigating the association between the public's trust in CCS stakeholders and acceptance of the technology describe an important but complex relationship. It is clear that trust is partially related to the public's perception of CCS stakeholders' competence and the degree to which stakeholders disclose information (Tokushige et al., 2007). However, Terwel et al., (2009) and Terwel and Daamen (2012) found that trust does not directly impact public acceptance but instead influences perceptions of a technology's risks and benefits. Midden and Huijts (2009) complicated the picture further with findings that trust most directly influences negative and positive affect (i.e., emotional attitude) toward a technology, which in turn influences perceived benefits and risks. Other studies have investigated the relationship between public acceptance, trust, and values, finding that public acceptance and trust are highest when individual or community values are perceived as in line with those of CCS stakeholders and when CCS stakeholders appear to be honest about the values they proclaim to act on (Huijts et al., 2007; Terwel et al., 2009). Trust itself has been analyzed as the combination of competence, predictability, and caring, but these values are often in conflict. Take the example of a CCS developer that provides residents with information early in the engagement process—demonstrating caring—only to retract it once a follow-up study emerges—thus demonstrating incompetence and unpredictability (Kasperson and Ram, 2013). Finally, two studies found that trust in policy-makers increases when a diverse array of interest groups and stakeholders has a voice in the decision-making process (ter Mors et al., 2010; Terwel et al., 2010).

2.2.2 Values and Social Narratives

Societal values have also been found to affect individuals' support for CCS (Seigo et al., 2014). In particular, CCS seems to have a particularly low level of acceptance among individuals and communities with values strongly related to non-interference with nature (Gough et al., 2009; Tukoshige et al., 2007; Wallquist et al. 2012). People with this value view nature as "an interconnected ecosystem web in which interference in any part will concatenate throughout with deleterious consequences" (Gough et al., 2009) and lack support for large-scale energy technologies such as nuclear and perhaps CCS (Sjöberg, 2000).

Social narratives related to tradeoffs between environmental and economic wellbeing may also affect public acceptance for CCS. Judith Bradbury’s survey (Markusson et al., 2013) of Midwesterners’ attitudes toward CCS found that residents primarily concerned with economic issues dismissed CCS as a financial waste, while residents prioritizing environmental wellbeing rejected it as a distraction from renewable energy. These studies demonstrate the ability of large-scale social narratives to impact public acceptance of new technologies and processes.

Values can also work in CCS's favor, however. For example, residents in Illinois initially accepted the original FutureGen project because they felt it made their town more sustainable and because they felt a sense of pride in being part of cutting edge innovation (Markusson, 2012). Accepting projects may give residents more altruistic benefits such as the knowledge that they have helped mitigate climate change. Ultimately, the people most likely to support CCS technology are those who believe that climate change is a critical problem (Oltra, 2010) but want to see CCS instituted as part of a broader clean energy portfolio (Palmgren et al., 2004).

2.2.3 Fairness and Efficacy

Perceptions and values related to fairness may also have a powerful effect on acceptance of CCS. Terwel et al. (2012) found that the perceived unfairness of the decision making process in Barendrecht partly led to the opposition to that project, and Visschers and Siegrist (2012) used a survey analysis to demonstrate that perceived fairness of decision outcomes related to the citing of new energy facilities affected not just local acceptance but acceptance of new energy technologies at the societal level. Conversely, Anderson et al. (2012) demonstrated that communities that feel powerless to resist siting of CCS technologies might not oppose local projects—though this passivity is not the same as acceptance. Finally, acceptance of local geologic storage is associated with increased support from people with an egalitarian mindset—which places a high value on fairness—and from those who think of themselves as pro-market individualists—and may therefore view CCS as a market-based solution to climate change (Krause, 2014).

2.2.4 Familiarity, Knowledge, Experience

One reason social narratives have such sway is that they provide coherence among otherwise complex and confusing information. Findings from Slovic (1987) and Singleton et al. (2009) on psychometric risk underscore the importance of familiarity and knowledge for a realistic assessment of risk. Atman et al. (1993) note that laypersons in the general public utilize mental models, albeit subjective ones, to assess risks: successful risk communication integrates new information into these existing models. Their study built on earlier work examining "confirmation bias," which is the tendency to interpret new information in a way that confirms existing beliefs (Nickerson, 1998). Schively (2007) further explains that residents often find themselves floundering in an “information haze.” As the information burden increases, residents are likely to abandon attempts to make sense of the data and instead turn toward opposition (Futrell, 2003). Developers and policymakers charged with risk communication must therefore strive to understand the public's current reference points, fill knowledge gaps, and gently correct misconceptions—all without overburdening residents with unnecessary technical information.

Likewise, familiarity and experience with similar technologies may help residents make sense of abundant and conflicting information. At least two studies have found that prior experience with the fossil fuel industry is positively correlated with acceptance of CCS (Upham and Roberts, 2011; Anderson et al., 2012), thus corroborating findings from Singleton et al., (2009) which linked acceptance for CCS and familiarity with the technology. Similarly, Tokushige et al. (2007) found that knowledge of natural analogues to carbon storage improved acceptance of CCS. Upham and Roberts (2011) also noted, however, that acceptance for CCS might experience particularly low levels of acceptance from communities that have experienced energy disasters—such as those near the Chernobyl disaster or natural gas explosions. This corroborates the finding that particularly dreadful risks can have "ripple effects" that impact public acceptance of adjacent technologies and industries (Slovic, 1987).

2.2.5 Affect

Relative to the other factors discussed in this background chapter, affect—which in this context means the feelings evoked by a technology—has received very little attention from the research community. One study found subjects provided with new information about CCS monitoring activities were likely to experience more negative affect than a control group that received only basic introductory information (Seigo et al., 2011). Another study found that residents in two towns in the Netherlands had a slightly positive affect toward CCS in general, but a negative affect toward carbon storage under their property (Huijts, 2007). Despite the dearth of research, however, it seems clear that new technologies evoke certain feelings that cloud assessments of risks and benefits. More research on this topic is needed.

2.3 From perceptions to decisions

Public acceptance for the existence of a new technology is different from support for nearby siting, and an individual who in the abstract supports CCS as a mitigation technology may oppose the storage of carbon dioxide underneath his or her property (Terwel and Daamen, 2012). While CCS may offer important climate mitigation benefits for society at large, it has real and perceived costs for residents near storage sites. Geologic carbon storage could therefore become NIMBY projects to local residents. NIMBYs are location-specific projects that create net benefits for large and diffuse populations but face opposition from a subset of the population that incurs large localized risks (Schively, 2007). Those perceived risks could include threats to human health and society (Schively, 2007) or damage to ecosystems or the aesthetic qualities of rural landscapes (van der Horst, 2007). For carbon storage, nearby residents have been shown to worry in particular about gas leakage, induced seismicity, and groundwater contamination (Carley et al., 2013; Seigo et al., 2014). NIMBY opposition is therefore more likely to target pipelines and storage sites than carbon capture operations (Wallquist et al., 2012).

NIMBYs are a collective action problem because a small, concentrated group is incentivized to oppose a project that on the whole is good for society (Olson, 2009). Neighbors near a NIMBY have a much higher incentive to organize—and a much greater ability to do so—than the broader and more diffuse population that benefits from the project (O'Hare, 2010). The resulting market failure is the risk of not building a project that will benefit society overall, because it is not politically feasible in any particular location (O’Hare, 2010). The failure in the case of CCS specifically is that society will not take a significant step toward climate change mitigation because the method for doing so will result in real or perceived losses for people near carbon sequestration sites.

While it is clear that risk and benefit assessments are subjective and mediated by the many factors discussed in the previous sections of this chapter, decisions about whether to oppose or accept nearby siting of projects can be analyzed through a rational framework. In deciding whether to oppose local development, residents weigh the perceived benefits and costs of both opposing and accepting a project. This becomes clear in the decision tree in Figure 6 (O'Hare, 2010).

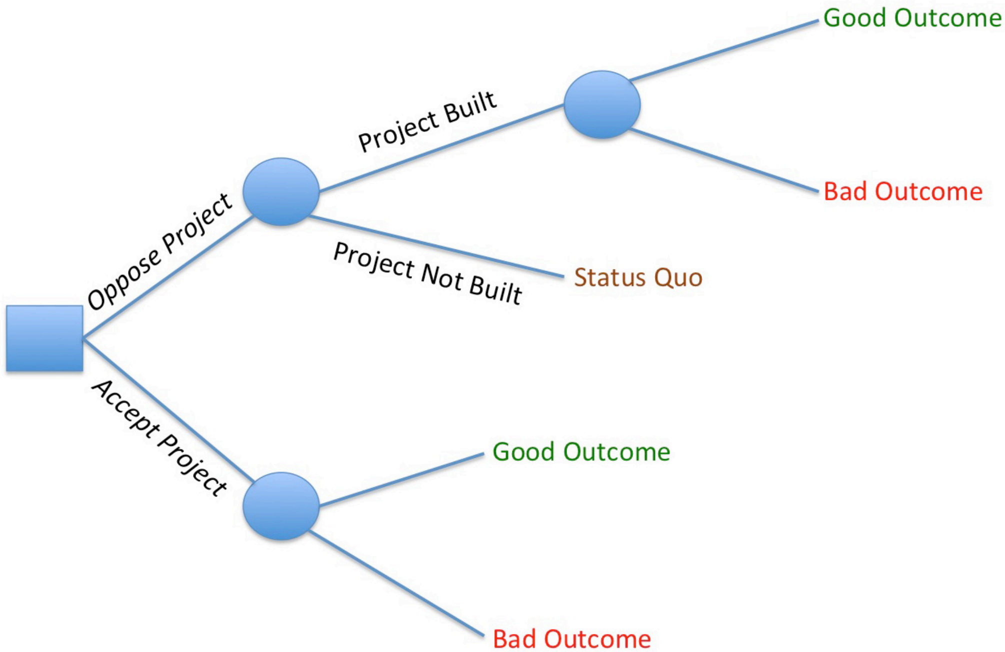


Figure 6: Decision tree representation of the NIMBY decision process. Square boxes represent decision nodes, where a resident must decide whether to accept or oppose development. Circles represent uncertainties, where a resident is unsure of the outcome. (O'Hare, 2010).

Opposing is beneficial to the extent it prevents risks from materializing. Additionally, temporary opposition could result in more compensation in the case of a negotiation. Opposition, though, also has costs. Lobbying against development projects requires significant amounts of time and money (O'Hare, 2010). Residents who oppose otherwise popular development projects may also risk upsetting neighbors who would prefer to see development—and perhaps compensation—proceed.

Of course, it is not only the potential outcome that is important, but also the probability associated with that outcome. Opposition is much less attractive when the chance of success is 10 percent than when its chance of success is 80 percent. Few residents want to spend money and time opposing a NIMBY project only for development to move forward. The significant costs of opposition and the often-low chances of successful opposition may lead to a free rider problem such that no opposition materializes because each resident passes the organizing burden to his or her neighbor. Uncertainty comes into play in subtler ways, too. As illustrated by the decision tree from O'Hare, 2010, there is always the chance that opposition will block a project that would have had a good outcome, or that residence will mistakenly accept a project that leads to a bad outcome. Finally, even when residents accurately estimate outcomes and probabilities, the resulting costs and benefits can be so similar that it becomes difficult to determine whether to oppose or accept—in such cases the public may eventually cease requesting additional information and err toward opposing development (Futrell, 2003).

This is not to say that residents consciously utilize decision trees when making decisions about whether to oppose a potential NIMBY project. The decision tree model does, however, approximate the rational decision-making process that residents likely use to decide the best course of action. Nor is it to say that residents are necessarily making accurate decisions; the decision-making process is, after all, based on subjective and potentially misguided risk perceptions. When applied to carbon storage siting and other energy planning efforts, however, the decision tree model may be instructive to developers and policymakers who need to understand how best to minimize public opposition. This framework is also useful for explaining why NIMBY opposition develops for some projects but not others:

When viewed through the lens of decision analysis, NIMBY opposition can be expected to materialize in situations when residents decide that opposition has a significant chance of halting a project with risks that exceed benefits. Put more precisely, NIMBY will occur when the expected value of opposition exceeds the expected value of acceptance. While residents estimate these elements using perceived risks and benefits of accepting and opposing, developers simultaneously calculate compensation offers based on a more scientific assessment of a project's risks and benefits. NIMBY can be expected to materialize when residents perceive the cost of opposition to be lower than the costs imposed by a project's risks less project benefits and compensation. This can be expressed using the following formula.

$$NIMBY \begin{cases} Oppose\ when, & OC \leq R-(B+C) \\ Accept\ when, & OC > R-(B+C) \end{cases}$$

Where:
OC is the cost of opposing development
R is the perceived risk of the project
B is the perceived non-financial benefit of the project
C is the compensation offered or expected

2.4 Key Chapter Findings

- Public acceptance of emerging technologies such as CCS is mediated by a variety of subjective factors, including perception of risk and benefit, trust in stakeholders, contextual values and social narratives, perceived fairness and efficacy, and affect evoked by the technology.
- Each factor in turn affects the others; acceptance of a new technology is an emergent property of this complex system of factors.
- Research on these factors has been uneven. Very little research has been done on some factors, such as affect. Substantial research has been conducted on other factors—particularly risk perception. Research on risk shows that the public tends to perceive a technology as riskier if potential hazards are relatively dreadful or unknown.
- NIMBY is a rational response to a development project that offers diffuse global benefits but that is associated with concentrated local costs.
- Nearby residents likely think about a project's outcome as a distribution of potential costs and benefits. If so, property owners are likely to worry disproportionately about the upper tail of risk—the worst-case scenario.

Chapter 3: Methods and Data for Analyzing Public Acceptance

Two of the main gaps in the existing body of literature on public acceptance of carbon storage are the lack of a consistent and comprehensive framework for public acceptance and the lack of robust data sources. Nearly all of the recent studies on public acceptance of CCS have focused on community perceptions and reactions to the technology (Seigo et al., 2014). This community focus ignores the reality that regulators and stakeholder groups such as firms and nongovernmental organizations often have a powerful effect on technology acceptance. Moreover, because CCS is not yet a commercially mature technology, quantitative studies must rely on surveys or coded interviews rather than real world data. This thesis introduces a more comprehensive acceptance framework for assessing the public acceptance of geologic carbon storage and tests the framework using data on hydraulic fracturing—a more commercially mature technological proxy for geologic carbon storage.

3.1 Public acceptance triangle framework

Traditionally, the concept of public acceptance has been synonymous with local community perceptions and attitudes (Wolsink, 2007). While community acceptance is indeed one facet of public acceptance—and perhaps the most visible one—it is insufficient by itself. Occasionally, researchers have emphasized the role of firms and markets or of governance structures in shaping public acceptance, but such analyses remain relatively uncommon (Wolsink, 2007).

Wüstenhagen, Maarten, and Bürer (2007) introduced the "triangle of public acceptance" to more comprehensively discuss public acceptance by characterizing it via the interactions among local communities, markets, and political forces. The authors, focusing on renewable energy technology, define community acceptance as the siting decisions made by local stakeholders, market acceptance as the market adoption of technical innovations, and socio-political acceptance as the degree to which broader cultural and political institutions enable the diffusion of new energy technologies.

In 2014, van Os et al., utilized the public acceptance triangle approach along with survey tactics to analyze the failure of the CCS Initiative in the village of Barendrecht in the Northern

Netherlands. The authors concluded that limited public acceptance among community and political stakeholders were the main reasons for the Initiative's failure, with lack of market acceptance playing a lesser but still substantial role in the project's demise. The study demonstrates the utility of the new framework for analyzing success and failure of individual CCS infrastructure decisions.

A modified version of this framework (see Figure 7) is useful for assessing the broader public acceptance dynamics associated with CCS and hydraulic fracturing, and it underpins the analyses contained in this thesis. The modified framework substitutes "stakeholder" acceptance for market acceptance, because CCS is not yet a mature commercial technology. The stakeholder category includes developers and other firms that benefit from siting, as well as organizations such as environmental NGOs and the media, which may be neutral or opposed to CCS technologies. Likewise, in the modified framework, "regulatory" acceptance replaces "socio-political" acceptance from the original framework, because among the US public CCS is to unknown (Curry, 2004) to be a cultural or political issue. Regulators strive to balance the concerns of communities and those of industry (Dammel et al., 2011). These modifications help make the public acceptance triangle framework a more useful and comprehensive tool for examining acceptance of geologic storage of carbon dioxide.

Feedbacks exist within and among the three elements in the triangle framework. For example, government policies tend to be path dependent, locking in a particular course of action from which it becomes increasingly difficult to deviate: energy policies encouraging or discouraging new energy technologies set the stage for reinforcement from future policies (Markusson, 2012). Likewise, residents in a community may base their siting decisions in part on the decisions of their neighbors. Public acceptance is also fraught with interaction effects: for example, government policies such as unitization and pooling regulations may encourage community acceptance, as might compensation offers from firms.

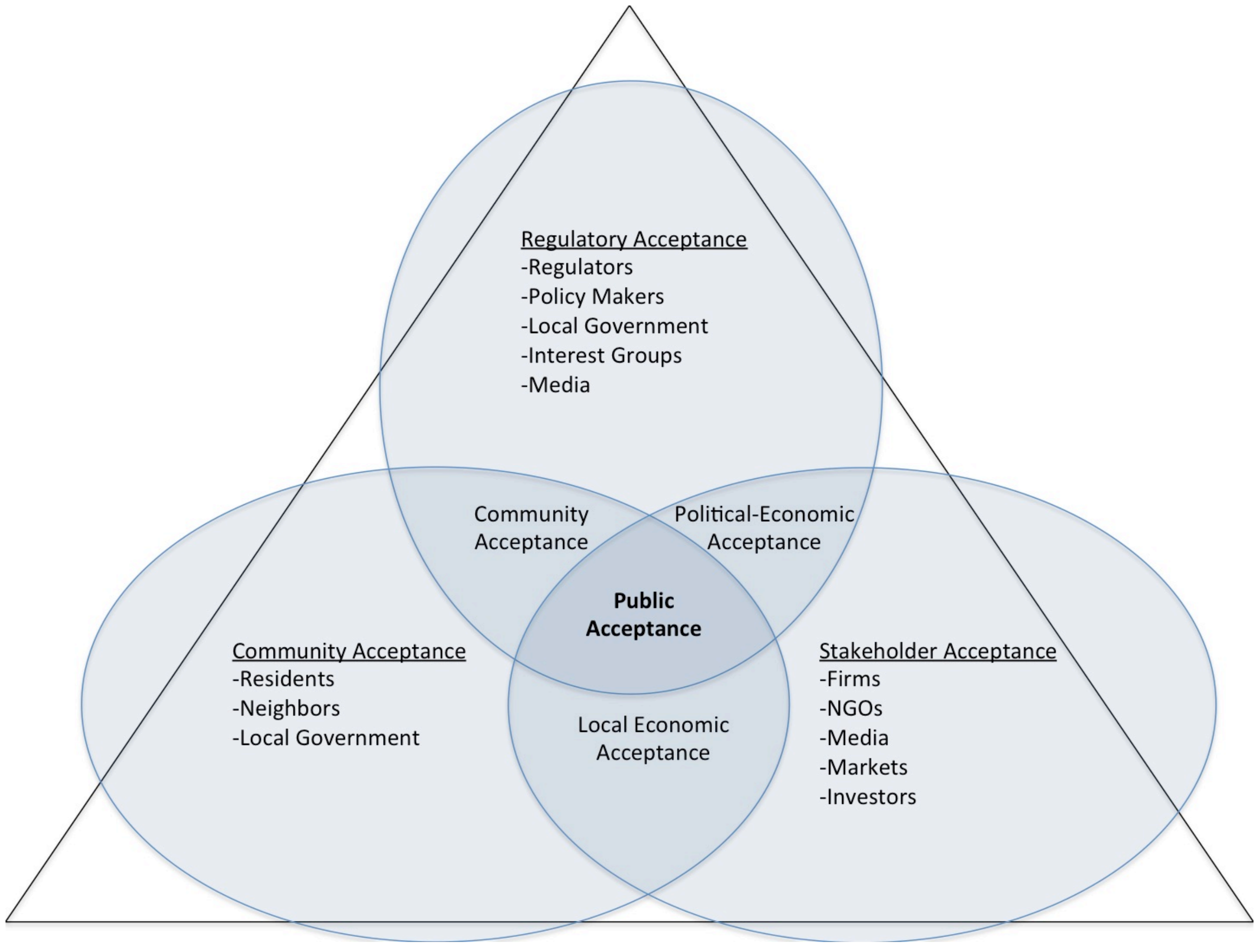


Figure 7: Public acceptance triangle framework

3.2 Hydraulic fracturing: a technological proxy for carbon storage.

An empirical examination of public acceptance for CCS, and for carbon storage in particular, is problematic because the technology is not yet mature and is largely untested in the commercial marketplace. Those carbon storage projects that exist today remain in the pilot or demonstration phase. Therefore, efforts to predict future trends in public acceptance for CCS are complicated by the fact that limited data exist from which to extrapolate.

One approach for predicting the future direction of an emerging technology or industry is to draw on lessons from a closely related but more mature field. Previous research has already used natural gas pipeline networks as an analogue for assessing public acceptance of the transportation infrastructure that would be necessary for commercial-scale CCS (Marsden and Markusson, 2011). The hydraulic fracturing industry has promise as a case study for the public acceptance of geologic storage. In addition to sharing similar technical characteristics, both processes face similar headwinds from public acceptance, regulatory pressures, and NIMBY opposition (Kerr, 2010; Dammel et al., 2011; Krause et al., 2014; Wolff and Herzog, 2014). Moreover, hydraulic fracturing may be the most appropriate analogue for examining the public acceptance of carbon storage, because it is one of the only other large-scale energy processes in which potentially hazardous activities occur both on the surface and underground (Krause, 2014). Hydraulic fracturing has already seen use as a technological analogue for geologic storage of CO_2 in legal research on pore space property rights (Anderson, 2009).

This analysis takes a broad view on what constitutes the process of hydraulic fracturing: as in Burger (2013) hydraulic fracturing is defined here as not only the actual moment during which an operator fractures a shale formation, but also the preceding exploration and mineral rights acquisition as well as the subsequent production and waste disposal processes.

3.2.1 Operational similarities

The operations associated with hydraulic fracturing strongly resemble those of carbon storage. Both processes use state of the art drilling techniques to create a wellbore extending deep underground: typically 4,000 to 7,500 feet for hydraulic fracturing (NETL, 2009) and 3,000 to 8,000 feet for carbon storage (Heddle et al., 2003). In the case of hydraulic fracturing, water is pumped at high pressure down the new wellbore in order to fracture shale formations and extract trapped natural gas. For carbon storage, the wellbore is used to move supercritical carbon dioxide (i.e., high pressure and liquid-like) underground to storage sites in porous rock formations, such as sandstone. Just as hydraulic fracturing operations utilize pipelines to transport natural gas away from the site, carbon storage operations would use pipelines to move carbon dioxide to the storage site. Wastewater from hydraulic fracturing operations is injected underground for permanent storage, as is carbon dioxide in the case of CCS. Finally, both hydraulic fracturing and carbon dioxide storage sites are typically sealed and monitored after site activity ceases.

3.2.2 Risks

Being operationally similar, carbon storage and hydraulic fracturing share a number of risks, many of them potentially impacting communities near sites. Risks may be categorized according to likelihood and hazard. Highly likely but low hazard risks shared by carbon storage and hydraulic fracturing include noise and nuisance from site construction, minor reductions in local air quality from site operations, and potentially unwanted changes to the local economy. Moderately hazardous and likely risks include the potential triggering of relatively small seismic activity, nonthreatening drinking water pollution, and the release of gaseous methane or carbon dioxide from the site at levels that are not threatening to health but that could contribute to climate change. Earthquakes from underground injection of wastewater have received much attention lately (Ellsworth, 2013; Horton, 2012; Keranen et al., 2014). Similar risks have been discussed for CCS (Zoback and Gorelick, 2012; Ruben et al., 2013). Unlikely but highly hazardous risks include irreversible drinking water pollution or catastrophic escape of carbon dioxide (potential for asphyxiation) or methane leading (potential for explosion). Each of these risks has the potential to affect nearby residents directly, but they also have the potential to contribute to second and third order risks that could, for example, further damage nearby residents by degrading home values.

3.2.3 Social narratives

Finally, hydraulic fracturing and CCS share a similar social narrative. Proponents of both hydraulic fracturing and CCS defend the technologies as "bridges" to a low carbon future (Marston and Moore, 2008). Many also claim that the technologies provide benefits beyond greenhouse gas mitigation: cheap energy and energy security in the case of hydraulic fracturing and recovery of stranded assets in the case of CCS (CarbonTracker, 2013). Meanwhile, some opponents view the technologies as a wasteful and polluting use of resources that could be more productively spent on non-fossil forms of energy such as wind or solar (Markusson et al., 2012). Others criticize the technologies as degrading environmental justice by asking isolated communities to bear the brunt of society's climate change mitigation costs (Markusson et al., 2012). Lastly, hydraulic fracturing often takes place in regions unfamiliar with fossil fuel operations (Deutch, 2012)—a characteristic that carbon storage is likely to share—differentiating it from another close proxy: enhanced oil recovery (EOR).

Public acceptance for new energy technologies is partly a function of social narratives and their underlying value clusters, and these factors differ from location to location. Stedman et al. (2012) found that public acceptance of hydraulic fracturing differed markedly between residents in Pennsylvania and residents in New York State, despite the fact that both states share various geomorphological characteristics and therefore have a similar levels of risk related to geo-mechanical processes such as hydraulic fracturing.

3.2.4 Differences

Of course, it is important to note the differences between hydraulic fracturing and CCS; we must keep these in mind as we seek to use fracturing to learn lessons about the public acceptance of CCS. Most importantly, at present hydraulic fracturing is a profitable activity while CCS is not. This could change somewhat with the advent of a carbon tax or cap and trade program—in that case industry might begin to view hydraulic fracturing as somewhat less profitable and view CCS as a cost cutting strategy—but even then hydraulic fracturing would remain an extraction technique for a useful energy resource and CCS a disposal technique for an environmental problem.

Another difference: the geomorphologies of hydraulic fracturing and carbon storage differ considerably. Fracturing takes place in relatively impermeable shale formations, which means that fracturing wells draw gas from a relatively small volume of substrate compared with the enormous saline formations in which CCS operations would likely store carbon dioxide. This has important implications for the degree to which processes like mineral rights acquisition, integration, and compensation might differ between hydraulic fracturing and CCS.

3.2.5 Data availability

Beyond the practices' similarities and differences, hydraulic fracturing is a useful test subject for learning about potential regulatory regimes for CCS simply because of the wide variety of approaches to regulating the industry. The Energy Policy Act of 2005 initiated sweeping changes to the energy industry (U.S. Congress, 2005), carving out for the hydraulic fracturing industry many exemptions from federal environmental regulations. The Act largely exempted most hydraulic fracturing operations from regulation under the Clean Water Act (CWA), Clean Air Act (CAA), and Safe Drinking Water Act (SDWA). Today, states represent the main entities governing the hydraulic fracturing industry. Each state regulates the process differently, based on residents' demographics, preferences, and viewpoints on industry and environmental protection. Hydraulic fracturing is an interesting research subject for learning about CCS not because we expect CCS to be regulated at the state level—federal regulators have already demonstrated an interest in CCS through actions such as EPA's class 6 well regulations (see Appendix A)—but because the vast range of hydraulic fracturing regulations can help us bracket the form of future CCS regulations and understand how community concerns over carbon storage translate into regulations and policies.

3.3 Key Chapter Findings

- Previous studies on public acceptance of CCS have tended to focus on individuals and communities and utilized interviews, surveys, and case studies as data sources.
- There is an opportunity to study public acceptance at a broader level, looking not only at perceptions and decisions made by individuals and communities, but also at the choices made by stakeholder groups and regulators.
- In terms of technology, risks, and perceptions, hydraulic fracturing is similar to geologic storage of carbon dioxide and may therefore be a data-rich proxy for studying public acceptance of CCS.

Chapter 4: Acceptance Among Regulators

A quantitative analysis of state regulations for hydraulic fracturing complements the preceding case studies. The purpose of the analysis is to better understand what demographic and industry factors correlate with stringent regulations for hydraulic fracturing. In particular, this analysis tests the hypothesis that familiarity and historical experience with fossil fuel extraction is a significant determining factor in the level of regulatory stringency for hydraulic fracturing.

4.1 Methodology and Datasets

4.1.1 Regulatory stringency data

The statistical analysis discussed here relies on a 2013 dataset of U.S. state-by-state regulatory stringency for the shale gas industry. In 2013, Richardson et al. attempted to examine state governance of hydraulic fracturing by calculating the relative stringency of 13 "quantitatively regulated elements" for states in which the industry has a significant presence. These elements pertained to a variety of hydraulic fracturing procedures, including: setback requirements, predrilling water testing, casing depth and circulation rules, water withdrawal limits, freeboard and pit liner requirements, wastewater transportation and tracking rules, well idle time limits, temporary abandonment limits, and accident reporting requirements. The authors quantified regulations by setting the most stringent state regulation in each category equal to 100 and then normalizing the stringency of the same regulation in other states according to the resultant percent scale. No state regulated all thirteen items—for example, California did not regulate the use of pit liner—and the authors addressed this by assigning each state a "zero stringency" value for elements that were apparently unregulated, resulting in the "adjusted stringency" ranking depicted in Figure 8.

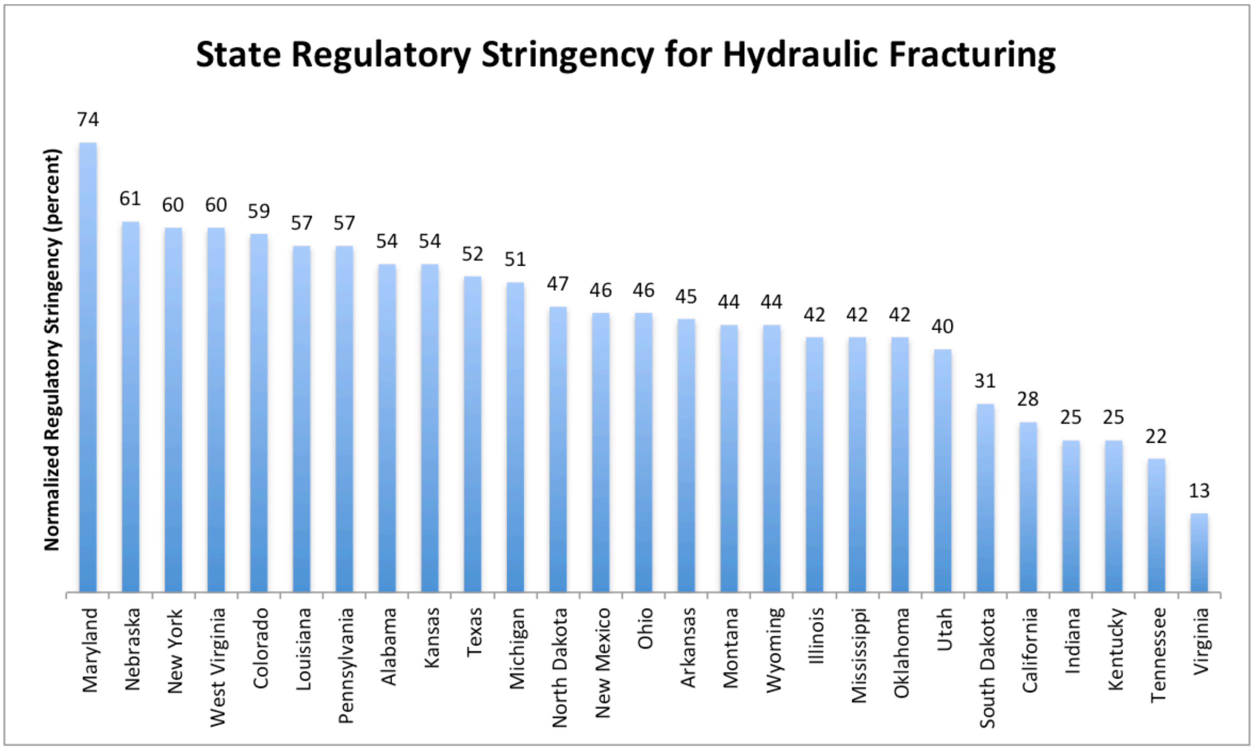


Figure 8: Regulatory stringency of hydraulic fracturing, by state. Each stat's score represents the percent of operational elements that state regulates out of the total possible number of elements. Richardson et al., 2013.

In their study, Richardson et al. (2013) performed a series of regression analyses on these regulatory stringency data, comparing them against a variety of variables related to demographics, geography, geomorphology, hydrology, ecology, oil and gas development, economics, and politics. Despite a rigorous series of analyses, the authors found relatively few statistically significant associations that would explain the heterogeneity in state regulatory stringency for hydraulic fracturing. Among their results, however, were the findings that:

- In general, states with more gas wells tend to have more shale gas regulations.
- A greater proportion of federally owned land in a state is associated with slightly weaker hydraulic fracturing regulations.
- States with a higher degree of surface water and groundwater usage tend to have more stringent hydraulic fracturing regulations.

Most importantly, however, Richardson et al. (2013) noted that the degree of regulatory heterogeneity for hydraulic fracturing appeared largely arbitrary. To build on the findings from

Richardson et al. (2013), this study examines in greater detail whether states with a higher degree of familiarity with the oil and gas industry are associated with a particular level of regulatory stringency. Richardson et al., used regression analyses to identify the effects of a wide variety of independent variables, but only two pertained to familiarity: *conventional gas wells in 1970* and *conventional gas wells in 1990.*

4.1.2 Fossil fuel experience data and confounding variables

The analysis in this thesis builds on the analysis in Richardson et al. (2013) by including more comprehensive measures of familiarity with the oil and gas industry. It relies on four variables as proxies for familiarity: oil production from 1989-2000 (EIA, 2014a), natural gas wells active between 1989 and 2000 (EIA, 2014b), percent of resident workers employed in the oil and gas industry in 2011 (American Petroleum Institute, 2013), and percent of state GDP due to oil and gas in 2011 (American Petroleum Institute, 2013). These variables were chosen based on data availability and because the fact that they best represented “familiarity” with the oil and gas extraction industry. While post-2000 gas well and oil production data were available, we chose to exclude them from the analysis to avoid interactions with the dependent variable—relative stringency of shale gas regulations. The goal of the analysis is to examine how familiarity with oil and gas may have affected regulatory stringency, not how regulatory stringency may have affected growth of the oil and gas industry, and therefore requires truncation of the familiarity dataset to the years before hydraulic fracturing accelerated in the early 2000s. Data on oil and gas sector workforce and revenue characteristics from the 1990s were unavailable; future extensions of this study include reproducing this analysis with such datasets.

In addition to familiarity data, the analysis regresses regulatory stringency against 2012 population density (Census.gov population estimates, 2012) and "conservative advantage" (Gallup, 2014) in 2013. Population density describes the number of residents per square mile. Conservative advantage tallies the difference between the percentage of state residents describing their views as conservative and the percentage describing their views as liberal (Gallup, 2014). See Table 1 for a summary of these variables.

Table 1: Variables used in regulatory stringency analysis

Variable	Type	Years
Oil extraction in each state	Independent	1989 – 2000
Natural gas wells drilled in each state	Independent	1989 – 2000
Percent of state residents employed in oil & gas	Independent	2011
State GDP from oil & gas	Independent	2011
Population density	Confounding	2012
Conservative slant	Confounding	2013
Regulatory Stringency for fracturing	Dependent	2013

4.1.3 Regression analysis

Following the methodology from Richardson et al. (2013), both multiple and simple linear regression analysis were used to identify how particular levels of familiarity were associated with stringency of shale gas regulations in each state. As in Richardson et al. (2013), this study did not find evidence of robust associations. Figure 9 illustrates the relationship between familiarity with oil production from 1989-2000 and regulatory stringency for shale gas in 2013. Additional plots of the remaining independent and confounding variables are available in Appendix B.

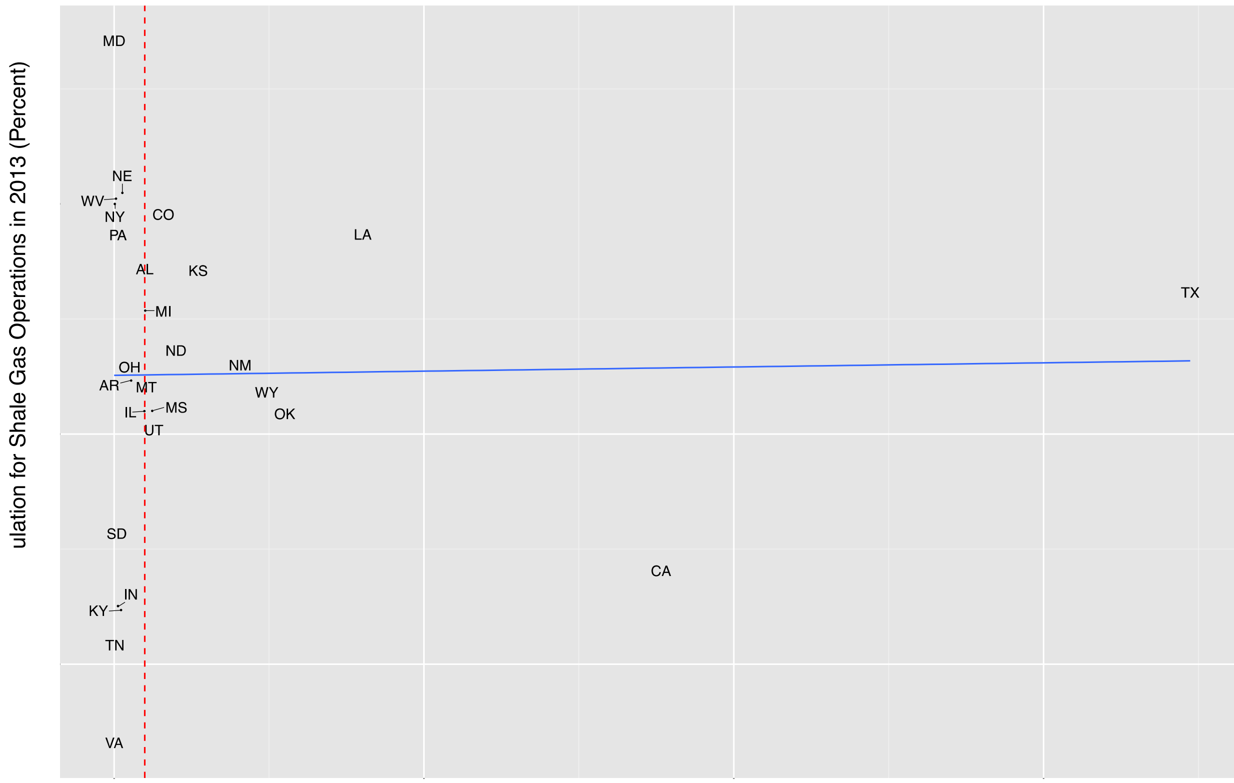


Figure 9: Scatterplot comparing states' oil production history and hydraulic fracturing regulatory stringency

4.1.4 Initial results and adjusted methodology

The blue trend line in Figure 9 shows the result of a simple regression of oil production and regulatory stringency; as indicated by the nearly flat slope of the line, the analysis could not find an association with 95 percent or greater statistical confidence. Similar results were found for all other independent and confounding variables (see Appendix B). While the analysis revealed insufficient evidence of a direct association between historic fossil fuel extraction experience and present day regulatory stringency for hydraulic fracturing, Figure 9 suggests that the group of states more familiar with relatively high levels of oil and gas production had a lower variation in regulatory stringency than the group of states with relatively low production levels. The 14 states to the left of the red dashed line are visually much more spread out than the 13 states to its right. This observation led to a new question: Do states that are more familiar with the oil and gas industry tend towards a common level of regulatory stringency?

Ultimately, the study relied on statistical analyses to detect relationships between independent variables and the level of variance (or consistency) in regulatory stringency *among* states. The association between familiarity and regulatory stringency was analyzed using variance tests to determine whether states with a higher degree of familiarity with the oil and gas industry (referred to here as "high familiarity states") had less variation in regulatory stringency than states less familiar with the industry ("low familiarity states"). In essence, these variance tests sought to determine whether high familiarity states had a larger degree of cross-state consistency. For each familiarity variable, the variance tests compared the bottom 52 percent of states in terms of familiarity to the top 48 percent (the dataset from Richardson et al. (2013) contained an odd number of states, making a 50/50 comparison impossible). Note that differences in regulatory variance between the two groups could exist even if the mean level of regulatory stringency was identical. The six scatterplots in Appendix B display the data we sought to analyze for each of our variance tests.

Two statistical tests were used to identify the relationship between familiarity and variance of regulatory stringency: the F-test and Levene's test. The F-test is the standard and most commonly used test for assessing homogeneity of variances between multiple groups. In this study, the F-test was used to assess the probability that the variances for the low familiarity group and the high familiarity group were heterogeneous. However, the F-test assumes that the standard error within each group is normally distributed; several of our datasets moderately violated this condition. To corroborate the results of the F-test and minimize the risk of erroneous results, an additional statistical test called Levene's tests was conducted. Like the F-test, Levene's test assesses the heterogeneity of variance among multiple groups, but unlike the F-test, it is non-parametric, meaning it does not require normal distributions.

4.2 Results

The statistical tests revealed a robust relationship between familiarity with the oil and gas industry and the variance of regulatory stringency across states. For each of the familiarity proxy variables, the high familiarity states had a lower variance in regulatory stringency than low familiarity states. That is, the high familiarity group of states was relatively more consistent in its regulatory stringency for hydraulic fracturing. Table 2 displays these results, which were statistically significant for all measures of familiarity, along with statistics on each group's mean, range, and standard deviation for regulatory stringency. For example, the group of states relatively familiar with oil extraction had less variation in regulatory stringency for fracturing than the group of states unfamiliar with oil extraction. Additionally, relatively rural states had a lower variance for regulatory stringency than did the group of more urban states. Conservative advantage showed some indication of an association with variance in regulatory stringency, but only for Levene's tests. Detailed results from the tests are displayed in Appendix B.

Table 2: Variance in regulatory stringency for test groups

Regulatory Stringency vs…	**Group**	**Mean**	**Standard Deviation**	**Range**	**Variance**
Oil extraction 1989-2000	Low familiarity	44.6	18.3	13 – 74	335
	High familiarity	45.9	8.2	28 – 59	67
Gas wells 1989-2000	Low familiarity	40.6	16.2	13 – 74	261
	High familiarity	50.2	9.8	25 – 60	96
State GDP from O&G	Low GDP share	40.9	17.7	13 – 74	313
	High GDP share	49.9	6.76	42 – 60	46
Workforce in O&G	Low workforce share	42.1	18.2	13 – 74	332
	High workforce share	48.6	6.92	40 – 60	48
Population Density	Low population density	47.6	8.57	31 – 61	73
	High population density	42.6	18.37	13 – 74	337
Conservative Advantage	Low conservative advantage	47.7	16.3	13 – 74	265
	High conservative advantage	42.5	11.4	22 – 60	129

Violin plots were constructed to visually assess differences between groups. Note that violin plots with relatively short vertical heights represent relatively low variance. The plots also display median (white dot), range (black line), and the middle 50 percent of data (black rectangle). The shape and top-to-bottom height of each plot represents the distribution of data.

Figure 10 illustrates the comparison the regulatory stringency of states familiar with oil extraction with that of states unfamiliar with oil extraction. Recall that to build these two groups, states were ranked according to total oil production between 1989 and 2000 and then the bottom half of states were placed in the "low familiarity" group (left violin plot) and the top half in the "high familiarity" group (right violin plot). The low familiarity group ranges from a minimum of 13 percent stringency to a maximum of 74 percent stringency, its median is 48.5, and its 25th and 75th percentiles are 26.5 and 59.3, respectively. The high familiarity group ranges from 28 to 59, its median is 44, and its 25th and 75th percentiles are 42 and 52, respectively. Based on the shapes of the low and high familiarity groups, it is apparent that the high familiarity group has a tighter distribution, while the low familiarity group is more spread out. These observations imply that the high familiarity group has less variation than the low familiarity group. Additional plots are included in Appendix B.

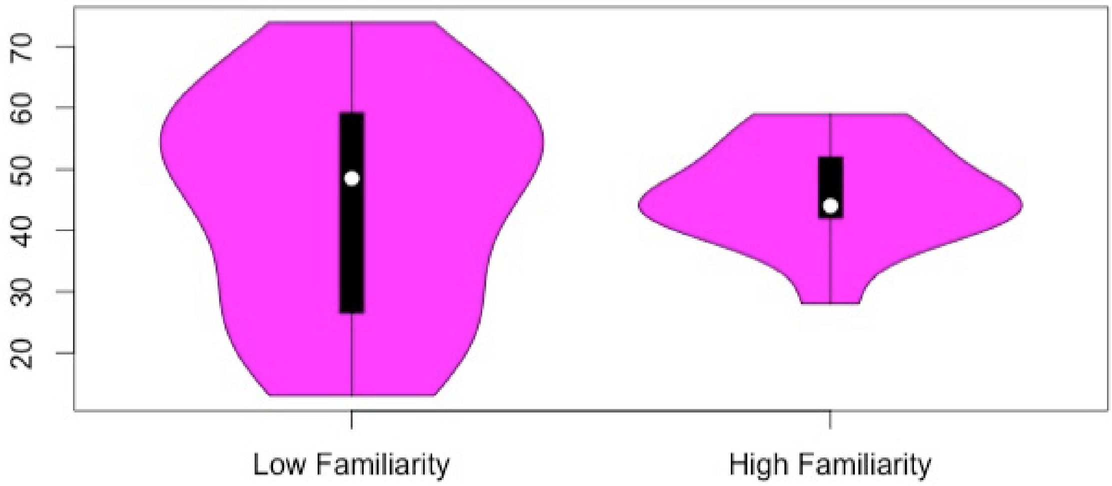


Figure 10: Distribution of hydraulic fracturing regulatory stringency for states familiar and unfamiliar with oil extraction

The F-test for variance showed, with 99 percent confidence, that three familiarity variables had a statistically significant association with regulatory variance: oil production between 1989 and 2000, portion of state GDP due to the oil and gas industry, and percent of resident workers in the oil and gas industry. Additionally, the F-test found with greater than 95 percent confidence an association between population density and regulatory variance and with greater than 90 percent confidence an association between active gas wells between 1989 and 2000 and regulatory variance.

Levene's test showed an association between all of our independent variables and regulatory variance with at least 95 percent confidence. Moreover, the test showed with more than 99 percent confidence that four variables—oil production, number of gas wells, percent of workforce in the oil and gas industry, and population density—had a statistically significant association with regulatory variance.

4.3 Discussion

This statistical analysis showed that states with a robust history of oil and gas development tended to converge on a relatively similar level of regulatory stringency for hydraulic fracturing. Conversely, states unfamiliar with oil and gas extraction were more unpredictable in their level of regulatory stringency for shale operations: some regulated quite stringently while others regulated scarcely at all.

This analysis lends support to the idea that risk perceptions are at least partially based on familiarity (Slovic, 1987). State regulators familiar with the risk of oil and gas operations may have better understood which aspects of hydraulic fracturing needed to be regulated and which did not. Conversely, regulators in states unfamiliar with the oil and gas industry may have been forced to make more subjective judgments that may in turn have been more vulnerable to public preferences. Despite the fact that regulators are ostensibly experts making probabilistic judgments about risk levels, a public fearful of an unfamiliar hazard may prompt policymakers to regulate more stringently (Singelton, 2007). Each population perceives hazards differently, and risk perceptions may be amplified and dampened by complex interactions with cultural and institutional systems (Kasperson et al., 1988). Among states unfamiliar with the oil and gas industry, those that lean liberal may prefer to err on the side of over-regulation, while those that lean conservative may prefer to err on the side of under-regulation. Meanwhile, states familiar with the industry can rely on empirical data rather than regulatory preferences.

This observation has important implications for developers and policymakers hoping to increase certainty for carbon storage projects. Developers may increase siting success by locating carbon storage projects in states familiar with oil and gas extraction. These states are more likely to have developed a more stable and predictable set of regulations related to the use of underground resources.

4.4 Key Chapter Findings

- States with a robust history of oil and gas development tended to converge on a relatively similar level of regulatory stringency for hydraulic fracturing.
- States already familiar with oil and gas operations may provide more stable and predictable regulatory environments for carbon storage projects.

Chapter 5: Case Study Analysis of Hydraulic Fracturing Regulations

To better understand the interplay between communities, stakeholder groups, and regulators, a comparative case study was conducted on the development of hydraulic fracturing regulations and industries in states of Pennsylvania, New York, and Colorado. These case studies elucidate the more nuanced and less quantifiable aspects of public acceptance, and also help identify potential causal mechanisms that could lead to high or low regulatory stringency in a state.

5.1 Methodology

New York State, Pennsylvania, and Colorado are ideal case studies for two reasons. First, Pennsylvania and New York State states lay over the Marcellus shale play, which is perhaps the nation's richest deposit of trapped natural gas (EIA 2014c). Due to the geomorphology shared by New York State and Pennsylvania, hydraulic fracturing operations and risks should be relatively unchanged across state borders. Nevertheless, each state has taken a different tack in policymaking for hydraulic fracturing. Pennsylvania has largely welcomed the industry, while the New York State Assembly recently voted in favor of banning the practice until 2017 (Kuzmich, 2014). The combination of similar geomorphology and dissimilar hydraulic fracturing governance strategies sets the stage for an interesting comparison. Colorado serves as an ideal control for the case study, as it too has substantial natural gas deposits but is located 1,500 miles west of Pennsylvania and New York State. Furthermore, Colorado's oil and gas politics are more heterogeneous than those of Pennsylvania and New York State.

Second, due to the wealth of natural gas locked in the Marcellus and Niobrara shale deposits, fracturing policy developments in these two regions have been widely reported on and documented. The existence of this relatively large trove of case data makes the comparison of Pennsylvania, New York State, and Colorado more comprehensive than comparisons of other states. This paper is certainly not the first to compare how regulatory strategies for hydraulic fracturing differ among the states (Krancer, Hill, and Tamulonis, 2014; Goho, 2012). However, it is one of the first attempts to examine the connections between the regulatory front, community acceptance, and industry growth. Moreover, it represents the first time these issues have been scrutinized for lessons germane to carbon storage.

The governance structures for hydraulic fracturing in Pennsylvania, New York State, and Colorado are dynamic. One common thread between the states is the consistent movement toward regulation at the local level. In fact, this process began in 2005, when the US federal government ceded regulatory control of many aspects of fracturing to the states. In 2008, as fracturing in the Marcellus region accelerated, New York State instituted a statewide moratorium on the industry. That same year, however, local zoning actions aimed at hydraulic fracturing in both Pennsylvania and New York State prompted the balance of regulatory power to shift from the state level to the municipal level. Interestingly, many of these events took place before hydraulic fracturing reached the attention of the US public (see Figure 11).

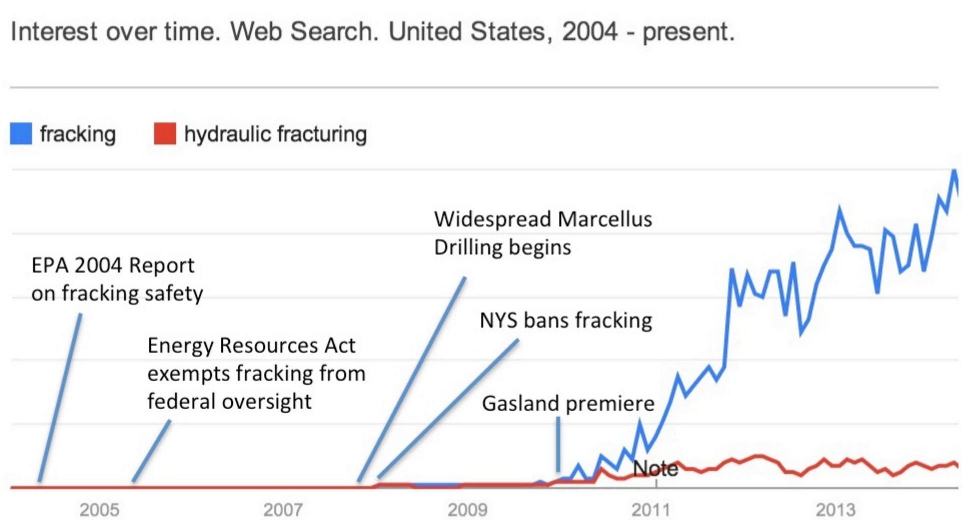


Figure 11: Google searches for "hydraulic fracturing" and "fracking." 2004-2014. (Google Trends).

Understanding the variation in states' hydraulic fracturing regulations requires the context afforded by a discussion on the National Energy Policy Act of 2005 (Rahm, 2011). In response to a 1997 groundwater pollution incident caused by a coal bed methane fracturing operation in Alabama, the US Court of Appeals for the 11th Circuit ordered US EPA to regulate hydraulic fracturing under its Safe Drinking Water Act (SDWA) authority. EPA responded to the order by undertaking a study on the risks that coal bed hydraulic fracturing operations posed to drinking water supplies, concluding that the practice was safe. That study, which EPA completed in 2004, as well as recommendations from the White House Energy Task Force, prompted the passage of the National Energy Policy Act (NEPA) of 2005. In passing NEPA, Congress exempted hydraulic fracturing from regulation under the SDWA. In its wake, states took responsibility for regulating fracturing to protect human health and the environment, albeit with varying degrees of stringency.

5.2 Pennsylvania

Hydraulic fracturing did not become a major industry in Pennsylvania until around 2008, as is evident from Figure 12. In the first quarter of that year, however, leasing prices for mineral rights jumped from $300 per acre of land to $2100 per acre (Krauss, 2008). Over the next two years, drilling increased by nearly five fold. By 2011, Pennsylvania accounted for more than 5 percent of domestic gas supply (EIA, 2012).

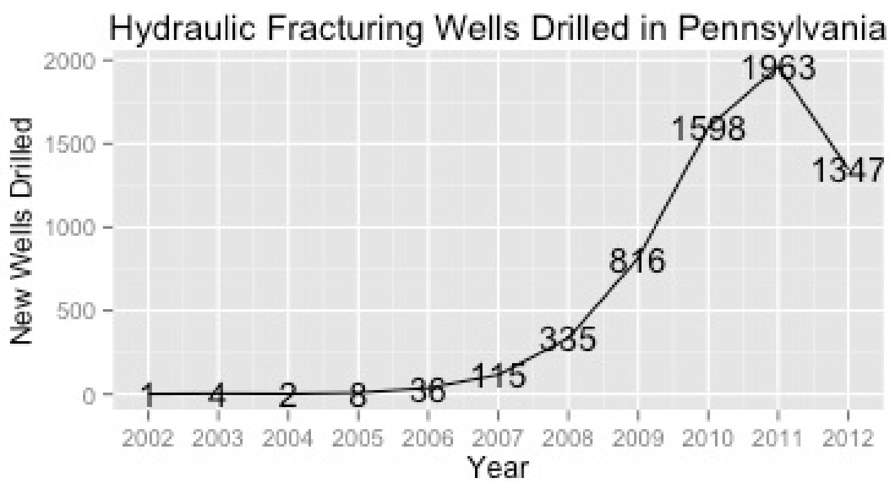


Figure 12: New fracturing wells in PA, 2002-2012

As drilling efforts expanded during 2008 and 2009, a series of incidents, including the infamous Dimock explosion, prompted many Pennsylvania municipalities to impose local regulations on hydraulic fracturing (Food&WaterWatch, n.d.). Developers and drilling lobbies such as the Marcellus Shale Coalition argued that the resulting patchwork of zoning, setback, and safety regulations hampered industry growth by increasing the cost of compliance (Detrow, 2012). Reacting to industry concern in early 2012, the Pennsylvania General Assembly passed Act 13, which amended the Pennsylvania Oil and Gas Act to establish standard, statewide zoning and setback regulations but simultaneously restricted municipalities' right to pass similar local regulations (PA Act 13 HB 1950, 2012). At least ostensibly, the law was intended to protect human health and the environment while affording industry the consistency it needed to continue expanding. To do so, Act 13 relied on a legal principle called "preemption," which allows state authority to supersede and constrain local authority.

Preemption of local ordinances by state law is not automatic, however. Most states, including Pennsylvania, have a constitutional provision called "home rule," which grants municipalities regulatory authority over matters of local concern (Goho, 2012). Local ordinances created under the auspices of the home rule are generally protected from state interference. The ordinances made possible by the home rule afford municipalities a degree of control over the local impacts of oil and gas drilling, potentially bolstering community acceptance for practices such as hydraulic fracturing. Pennsylvania's constitution in particular contains a section dating back to the 1970s called the Environmental Rights Amendment (ERA), which expressly guarantees state residents access to clean air, pure water, and preserved natural spaces (Pennsylvania Constitution, Art. I, § 27). Though the ERA names the Commonwealth as the trustee of the environment, municipalities are responsible for implementing regulations and ordinances necessary for protecting the local environment (conserveland.org, 2014). Thus, the amendment is a type of home rule, allowing municipalities the latitude to protect the wellbeing of residents by implementing ordinances that are limited but nonetheless immune to state interference. In a pair of 2009 cases, the Pennsylvania Supreme Court affirmed this interpretation of the ERA and clarified the relationship between state preemption and home rule, explaining that the Commonwealth could preempt local ordinances that dictate fracturing well permitting and monitoring procedures but could not preempt local ordinances pertaining to well zoning and setbacks (Goho, 2012). For example, the Pennsylvania Oil and Gas Act could nullify a Dryden, PA, ordinance requiring pre-drilling testing of a new well, but not an ordinance forbidding drilling within 1000 feet of a residential area. This tradeoff between preemption and home rule, state and local governance, helped strike a balance between achieving the consistency necessary for the growth of the fracturing industry and protecting the local environmental in order to bolster community wellbeing and acceptance.

With its enactment in February 2012, however, Act 13 amended the Pennsylvania Oil and Gas Act to preempt nearly *all* local regulations pertaining to hydraulic fracturing (PA Act 13 HB 1950, 2012). Almost immediately, Pennsylvania's state government faced a lawsuit from a group of municipalities, individuals, and interest groups in *Township of Robinson v. Commonwealth* (Krancer, Hill, and Tamulonis, 2014). In the case's 2013 decision, the court ruled that the preemptive parts of Act 13 were unconstitutional because, in forbidding municipalities from regulating zoning and setback issues, they violated the ERA (J-127A-D-2012). By invalidating portions of Act 13, the court in effect transferred responsibility for zoning and setback regulations back to Pennsylvania's municipalities. Interestingly, because the Richardson et al. (2013) study of state regulatory stringency took place before the court's decision in *Township of Robinson v. Commonwealth*, a repeat study might show that the stringency of Pennsylvania's state regulations has fallen, even as the state on balance gains regulatory stringency through municipal action. The ultimate effects of the case remain to be seen, however. Will a patchwork of inconsistent local regulations emerge once again and stymie industry investment? Will communities be more accepting of hydraulic fracturing now that they've won a greater degree of regulatory control over the process?

5.3 New York State

Despite occupying the same Marcellus shale play as Pennsylvania, New York State has taken a quite different regulatory approach. While the first modern fracturing well in Marcellus began producing only in 2002, the seeds for New York State's moratorium were sown much earlier, in 1978, when the state implemented the State Environmental Quality Review Act (NYDEC, 2014). That act requires that any action that might have a "significant adverse environmental impact" be assessed via an Environmental Impact Statement, or "EIS" (NYDEC, 2014). In 1992, the New York State Department of Environmental Conservation (NYDEC) released a Generic Environmental Impact Statement (GEIS) for oil, gas, and mineral development. A decade later, hydraulic fracturing began in Pennsylvania, and as the gas rush accelerated, companies such as Anschutz Energy began spending millions of dollars to accumulate tens of thousands of acres of mineral rights in southern New York State (Ayala, 2011). By 2008, the oil and gas companies began to approach NYDEC for drilling licenses and environmental activists began to hold community outreach meetings to advocate for stronger drilling regulations (Ayala, 2011). Of particular concern was the integrity of the New York City watershed, which sits directly atop the Marcellus region. The concern led to public interest groups and protesters to call for Albany to institute a statewide ban on hydraulic fracturing

(Ayala, 2011). In July 2008, Governor Patterson signed an executive order requiring NYDEC to update the 1992 GEIS with a new "Supplementary GEIS (SGEIS)" for hydraulic fracturing and forbidding hydraulic fracturing until after the release of the SGEIS (Krancer, Hill, and Tamulonis, 2014). The result was a de facto statewide moratorium on hydraulic fracturing, which has been renewed year after year as the NYDEC and Department of Public Health work to investigate the environmental and human health effects of hydraulic fracturing.

The latest legal actions on fracturing may have rendered the statewide moratorium moot. Starting in 2011, Dryden and several other New York State towns in the Marcellus region essentially banned fracturing through a combination of environmental, noise, and road use ordinances (Mufson, 2014). Anschutz Energy, having anticipated an eventual end to the statewide moratorium, sued, claiming that the local zoning regulations violated state oil and gas regulations. During summer of 2014, the New York State Court of Appeals awarded the lawsuit to the towns of Dryden and Middlefield, holding that the municipal ordinances limiting fracturing were within the local authority guaranteed under the home rule (NYS Court of Appeals, 2014). The majority opinion for the case explained that the justices did not believe the state law explicitly preempted local ordinances (Norse Energy v. Town of Dryden, 2014). The case legitimizes the large number of local fracturing regulations emerging across New York State: as of mid-2014, 178 New York State towns had instituted bans on fracturing, while 87 had issued binding and nonbinding resolutions supporting industry by prohibiting bans (FracTracker.org, 2014; see Figure 13). As in Pennsylvania, regulatory control over hydraulic fracturing in New York State began moving to the local level.

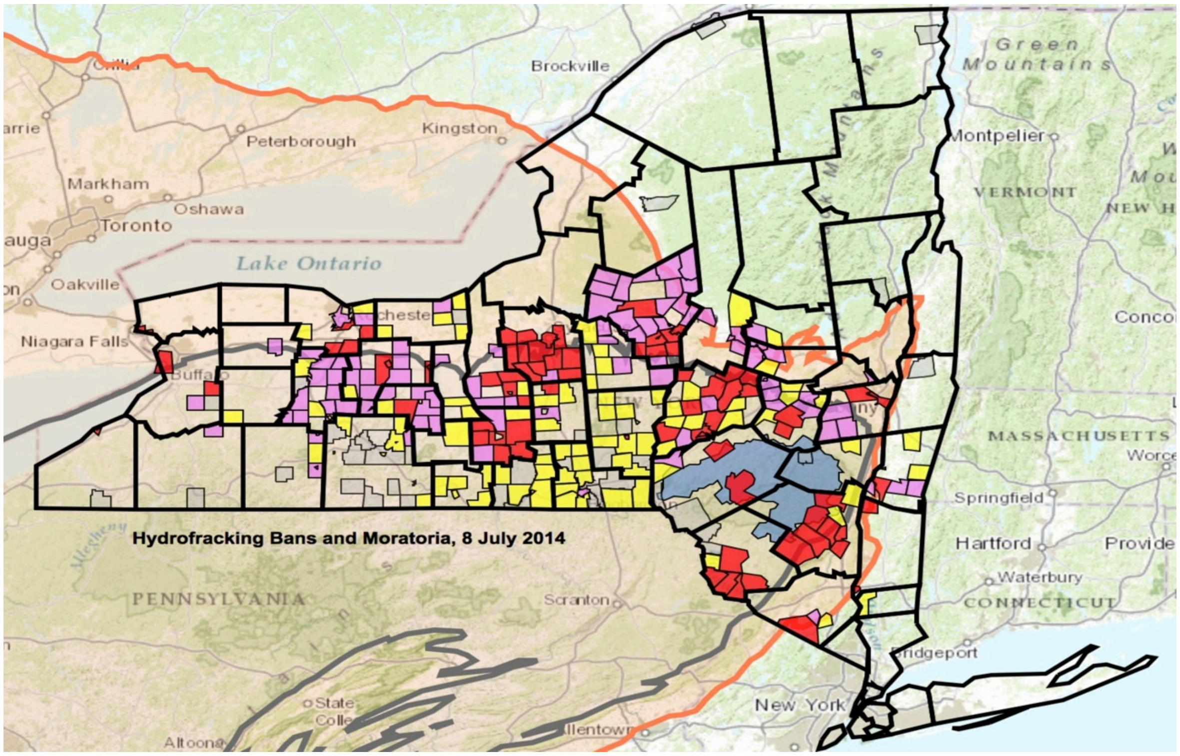


Figure 13: Local bans and moratoria in New York State as of July 2014. Bans in red; moratoria in purple; proposed bans in yellow; pro-fracturing areas in grey; blue polygon depicts New York City watershed; orange line depicts extent of Marcellus shale play. (Fractracker.org, 2014)

Meanwhile, the on-going moratorium prevented thousands of landowners and dozens of oil and gas firms from capitalizing on the natural gas deposits. By 2008, for example, Anschutz Energy had spent almost $5 million to acquire leases on 22,000 acres in New York State (Ayala, 2011). The moratorium not only prevented Anschutz from recouping these costs, but also barred landowners from capturing additional royalties for gas extraction. In November 2013, the Joint Coalition of Landowners of New York State announced a draft complaint alleging that political motivations had prompted the state administration to repeatedly postpone the updating of the SGEIS (Krancer, Hill, and Tamulonis, 2014). The resulting moratorium, the complaint alleged, represented an unconstitutional "taking" of mineral rights, an unauthorized seizure of private property (Krancer, Hill, and Tamulonis, 2014). The group sued in early 2014, calling for New York State to expedite the SGEIS process (Moody, 2014), but the case was dismissed at court (Litvak, 2014).

At a cabinet meeting on December 18, 2014, Governor Andrew Cuomo announced a decision to impose an indefinite ban on large-scale hydraulic fracturing in New York State

(Cuomo administration meeting video log, 2014). The announcement coincided with the New York Department of Health's long awaited release of its "Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development" (NYS Dept. of Health, 2014). The report recommended that high volume hydraulic fracturing not proceed in New York State until "the science provides sufficient information to determine the level of risk to public health from high volume hydraulic fracturing to all New Yorkers and whether the risks can be adequately managed."

This lack of sufficient information constituted the report's main theme: the document posited not only that the costs of hydraulic fracturing in New York State might outweigh the benefits, but that there exists so much scientific uncertainty around the health effects of hydraulic fracturing that traditional cost benefit analysis is not possible at this point. The report cited several potential impacts of hydraulic fracturing, including air and water pollution, greenhouse gas emissions, earthquakes, and socioeconomic effects. In each of these areas, though, Acting Health Commissioner Dr. Howard Zucker pointed out that policymakers could not make an accurate risk assessment based on the information available today. His report states in its conclusion that while ongoing studies may eventually supply the necessary information for a true cost benefit analysis, it is not currently possible to determine with sufficiently high confidence whether overall risk is sufficiently low enough for hydraulic fracturing to proceed in New York State. During the cabinet meeting (Cuomo Administration, 2014), the commissioner stated his feelings more plainly, saying that based on the current information and lack thereof, "Would I let my child play in a school field nearby [hydraulic fracturing sites] or let my family drink the water from the tap or grow their vegetables in the soil?... my answer is no." Dr. Martens, Commissioner of the New York Department of Environmental Protection, added that hydraulic fracturing's potential benefits for New York State are limited by regulations that forbid operations in more than 60 percent of the area occupied by the Marcellus Shale.

5.4 Colorado

Colorado is home to two distinct shale plays: the Niobrara formation located primarily in the northeastern corner of the state, and the smaller Gothic formation located primarily in the southwestern corner (USGS, 2012). The Niobrara shale alone is estimated to hold as much as 2 billion barrels of recoverable oil (Stark, 2013) and one of the largest natural gas reserves in the world. The abundance of energy resources has incentivized an influx of development over the last decade: since 2007, Colorado has seen between 2,000 and 4,000 well starts each year (COGA, 2012). Even as Colorado has become an important site for unconventional drilling, recent analysis has shown that hydraulic fracturing in Colorado creates large risks—such as water shortages—relative to other states (Freyman, 2014).

Colorado's political leadership has demonstrated a keen recognition of both the opportunities and risks of hydraulic fracturing. The state's governor, John Hickenlooper, is a moderate democrat who worked as a petroleum geologist before entering politics (Politico, 2011). His administration has sought to encourage development of state energy resources while maintaining relatively stringent environmental health and safety regulations on the drilling industry. Moreover, this stance is borne out by the Colorado Oil and Gas Conservation Act (COGCA), which gives the Colorado Oil and Gas Conservation Commission (COGCC) the authority to regulate:

> …oil and gas operations so as to prevent and mitigate significant adverse environmental impacts on any air, water, soil, or biological resource resulting from oil and gas operations to the extent necessary to protect public health, safety, and welfare, including protection of the environment and wildlife resources, taking into consideration cost-effectiveness and technical feasibility (COGCC, 2014)

A revised version of OGCA took effect in April 2012 and requires operators to publicly disclose the composition of the fluids used for hydraulic fracturing (CO Code Regs. § 404-1:205A(b)(2)(A), 2011). The Act makes an exception for fluid mixtures that could be considered a trade secret, but in such cases companies are still required to identify the chemical composition of the mixture to the COGCC. The revised OGCA also requires operators to provide landowners within 500 feet of a proposed well with an information sheet on hydraulic fracturing, and provide the COGCC with a written notice of intent to drill at least 48 hours before drilling commences (CO Code Regs. § 404-1:205A(b)(2)(A), 2011).

In 2013, the COGCC voted to approve the new "Statewide Groundwater Baseline Sampling and Monitoring" rule, the first such law in the nation, which requires operators to collect baseline water samples from aquifers, existing wells, and other water sources within a half mile of proposed wells (Streater, 2013). In February 2014, the Colorado Air Quality Control Commission (CAQCC) instituted a series of emissions regulations capping methane and volatile organic compound emissions from natural gas operations across the state (Baumstark, 2014). Governor Hickenlooper called on industry groups—including Encana, Anadarko Petroleum, Noble Energy, and DCP Midstream Denver—and environmental advocacy groups—including Environmental Defense Fund, Conservation Colorado, EarthJustice, Sierra Club, Natural Resources Defense Council, WildEarth Guardians, and the Earthworks Oil and Gas Accountability Project—to work together collaboratively toward the formulation of the new fugitive emissions rules (Baumstark, 2014). The resulting regulations directly police emissions throughout the natural gas system; both the regulations themselves and their stakeholder-centric development process have been hailed as a template for the rest of the nation (Goldberg, 2015).

Despite the Hickenlooper administration's desire to strike a balance between exploitation of oil and gas reserves and assurance of environmental safety, Colorado has become another legal battleground between drilling advocates and opponents. In 2012, the City of Longmont imposed new local ordinances restricting drilling from residential areas and requiring that water quality be monitored for five years after wells are hydraulically fractured (City of Longmont, 2015).

The new regulations caused an outcry amongst industrial stakeholders, and prompted the COGCC to sue Longmont, maintaining that state laws preempted the local ordinances. Governor Hickenlooper supported the lawsuit and criticized the actions of the Longmont city council, saying that the de facto hydraulic fracturing ban would put pressure on other communities to follow suit and could result in an inefficient patchwork of local regulations (Kenworthy, 2012). Longmont, however, asserted its right to protect the wellbeing of its residents and the local environment (Kenworthy, 2012). Also in 2012, a citizen ballot initiative in the November polls succeeded in banning hydraulic fracturing entirely in Longmont. The movement behind that ban first began taking form in 2011 when residents learned that drilling was to take place near a scenic lake called Union Reservoir (Healy, 2015). An environmental advocacy campaign emerged, and was ultimately successful in convincing voters to approve the ballot initiative for a ban despite being outspent ten to one by an industry public relations effort during the campaign. It was estimated that the ban stranded up to $500 million of oil and natural gas below Longmont, CO (Kenworthy, 2012).

In October 2014, the COGCC dropped the state's suit against the Longmont hydraulic fracturing restriction and water testing regulations, and the court granted a Stipulated Dismissal of All Claims and Covenant Not to Sue, forbidding similar suits against Longmont in the future (City of Longmont, 2014). However, the COGCC and the Colorado Oil and Gas Association (COGA) opened a second suit in challenging the citizens' fracturing ban. In July 2014, a Boulder Country Judge struck down the ban, citing preemption by the COGCA (Rochat, 2014). By the end of 2014, Longmont had spent about $136,000 arguing the case (Healy, 2015).

5.5 Discussion

The legal and regulatory events surrounding hydraulic fracturing in Pennsylvania, New York State, and Colorado have several implications for future carbon storage efforts.

First, municipalities are increasingly taking legal action to ensure a high degree of local regulatory control over hydraulic fracturing. Cities and towns in New York State, Pennsylvania, and Colorado have utilized zoning laws to impose local bans and moratorium over hydraulic fracturing, and have proven themselves willing to defend the legality of such ordinances in court. In turn, courts in New York State and Pennsylvania have tended to side with municipalities, ruling that state oil and gas acts cannot implicitly preempt local ordinances protected by the home rule. Such rulings should be viewed as an endorsement of municipalities' right to protect their local environment rather than as a rejection of hydraulic fracturing itself. It is unclear whether state oil and gas acts that attempt to explicitly supersede local environmental ordinances would be successful in doing so. Colorado's Oil and Gas Conservation Act most explicitly attempt to preempt local regulations, and the 2014 court decision did in fact validate the state in doing so. Yet that case may soon head to the appellate circuit. It is also uncertain whether municipalities could use the home rule to pass pro-fracturing ordinances as a means for improving local economic wellbeing. These are areas for future legal research.

The carbon storage industry should seek to better understand how local regulations and community acceptance could impact injection activities. Oil and gas firms have traditionally focused on anticipating and influencing regulations at the state and federal levels, but storage firms should be prepared to engage decision makers and citizens at the municipal level. This need not necessarily lead to dramatic cost increases. Future research should strive to create a typology of municipal zoning frameworks such that storage firms can quickly and efficiently respond to local concerns and ordinances.

Second, the oil and gas industry has demonstrated a similar willingness to challenge local regulations restricting drilling. In Longmont, CO, for example, industry groups spent over a half million dollars advocating (unsuccessfully) against the 2012 fracturing ban ballot initiative and then several hundred thousand dollars more suing the city in 2014 after the ban took effect. These expenditures are unsurprising in light of the value of oil and gas that might be extracted through hydraulic fracturing—nearly $500 million under Longmont alone.

It is difficult to predict whether the oil and gas industry would expend similar quantitates of time and effort to defend carbon storage operations against public opposition and local regulatory obstruction. Oil and gas companies spend resources to affect public acceptance because local opposition has the potential to block extraction of resources with real value. The fact that the industry fights local opposition to drilling implies that the current value of natural gas is enough to incentivize such efforts. A simple analysis was performed to identify a range of CO_2 prices that corresponds to current natural gas price levels. In 2014, the Henry Hub spot price for natural gas averaged about $4.50 per million British Thermal Units (MMBtu) (EIA, 2015). It is reasonable to assume that a roughly similar hub price for CO_2 would be sufficient for the oil and gas industry to mount a comparable defense of carbon storage, though it is unclear whether lower prices could also be sufficient.

The analysis sought to identify per-ton CO_2 prices that correspond with Henry Hub natural gas prices. To conduct the analysis, which was performed using Microsoft Excel, Henry Hub natural gas prices were first converted from dollars per MMBtu to dollars per thousand cubic feet (Mcf). An assumption was imposed that CO_2 and natural gas have similar volumetric costs in terms of dollars per Mcf, and then CO_2 costs were converted from volumetric-based ($/Mcf) to mass-based ($/ton). This indicated that a per-ton CO_2 price in $/ton must be about 20 times greater than a given natural gas price in $/MMBTU to incentivize a similar level of action among industry players.

Figure 14 illustrates the result of this simple volume-to-mass conversion to demonstrate the per-ton CO_2 price that corresponds to a given per-MMBTU gas price. A gas price of $4.50 per MMBTU corresponds to nearly $100 per ton CO_2.

Moreover, the Henry Hub prices used in this calculation cover costs related to natural gas extraction and transportation—meanwhile, the CCS industry faces similar costs from injection and transportation, plus the additional and much more substantial cost of capture. These calculations therefore likely underestimate the CO_2 price corresponding with current natural gas prices. That said, even a natural gas price of $2.50 per MMBTU equates to a carbon price of $50 per ton, which is higher than the current $37 U.S. social cost of carbon estimate for 2015 at a 3 percent discount rate (Interagency working group on the social cost of carbon, 2013). These calculations indicate that without a very high carbon price, industry may not be incentivized to contest local opposition to carbon storage with the same enthusiasm as is currently seen in the fight against municipal hydraulic fracturing bans. A qualitative discussion of the uncertainties that developers face is presented in Appendix A.

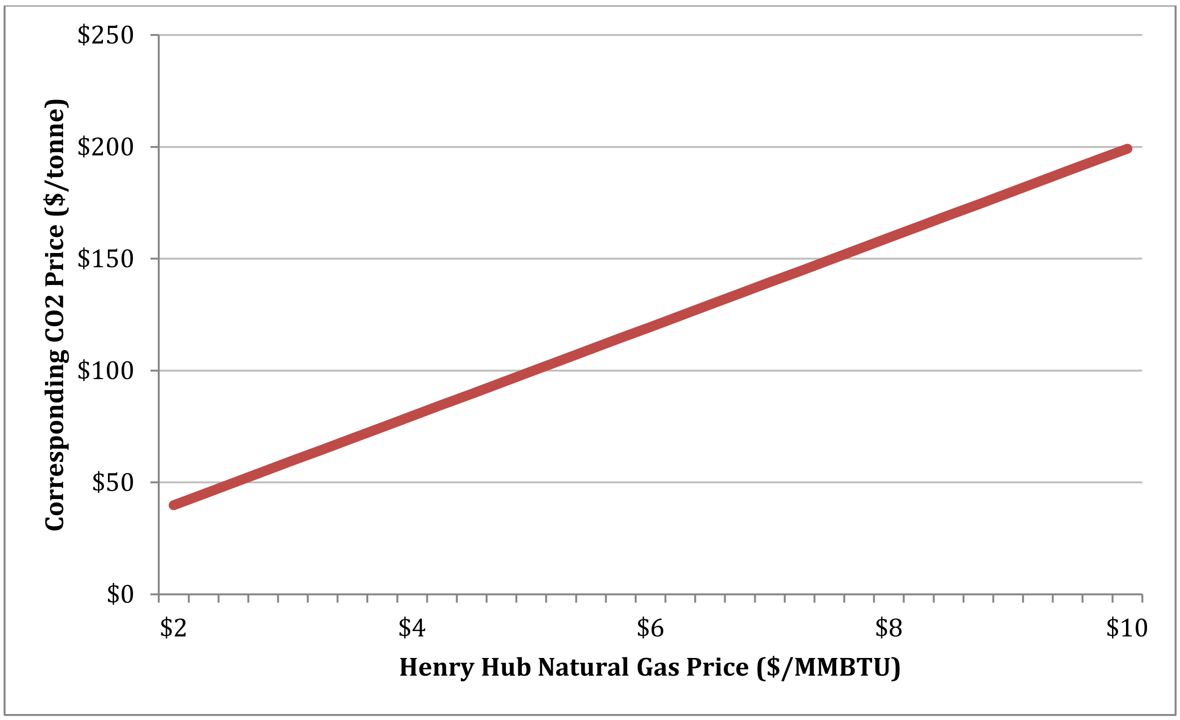


Figure 14: CO_2 prices corresponding to Henry Hub natural gas prices. Assumes that CO_2 and natural gas have equivalent volumetric costs in $/MCF

Third, large urban areas may successfully capture state oil and gas regulations and impose environmental restrictions such as statewide bans or moratoria. The most common justification for New York State's moratorium on hydraulic fracturing has been that the New York City watershed lies atop the Marcellus shale play. While local hydraulic fracturing regulations may create a “patchwork” problem that drives up industry costs due to inconsistent regulations, an emphasis on standardized statewide regulations increases the possibility of such capture by large urban areas. This implies a tradeoff: the energy industry's drive for regulatory consistency over large areas may help eliminate the inefficiencies of patchwork regulations, but it creates a situation in which anti-CCS policies have the opportunity to dominate entire states (or nations). More research is necessary to determine how and how often large urban centers influence statewide oil and gas regulations. Carbon storage firms should be prepared to at least initially avoid locating operations near large urban centers and their watersheds.

Fourth and finally, many of the most important decisions related to public acceptance of hydraulic fracturing—the ERA of 2005, the exponential increase in shale extraction in Pennsylvania, New York State’s moratorium, the influx of operators into Colorado—took place before much of the US public had even heard of the technique. The frameworks that emerge from such decisions have tended to become “locked in” as the industry developed and public awareness grew. While some Pennsylvania municipalities may decide to ban fracturing, the technique has become an economic engine for the state and is unlikely to vanish anytime soon. In New York State, political pressure from New York City and from environmental activists across the country has compelled the governor to renew the moratorium year after year and more recently institutionalize it as law.

5.6 Key Chapter Findings

- Municipalities are increasingly taking legal action to ensure a high degree of local regulatory control over hydraulic fracturing. Similar legal battles for local regulatory control of carbon storage projects may be likely in the future.
- State policymakers are challenged to balance the municipalities' right to protect local interests and industry's desire for uniform oil and gas regulations. It is currently unclear whether carbon storage will be regulated primarily by federal or state authorities, but policymakers at all levels of government should be expected to face tradeoffs between local, regional, and national interests.

- The oil and gas industry has shown itself willing to challenge municipal hydraulic fracturing bans in court. Storage projects may not provide industry with enough financial incentive to prompt a similarly vigorous legal defense.

Chapter 6: Survey analysis

This chapter analyzes two nationally representative surveys on hydraulic fracturing and CCS—one from the U.S. and one from the U.K. These surveys and the associated data analysis serve two purposes. First, they empirically assess the extent to which hydraulic fracturing might serve as a technological analogue for CCS. Second, they identify public attitudes toward CCS and hydraulic fracturing—and the demographic, familiarity, worldview factors associated with those attitudes—more directly than do the analyses in previous chapters, which instead characterize the association between public acceptance and the regulatory environment for the technologies. As such, the goals of this survey analysis are to quantitatively assess:

- The similarities in respondent acceptance between hydraulic fracturing and CCS
- The factors relevant to public acceptance of each technology
- Compensation as a potential solution for increasing public acceptance
- The extent to which each of these elements vary between the US and the UK

6.1 Methodology: Survey Design and Distribution

This survey analysis is the result of an ongoing partnership between researchers at MIT and the University of Cambridge, in collaboration with two survey contractors. MIT researchers conducted similar projects in 2003, 2006, 2009, and 2012, with varying levels of analysis.

The analysis in this chapter relies upon two separate survey datasets (see Table 3: Survey Designs). Researchers at MIT and the University of Cambridge collaborated on the design of both surveys, which this chapter will refer to as the "US survey" and the "UK survey." Both surveys asked questions intended to understand respondents' perspectives and preferences on tradeoffs between economic and environmental security, climate mitigation strategies, and familiarity with clean energy technologies. Questions were phrased similarly in order to allow for comparison across countries. Both surveys also included experimental questions using a modified willingness-to-pay method to characterize the effects of compensation on public acceptance of nearby energy siting. In addition to the question responses, both surveys collected a variety of demographics data from respondents, such as age, income, education level, location. Questions and demographic categories for each survey are available in Appendix C.

GFK, a consumer information company, administered the US survey, while YouGov administered the UK survey. The use of third party survey contractors helped to achieve representative sampling. GFK recruits respondents through address-based sampling, which ensures that hard-to-reach groups such as young adults and other demographics without traditional landline phone numbers are included in the survey population. The firm also provides laptops and internet access to non-internet households. YouGov uses internet-based "active sampling" approach to select a sample from within a larger panel of regular respondents. These approaches ensured that the US survey generated a representative sample of the United States population, and the UK survey was similarly representative of Great Britain (i.e., England, Wales, and Scotland).

Table 3 describes the surveys. The UK survey preceded the US survey by about eight months: its questions were finalized in May 2014 and survey distribution commenced in June 2014, while the US survey was finalized in January 2015 and distributed during March 2015. With 25 questions and 2,080 respondents, the UK survey was much large than the US survey, which contained four questions and garnered 1,012 responses.

Table 3: Survey Design Comparison

Attribute	**US Survey**	**UK Survey**
Location of survey	United States	United Kingdom
Survey Research Firm	GFK	YouGov
Date of survey	March 2015	May 2014
Number of respondents	1,012	2,080
Number of questions	4	25
Number of experimental questions	1	3
Technological focus	CCS, hydraulic fracturing	CCS, hydraulic fracturing, nuclear power

Experimental design	Half of respondents were asked "willingness to accept payment" questions intended to identify an effective level of monthly compensation for nearby siting of GS. The remaining respondents received a similar question related to nearby siting of hydraulic fracturing. Each group was offered initial compensation of $500 per month, which then increased to $1,000, $2,500, and finally $5,000.	Each respondents was asked "willingness to accept payment" questions intended to identify an effective level of one-time compensation for nearby siting of CO_2 pipelines, hydraulic fracturing, and a nuclear power plant. Initial payment amounts were derived randomly from a uniform distribution spanning from £1,000 to £10,000. Each payment was then halved and re-offered if the respondent accepted or doubled and re-offered if the respondent refused.

6.2 US Survey Results

6.2.1 Familiarity with energy technologies

The US survey included a question asking respondents: "Have you heard of or read about any of the following in the past year?" The list of technologies, from which respondents could select all that applied, included hydraulic fracturing and carbon capture and storage, as well as two aliases for each technology: "fracking" and "shale gas", "carbon sequestration" and "clean coal." Table 4 lists the results from this question; respondents could choose multiple technologies or "none of these." Figure 15 illustrates changes in familiarity over time, comparing results from the current survey to similar surveys from 2003 – 2012.

Table 4: Responses to question: "Have you heard of or read about any of the following in the past year?"

Technology or Energy Source	Heard or read about (%)
Hybrid cars	66
Solar energy	65
Fracking	56
Wind energy	55
Nuclear energy	43
More efficient appliances	41
Hydraulic fracturing	31
Shale gas	28
Clean coal	25
Hydrogen cars	24
Bioenergy / biomass	16
Carbon capture and storage	10
Carbon sequestration	8
Iron fertilization	3
None of these	18

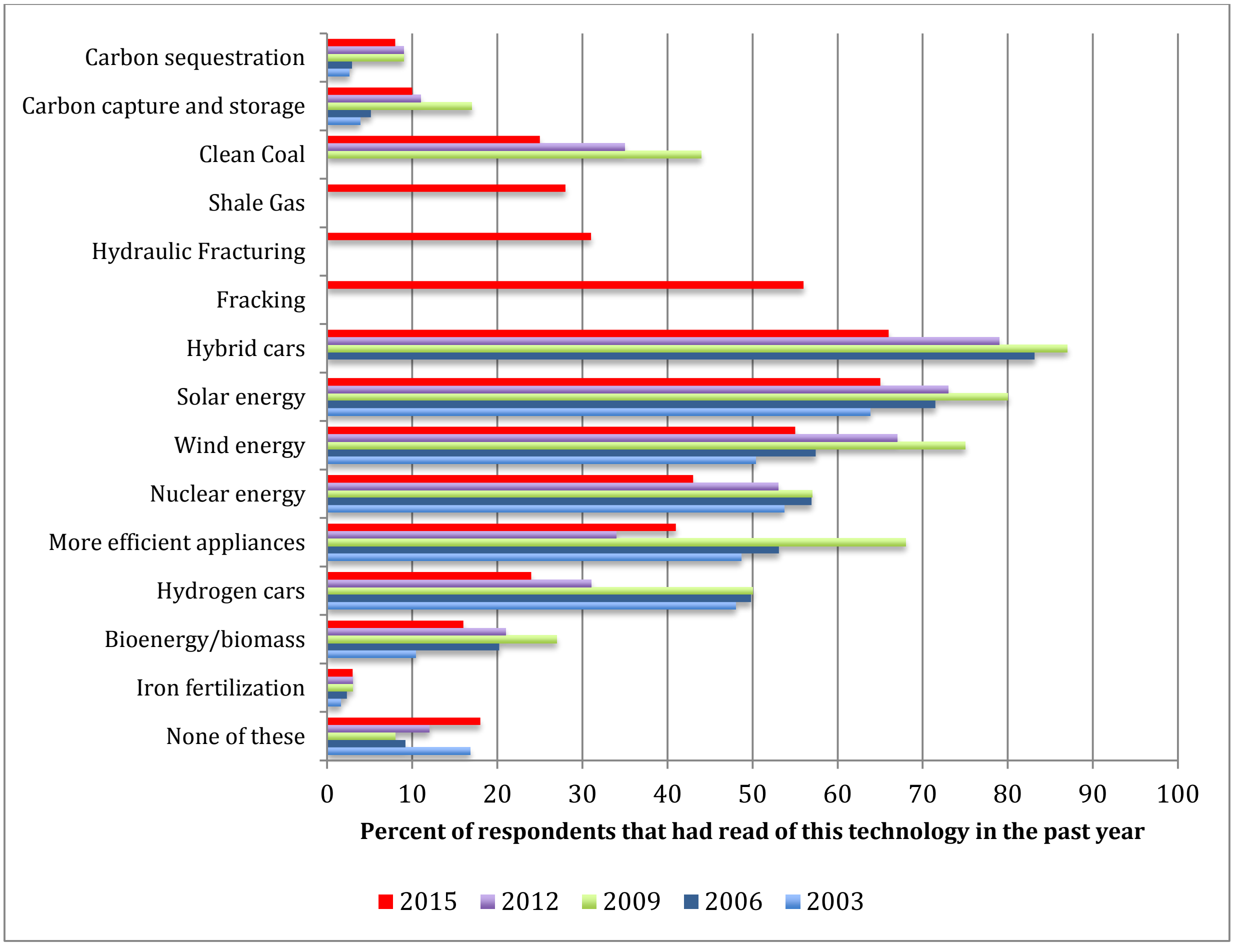


Figure 15: Familiarity with clean energy technologies, by year.

Familiarity with CCS among respondents was quite low: fewer than 10 percent of the sample population had heard about carbon sequestration or carbon capture and storage in the past year, although almost 30 percent had heard about "clean coal." Hydraulic fracturing enjoyed higher familiarity: over 30 percent of respondents had heard or read about "hydraulic fracturing," and nearly 60 percent had heard or read about "fracking."

6.2.2 Economic and Environmental Values

The US survey included a question asking respondents: "Many environmental issues involve difficult trade-offs with the economy… Which of the following statements best describes your view?" Table 5 lists the results from this question. Respondents tended to have moderate views: only about a tenth of respondents said that either the economy or environment should always take priority. Just under half of all respondents would prioritize environmental well-being, while a third would prioritize the economy and a fifth was unsure.

Table 5: Responses to question: "Which of the following statements best describes your view?"

Top Priority	**US Response**
The highest priority should be given to the economy even if it hurts the environment.	4%
Both the environment and the economy are important, but the economy should come first.	28%
Both the environment and the economy are important, but the environment should come first.	40%
The highest priority should be given to protecting the environment, even if it hurts the economy.	7%
Not sure	20%

6.2.3 Climate Change Solution Preferences

The US survey also included a question asking respondents: "Which statement comes closest to your views on how the problem of global warming should be addressed?" The question allowed respondents to choose from a number of strategies for tackling climate change, and also allowed respondents to indicate that they believe concern about climate change is unwarranted. Figure 16 illustrates the results from this question. The most commonly identified response to climate change was lifestyle change, followed by technological development. A substantial number of respondents indicated that climate change is not an issue of concern. Comparatively few respondents chose adaptation as the best response to climate change.

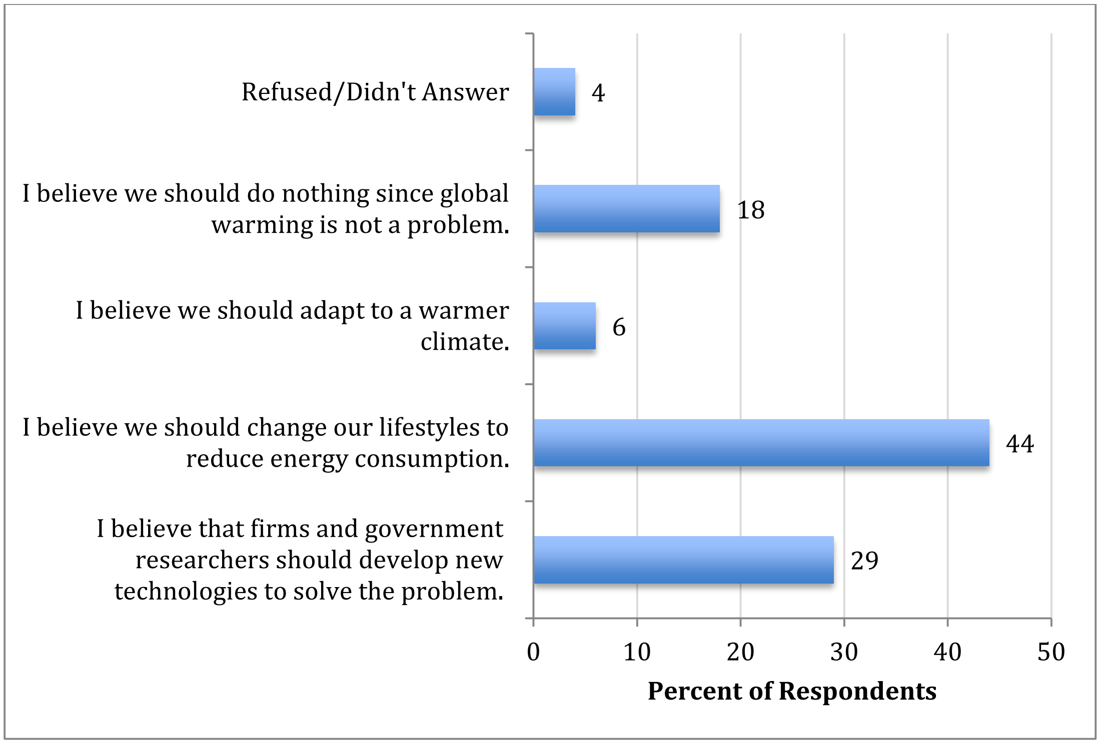


Figure 16: U.S. opinions on climate change response strategies. Responses to question: "Which statement comes closest to your views on how the problem of global warming should be addressed?"

6.2.4 Compensation

The US survey included one experimental question regarding compensation. The survey question randomly assigned respondents to either a CCS group or a hydraulic fracturing group. Each respondent was presented a short paragraph explaining CCS or hydraulic fracturing, and then asked whether they would accept $500 of compensation per month in return for allowing nearby citing of either geologic storage or hydraulic fracturing infrastructure, depending upon their group assignment. If they rejected the $500 payment, they were offered $1,000. Likewise, rejection of the $1,000 initiated an offer of $2,500, and rejection of that led to a final offer of $5,000.

Respondents assigned to the CCS group were presented with the following technical explanation and question:

Carbon capture and storage (CCS) is a way to reduce carbon dioxide emissions in response to climate change concerns and is compatible with our current fossil energy infrastructure. CCS *technologies "capture" carbon dioxide from the exhaust of fossil fuel-fired power plants and other industrial facilities, and then pump it deep underground into safe and permanent storage areas at least a half mile below the earth's surface. Many studies show that the use of CCS technologies will reduce the overall costs of meeting carbon dioxide emissions reduction goals.*

Imagine that an energy company approaches you about beginning carbon storage operations in your area. The company asks to lease your mineral rights in return for a royalty payment.

Would you be willing to accept carbon storage near your home if you got a royalty of [START PAYMENT AT 500, THEN 1000, 2500, 5000 UNTIL PERSON ACCEPTS] per MONTH for the active lifetime of the project?

Respondents assigned to the hydraulic fracturing group were presented with the following technical explanation and question:

Hydraulic fracturing, or "fracking," is a way to extract natural gas from shale rocks found deep underground. The hydraulic fracturing process pumps millions of gallons of sand, water, and chemicals deep underground to break apart rocks that contain the natural gas. The produced natural gas is used to help generate electricity, heat homes, and power industry. As a fossil fuel, natural gas is cleaner than coal and less expensive than oil.

Imagine that an energy company approaches you about beginning hydraulic fracturing operations in your area. The company asks to lease your mineral rights in return for a royalty payment.

Would you be willing to accept hydraulic fracturing near your home if you got a royalty of [START PAYMENT AT 500, THEN, 1000, 2500, 5000 UNTIL PERSON ACCEPTS] per MONTH for the active lifetime of the well?

Figure 17 illustrates the percent of respondents that indicated willingness to accept various levels of compensation for nearby siting of either hydraulic fracturing or geologic storage infrastructure. About 50 percent of respondents said they would allow nearby hydraulic fracturing or geologic storage for monthly compensation of $500. Another 20 percent of respondents expressed willingness to accept nearby project siting for a larger monthly compensation of $1,000 to $5,000 per month.

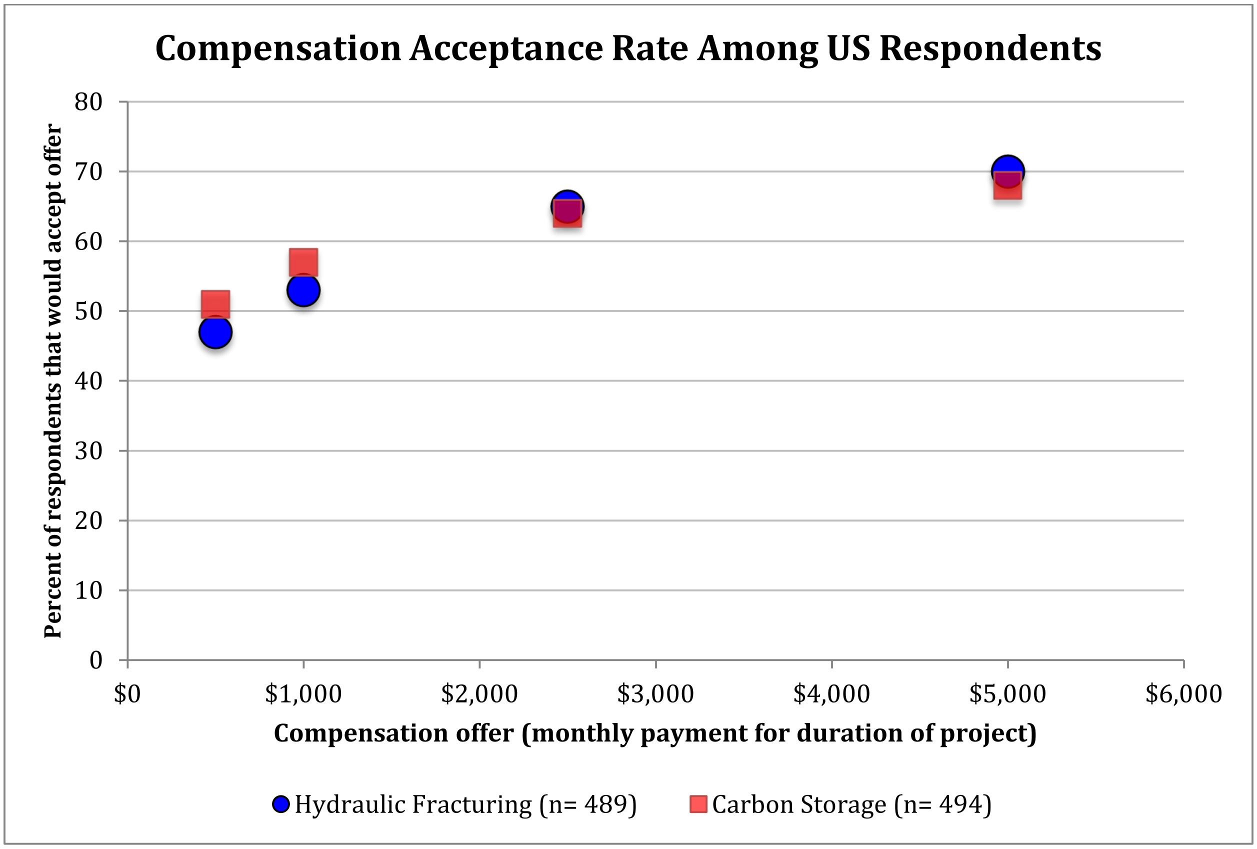


Figure 17: Acceptance rates for various compensation offers

6.3 US Survey Analysis

6.3.1 Analysis methodology

The survey analysis, which was carried out using the statistical software R, utilized a variety of analytical techniques, including cross tabulation, data plotting, and regression. Tabulation and plotting were the most commonly relied upon technique for parsing survey data, as these methods lent themselves to clear and intuitive interpretation of results. In most cases, statistical tests such as simple regression were used to determine the significance of observations made using tables and plots. Multiple logistic regression analysis was used to identify correlative relationships between respondent characteristics and rates of acceptance of hydraulic fracturing and CCS technologies, as denoted by willingness to accept compensation. Table 6 indicates how these methods were used to answer specific evaluation questions about the datasets. Distribution and cross tabulation statistics are reported for a select number of survey items; a complete listing of survey questions is available in Appendix C.

Table 6: Analysis methodologies for US and UK surveys

Question	Method of Investigation
Do respondents tend to have similar acceptance rates for both hydraulic fracturing and GS similarly?	Cross tabulation, Visual analysis
What are the factors associated with public acceptance of hydraulic fracturing and GS?	Cross tabulation, Visual analysis, Regression
Is compensation associated with an increase public acceptance of hydraulic fracturing and GS?	Cross tabulation, Visual analysis
How do the answers to the previous questions differ between respondents from the UK and US?	Cross tabulation, Visual analysis, Regression

6.3.2 Acceptance Rates for CCS and hydraulic fracturing

The US survey allowed for the transformation of quantitative data on compensation demand into categorical data on acceptance. Respondents who accepted the original compensation offer were assigned to the "accept" category. Respondents who rejected the original offer but accepted a higher offer were assigned to the "negotiate" category. Respondents who rejected all compensation offers were assigned to the "reject" category. This data generation process created the dependent acceptance variables used by several of the survey analysis approaches. Figure 18 illustrates this approach for the US survey.

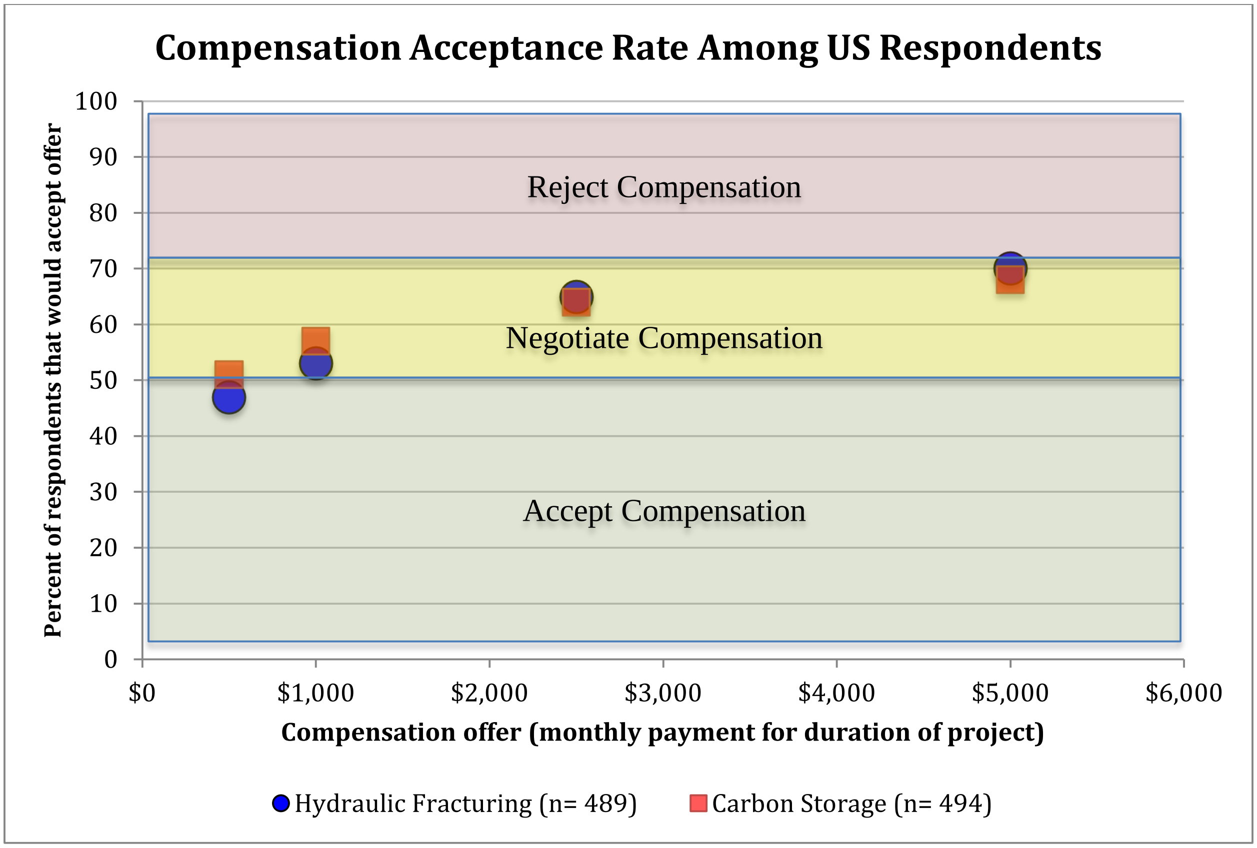


Figure 18: Compensation response modes

Overall, about 50 percent of US respondents immediately accepted compensation for either hydraulic fracturing or geologic storage, another 20 percent negotiated for a higher compensation package, and 30 percent rejected the highest compensation offer. Figure 18 implies several additional takeaways. First, the trend in willingness to accept compensation is nearly identical between those in the hydraulic fracturing group and those in the geologic storage group. These results further support the hypothesis that hydraulic fracturing may be a good technological analogue for geologic storage. As indicated by Table 7, survey respondents show similar breakdowns of acceptance, negotiation, and rejection for the two technologies.

Second, increasing compensation may have diminishing returns. As evident from the "compensation curve" in Figure 18, higher levels of compensation led to acceptance among a larger portion of the sample population. However, the improvement in acceptance yielded by a relatively small increase from $500 per month to $1,000 per month exceeds the improvement yielded by a much larger increase from $2,500 per month to $5,000 per month. This appears true for both hydraulic fracturing and geologic storage.

Table 7: Response from US residents to compensation in return for local siting of CCS or hydraulic fracturing

Response to compensation in return for local siting	CCS	Hydraulic Fracturing
Accept	51%	47%
Negotiate	17%	23%
Reject	32%	30%

6.3.3 Factors associated with public acceptance

6.3.3.1 Demographics

A logistic regression was conducted to determine the association between various demographic factors and willingness to accept compensation for nearby siting of either hydraulic fracturing or geologic storage infrastructure. For both hydraulic fracturing and geologic storage, the most predictive combination of demographic variables was gender, age, and internet access. These variables were each statistically significant with greater than 90 percent confidence. Males, people younger in age, and those with internet access were all more likely to accept compensation for nearby infrastructure siting.

Despite the statistically significant correlation between these demographic variables and the likelihood of compensation success, the resulting model showed no predictive improvement over a "naïve" baseline model in which all respondents were predicted to accept compensation. In either case, the predictive accuracy of the model was about 68 percent for geologic storage and 70 percent for hydraulic fracturing.

6.3.3.2 Familiarity

Age, gender, and education all correlated with familiarity at a 99 percent confidence level, such that older, male, and more highly educated respondents were more likely to have heard or read about either CCS or hydraulic fracturing. However, familiarity itself appears to have no significant association with acceptance of either geologic storage or hydraulic fracturing. Regression tests indicate that these variables are not correlated at a 90 percent confidence level.

Nevertheless, CCS and hydraulic fracturing appear to share similar levels of acceptance among those familiar with the technologies. Table 8 summarizes acceptance data from respondents who were offered compensation for siting of either hydraulic fracturing or geologic storage and had read about the respective technology during the past year. It demonstrates nearly identical rejection rates among a respondent population with at least some familiarity with CCS or hydraulic fracturing.

Table 8: Responses from US residents who have familiarity with CCS or hydraulic fracturing

Response to compensation in return for local siting	**CCS**	**Hydraulic Fracturing**
Accept	52%	43%
Negotiate	17%	24%
Reject	32%	33%

Table 9 summarizes acceptance rates among a respondent population with deep familiarity with both CCS and hydraulic fracturing. The US survey not only asked respondents whether they had heard of "carbon capture and storage" or "hydraulic fracturing," but also whether they had heard of the technologies' other aliases, including "carbon sequestration," "clean coal," "fracking," and "shale gas." Table 9 includes data from respondents who had heard or read about at least two out of three aliases for each technology. The table demonstrates a higher rate of acceptance for both technologies among this population. For CCS, this higher acceptance rate is indicative of lower rates of both outright rejection and of negotiation. For hydraulic fracturing, the higher acceptance rate correlates with a lower negotiation rate; the rejection rate is similar to that of less knowledgeable respondents. Nevertheless, the very small change in rejection rates among respondents with substantial familiarity with these technologies corroborates the finding that familiarity is at best weakly correlated with public acceptance.

Table 9: Responses from US residents who are very familiar with both technologies

Response to compensation in return for local siting	**CCS**	**Hydraulic Fracturing**
Accept	61%	50%
Negotiate	13%	17%
Reject	26%	33%

6.3.3.3 Economics and Environmental Tradeoffs

Additional tests were conducted to determine the extent of a relationship between values related to the economy and environment and willingness to accept hydraulic fracturing or geologic storage. Figure 19 illustrates the breakdown of compensation acceptance within each preference level from the environment vs. the economy question of the US survey and for both hydraulic fracturing and geologic storage. Both technologies appear to enjoy similar levels of support—meaning hypothetical willingness to accept or negotiate compensation—from respondents who are "not sure" whether to prioritize economic or environmental well-being. However, support for hydraulic fracturing is highest among those who prioritize economic well-being, and conversely support for geologic storage is highest among those who prioritize environmental well-being (although respondents who stated their preference as "usually economy" also show high levels of support).

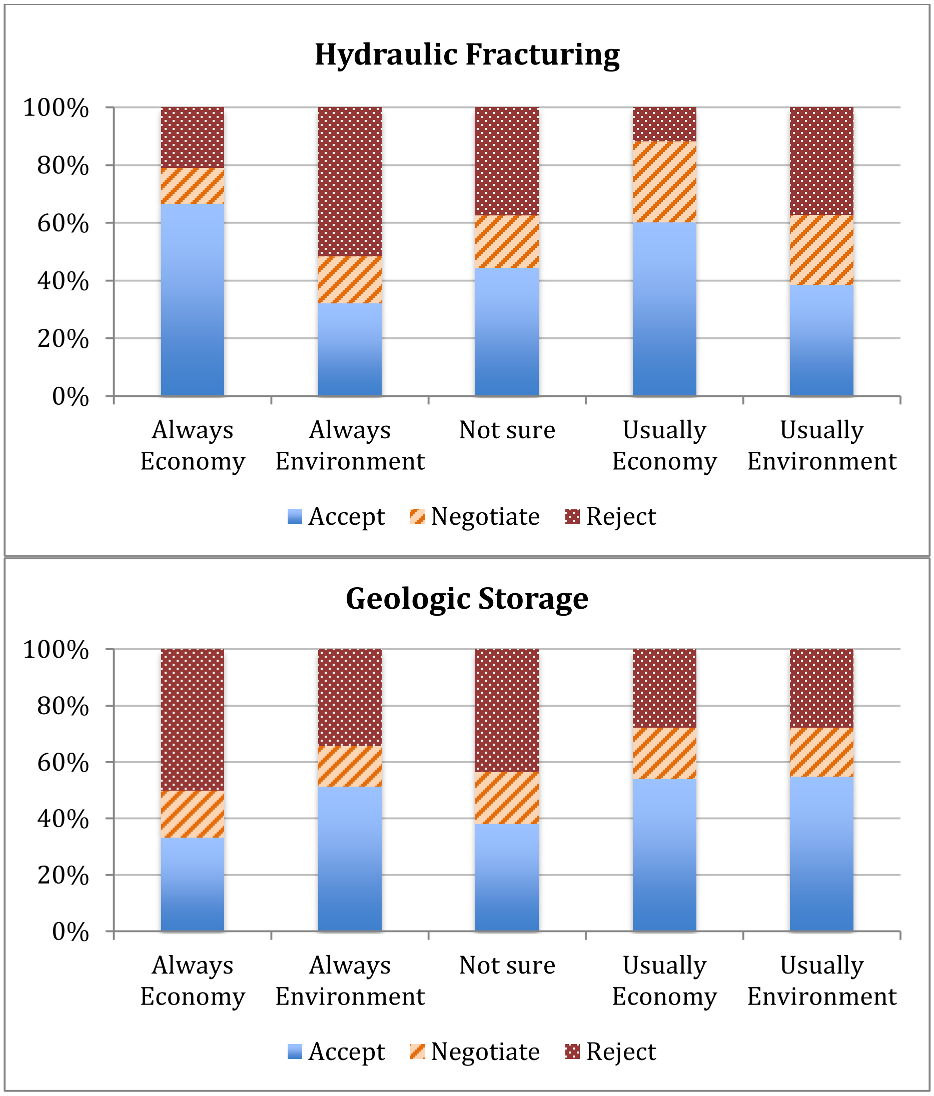


Figure 19: Compensation acceptance for various stated preferences regarding environmental and economic trade-offs

Statistical analysis of these trends paints a more complicated picture. While the association between environmental and economic preferences and acceptance of nearby siting of hydraulic fracturing is statistically significant with 95 percent confidence, a similar analysis for geologic storage does not show evidence of statistical significance. This is likely due to the lower familiarity with CCS; respondents may be unsure about how the technology fits into environmental and economic frameworks. A statistical analysis of a subset of respondents that have heard or read about CCS in the last year is statistically significant with 90 percent confidence. In Figure 20, this subset displays a similar but more pronounced pattern of acceptance to that shown in Figure 19. Respondents who prioritize the environment or who "usually" prioritize the economy have much higher rates of acceptance than respondents who "always" prioritize the economy or who are "not sure."

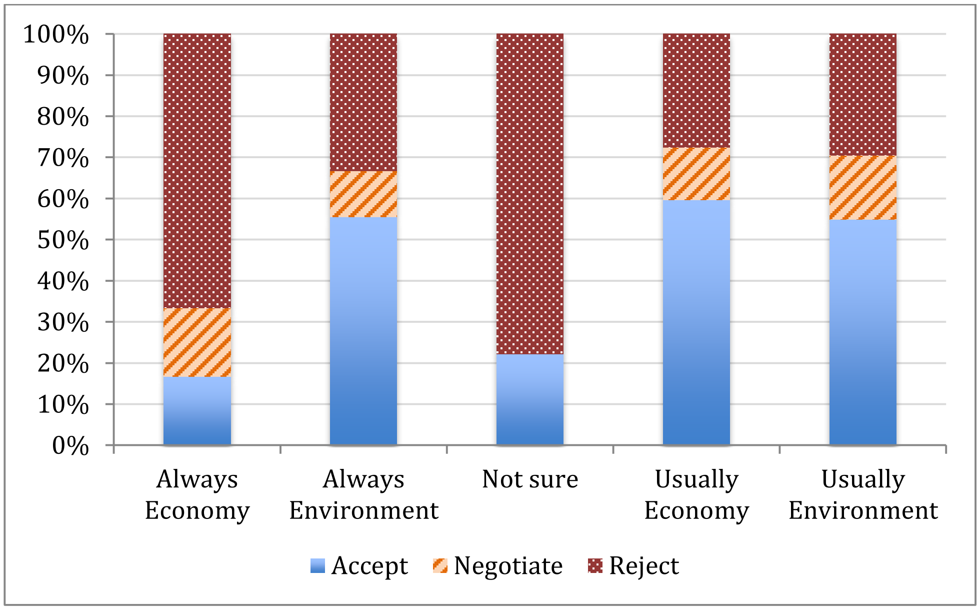


Figure 20: Compensation acceptance of geologic storage among various economic and environmental preference groups for respondents who are familiar with CCS

6.3.3.4 Climate Values

As illustrated by Figure 21, acceptance rates for hydraulic fracturing compensation were highest among respondents who believe that we should not try to mitigate climate change because it is not a problem. This result is statistically significant at the 99 percent confidence level. Acceptance rates were relatively similar among those who believe we should develop new technologies, those who believe we need to institute lifestyle changes, and those who perceive adaptation as the best solution.

In contrast, geologic storage saw relatively constant rates of acceptance across all groups. Ironically, the group that showed the highest degree of acceptance of geologic storage comprised respondents who believe that adaptation is the best response to climate change. While this result is surprising, it is important to remember that this survey asked about acceptance of local infrastructure siting in return for compensation; the survey did not ask respondents to assess the more general role of hydraulic fracturing or CCS in a climate mitigation technology portfolio. The association between choice of best response to climate change and acceptance of nearby geologic storage was significant only at the 90 percent confidence level. Subsetting to only those respondents familiar with CCS did not improve the statistical significance. Interestingly, higher levels of compensation yielded a 20 to 30 percent increase in acceptance among nearly all groups, with the exception of climate skeptics offered compensation for nearby siting of geologic storage infrastructure.

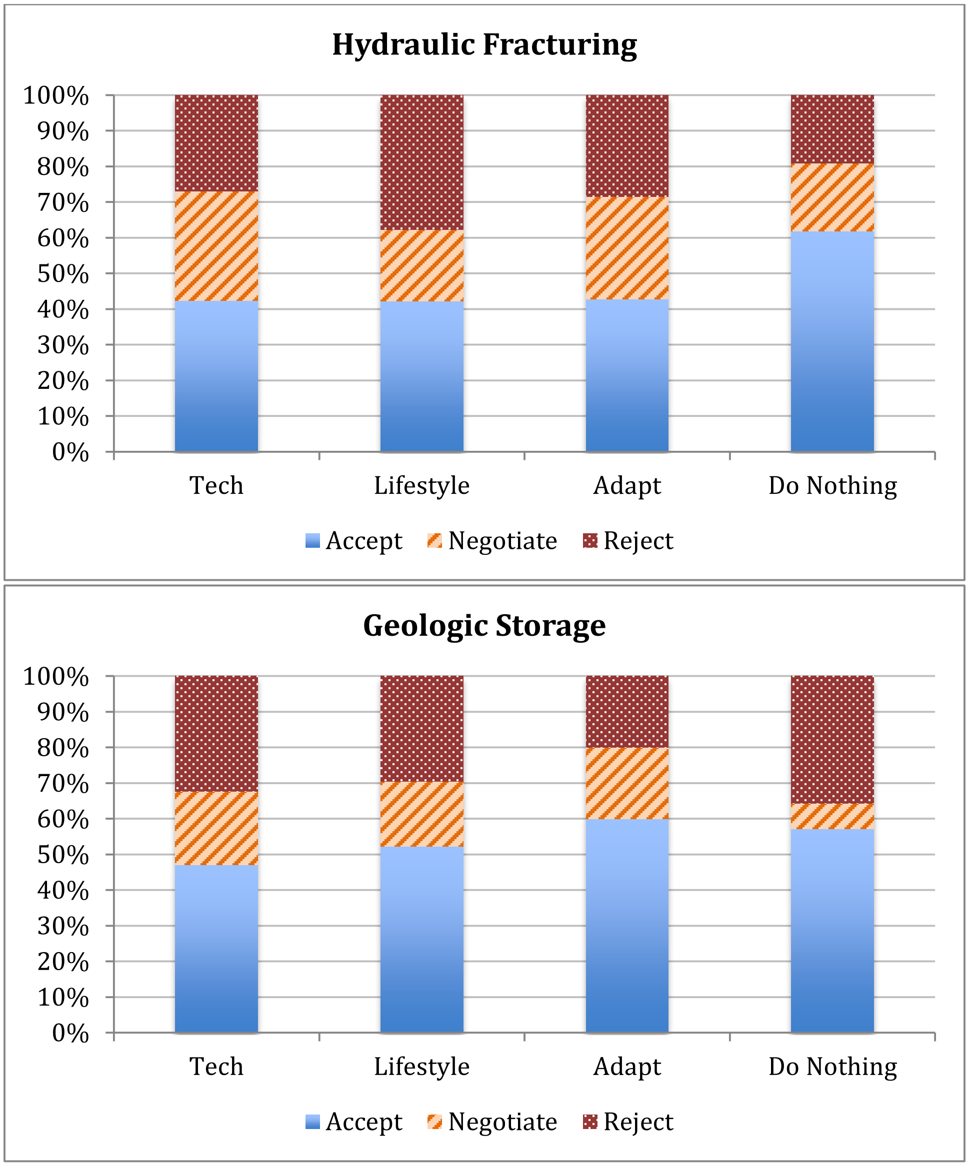


Figure 21: Compensation acceptance based on preferred climate change response strategy

6.4 Comparing the US and UK Surveys

Underpinning this chapter subsection is a collaboration between researchers at MIT and researchers at the University of Cambridge that seeks to understand how public attitudes toward

CCS and hydraulic fracturing vary between the United States and the United Kingdom. The US and UK surveys informed each other's design, and while questions are not identical and therefore don't allow for data aggregation between the two surveys, they do allow for a qualitative discussion.

Table 10 presents a comparison of demographics between the US and UK survey samples.

Table 10: US and UK survey demographics

Demographic Variable	**US**	**UK**
Age	18 years and older with a median of 45 years	18 years and older with a median of 48
Gender	54% male, 46% female	50% male, 50% female
Median Household Income	$60,000 to $75,000	£40,000 to £45,000 ($60,000 to $70,000)
Married	62 percent	49 percent
Households with Children	30%	27%

The UK survey included three experimental questions regarding compensation. Rather than assigning respondents to groups, this survey asked all respondents about willingness to accept compensation for nearby hydraulic fracturing infrastructure, carbon dioxide pipelines, and nuclear power plants (the survey used random ordering to ask respondents about these technologies). Respondents were, however, randomly placed into one of two groups based on hypothetical distance from infrastructure: either one mile or 50 miles.

Compensation offers were also made differently in the UK survey. Each respondent was randomly assigned a starting compensation amount chosen from a uniform distribution of between £2,000 and £20,000. The lack of "per month" or "per year" wording in the survey likely led most respondents to believe that this was a one-time payment. For each respondent, the starting compensation offer was constant across all three energy technologies. Beginning with hydraulic fracturing, respondents were asked whether they would accept the given amount in return for allowing energy infrastructure within one or 50 miles of their home. If respondents rejected the compensation, the package was doubled and then reoffered. If they accepted, the package was halved and reoffered. After this second and final round, each respondent had either accepted compensation at 0.5x, 1.0x, or 2.0x the original offer, or rejected compensation altogether. See Figure 22 for a decision tree illustration of this process. As with the US survey, the UK dataset allowed for the transformation of quantitative data on compensation demand into categorical data on acceptance.

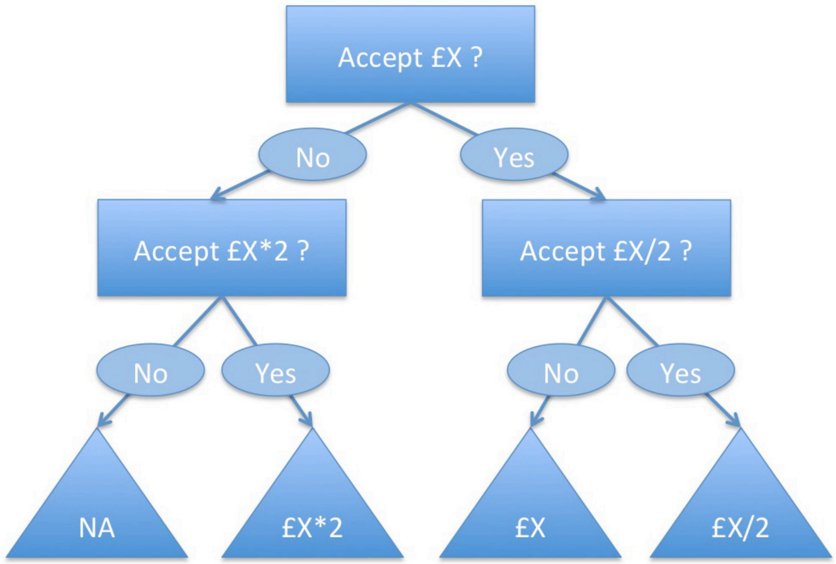


Figure 22: Illustration of compensation data generation process for UK survey

Figure 23 illustrates the compensation curves for UK respondents. While US residents appear to view hydraulic fracturing and geologic storage quite similarly, data from the UK indicate that residents in that country perceive hydraulic fracturing more like nuclear energy than like CCS. Hydraulic fracturing and nuclear power both have rejection rates close to 50 percent in the UK, while CCS has a rejection rate of 30 percent. Meanwhile, US residents reject both hydraulic fracturing and CCS with a frequency of about 30 percent.

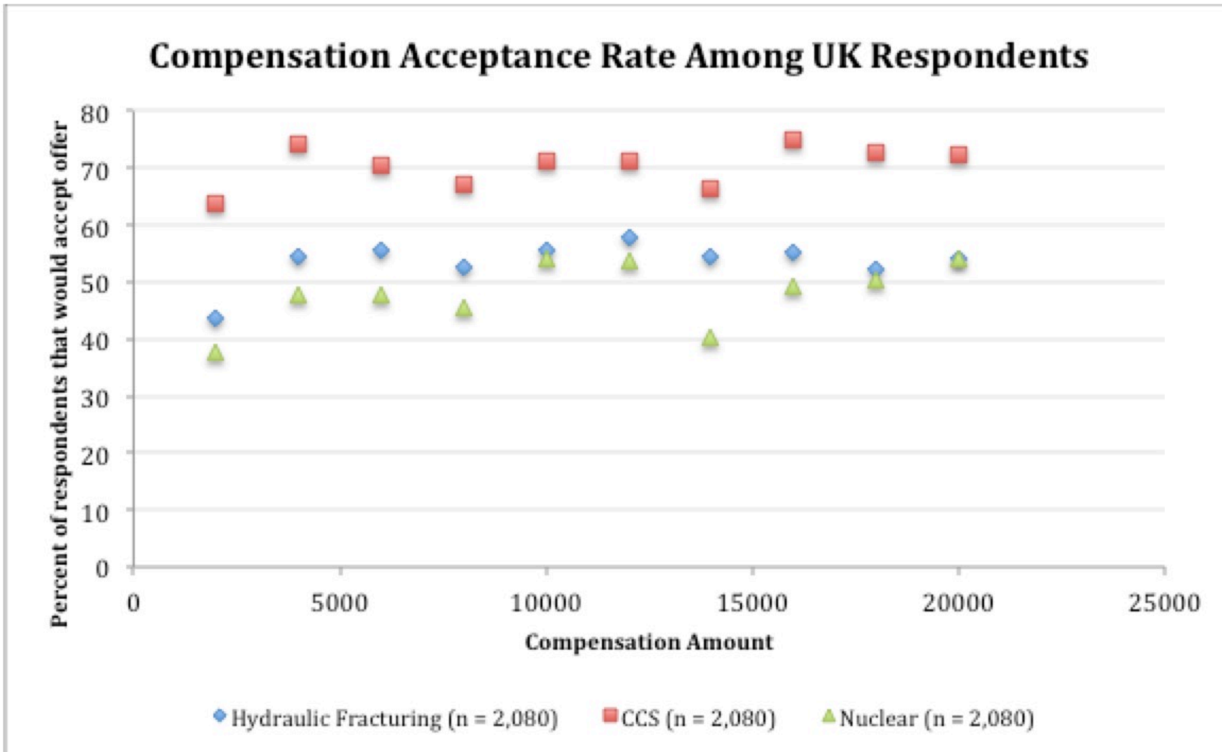


Figure 23: Acceptance rate for various compensation offers among UK respondents

Table 11 indicates that UK residents indicate willingness to reject compensation for nearby hydraulic fracturing development with greater frequency than do US residents. Conversely, they indicate greater willingness to accept compensation for nearby CCS infrastructure. For both technologies, UK respondents were less likely to negotiate compensation.

Table 11: Compensation response rates for US and UK survey-takers

Response to compensation in return for local siting	**CCS***		**Fracturing**		**Nuclear**	
	US	UK	US	UK	US	UK
Accept……………………..	51%	59%	47%	45%	NA	41%
Negotiate…………………..	17%	11%	23%	9%	NA	7%
Reject………………………	32%	30%	30%	47%	NA	52%

*Note that the US and UK surveys treated CCS differently. Respondents in the US survey were offered compensation in return for nearby carbon dioxide storage, while UK respondents were offered compensation in return for a nearby carbon dioxide pipeline.

A logistic regression of the association between demographic variables and UK residents' likelihood of accepting compensation for nearby siting of hydraulic fracturing infrastructure finds that gender is significantly correlated with acceptance. As in the US, UK males are more likely to accept compensation for nearby siting of hydraulic fracturing infrastructure. UK residents' 2010 voting choice also shows a strong correlation with acceptance, such that conservatives are more likely to accept hydraulic fracturing. Both of these correlations are significant with over 99 percent confidence. Together, they form a model that yields a 3 percent predictive improvement over a naïve baseline model that predicts that all respondents will accept compensation.

A similar analysis for CCS paints a more complex picture. The most robust logistic regression model for CCS found that gender, 2010 political vote, education status, and marital status were all correlated with compensation acceptance with 95 percent or greater confidence. Again, males and conservatives were more likely to accept the technology. Likewise, married people and people with more education were more likely to accept compensation for nearby siting. However, the model as a whole showed no increase in predictive accuracy over a baseline model.

There are several limitations to the comparison between the UK and US surveys. First, the compensation questions used to generate the accept-negotiate-reject data in Table 11 varied in design between the two surveys. Second, the US survey asked residents about the acceptability of nearby geologic storage of CO_2, while the UK survey asked residents about the acceptability of a nearby CO_2 pipeline (because geologic storage in the UK is most likely to occur offshore). Third, the structures of hypothetical compensation offers differed between the two surveys, as discussed at the start of this chapter. Finally, the US survey randomly divided the respondent sample in half, such that one group considered compensation for nearby siting of hydraulic fracturing infrastructure and another group considered compensation for nearby siting of geologic storage. Meanwhile, the UK survey asked all respondents about hydraulic fracturing, a nuclear power plant, and a CO_2 pipeline (in that order).

Nevertheless, as in the US, respondents to the UK survey showed much higher rates of familiarity with hydraulic fracturing than with CCS: 68 percent of UK respondents had heard or read about hydraulic fracturing in the past year, while only 21 percent had heard or read about

CCS. Interestingly, these statistics indicate that UK residents may have a higher level of familiarity than US residents for both hydraulic fracturing and CCS.

Table 12 displays the US and UK responses to the question about tradeoffs between economic and environmental priorities. The largest difference between the two respondent populations is the fact that fewer UK respondents chose "not sure" as their response.

Table 12: UK and US responses to question: "Many environmental issues involve difficult trade-offs with the economy. Which of the following statements best describes your view?"

Top Priority	**US Response**	**UK Response**
The highest priority should be given to the economy even if it hurts the environment.	4%	5%
Both the environment and the economy are important, but the economy should come first.	28%	33%
Both the environment and the economy are important, but the environment should come first.	40%	42%
The highest priority should be given to protecting the environment, even if it hurts the economy.	7%	8%
Not sure	20%	12%

Figure 24 illustrates UK residents' willingness to accept compensation for nearby hydraulic fracturing or CCS infrastructure, broken down by the environment vs. the economy priorities from Table 12 (see Figure 19 for comparable US survey results). The association between this variable and acceptance of both hydraulic fracturing and carbon dioxide pipelines is statistically significant at the 99 percent confidence level. Notably, willingness to accept compensation for CCS infrastructure is nearly identical between US and UK respondents, although with slightly lower negotiation rates among UK respondents. UK respondents show a higher rate of rejection for compensation related to siting of hydraulic fracturing—however, this surplus appears to derive mostly from lower negotiation rates than from lower acceptance rates. These differences in negotiation rates don't necessarily point toward real differences between US and UK populations: they may instead be more attributable to the fact that the compensation questions were structured differently between the two surveys.

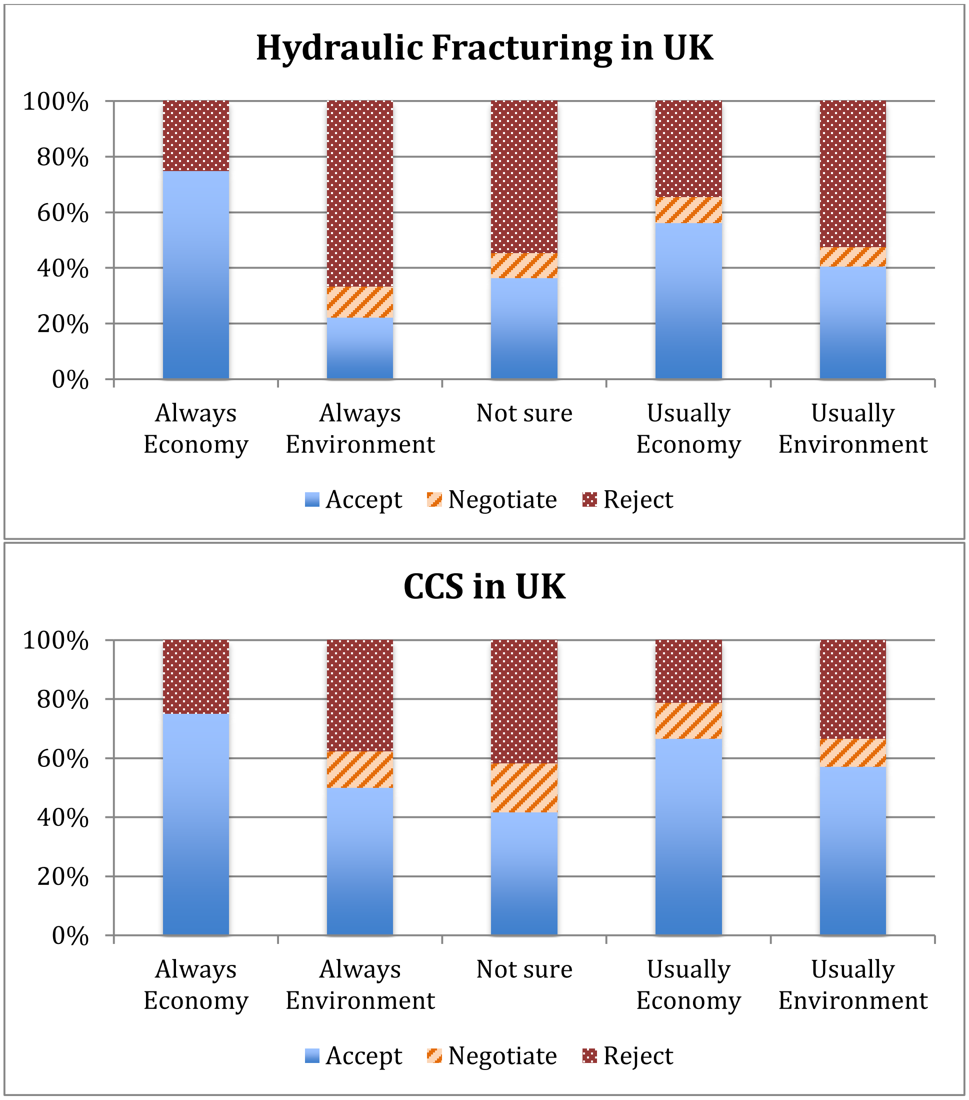


Figure 24: Compensation acceptance among UK residents with different environmental and economic preferences

Figure 25 illustrates UK respondents' views on using technology and behavior change to mitigate climate change (see Figure 16 for comparable US survey results). The association between this variable and acceptance of both hydraulic fracturing and carbon dioxide pipelines is statistically significant at the 99 percent confidence level. Respondents in the UK show a higher interest in mitigation technologies and a lower interest in behavior change than do their US counterparts. UK residents are also much less likely to deny the existence of climate change and more likely to identify adaptation as the best option to climate change. Note that minor differences exist in question phrasing between the two surveys.

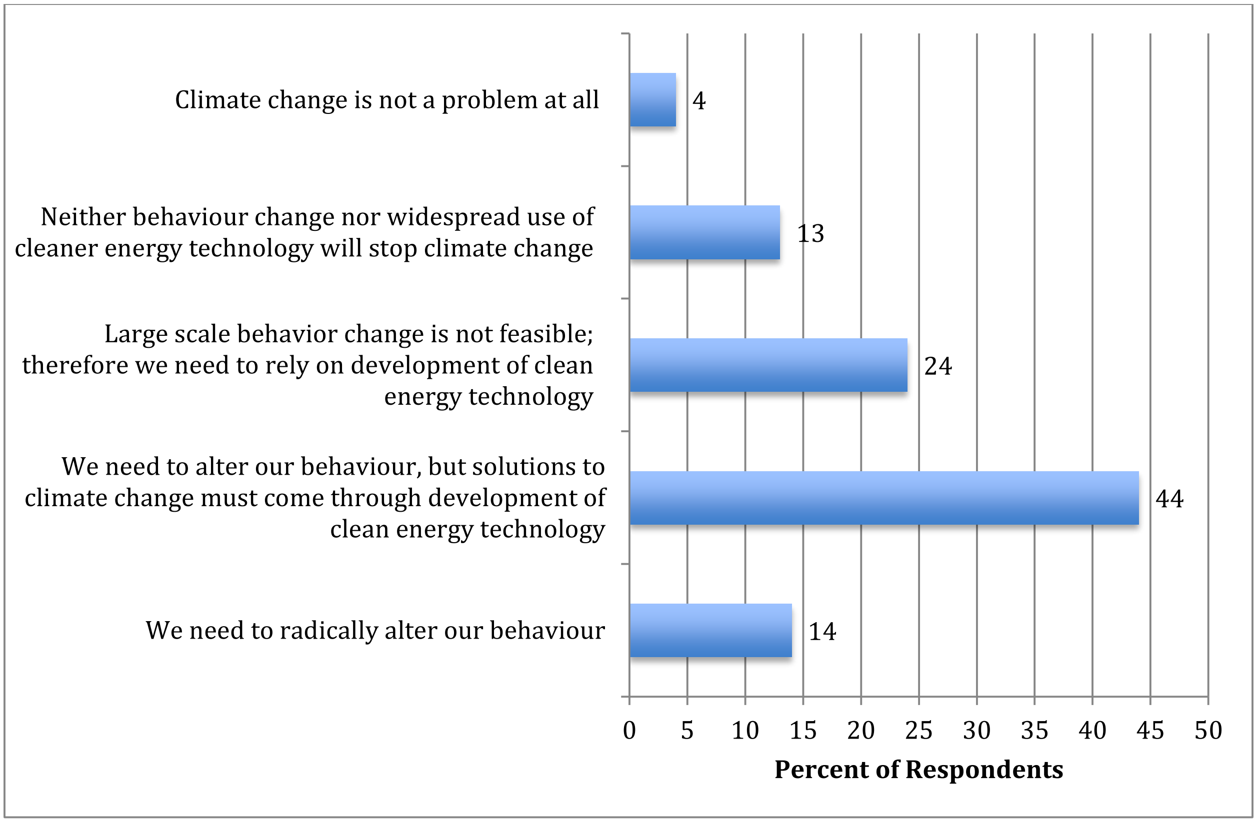


Figure 25: UK opinions on climate change response strategies. UK responses to the question: "How much change do you think is needed to our general lifestyle and consumption habits to stop the effects of climate change from happening?"

Figure 26 illustrates UK respondents' willingness to accept compensation, broken down according to the stated best solution for climate change (see Figure 21 for comparable US survey results). Again, UK residents show higher rejection rates and lower negotiation rates than do their US counterparts. Beyond that, there appear to be two major differences between UK and US respondents. First, UK respondents who cited behavior change as the ideal response to climate change appear to have lower rates of acceptance for compensation for hydraulic fracturing infrastructure than do their US counterparts. Second, UK respondents who cited technology development as the ideal response to climate change appear to have higher rates of acceptance for CCS infrastructure than do their US counterparts.

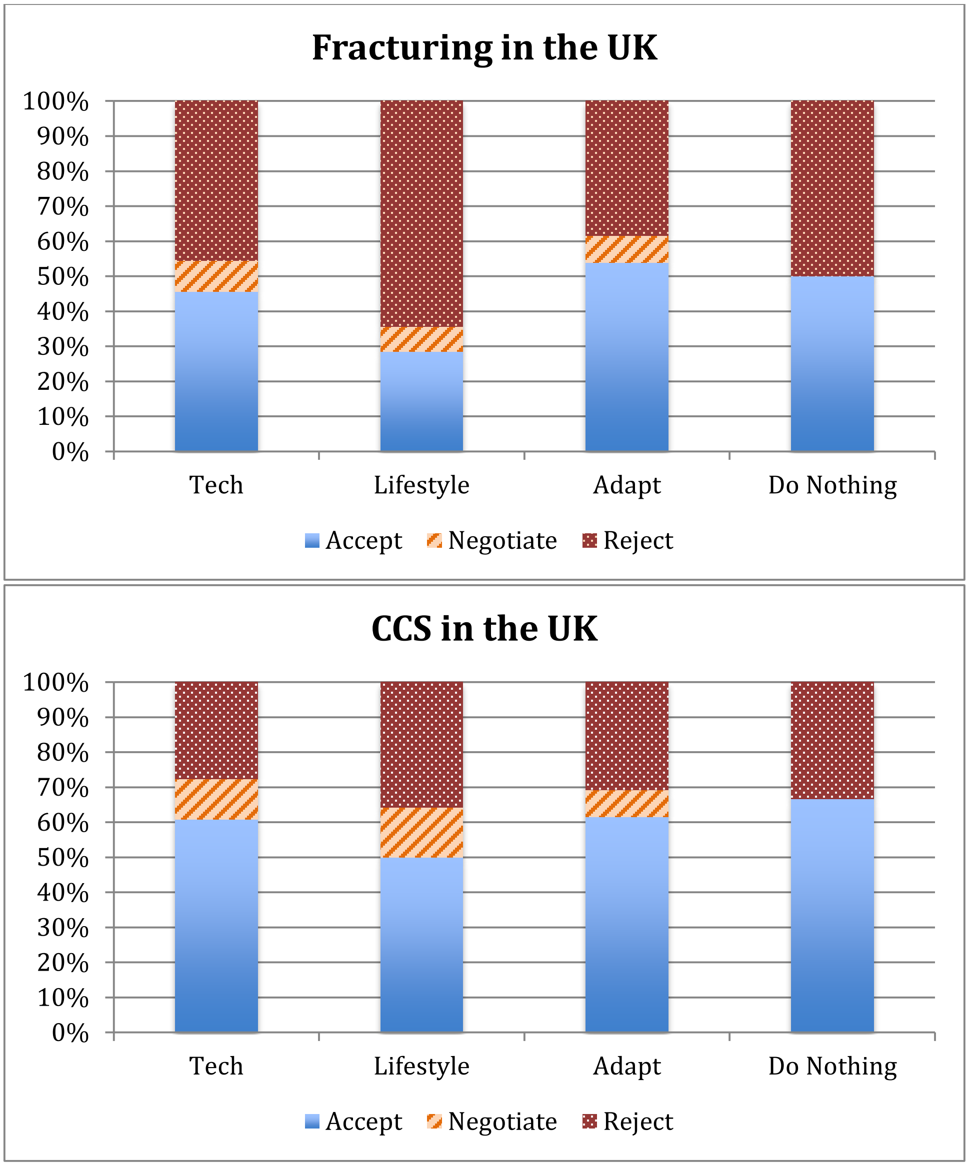


Figure 26: UK compensation acceptance based on preferred climate change response strategy

6.5 Discussion

The results from this survey analysis have four overarching implications for CCS. First, they lend support to the theory that hydraulic fracturing may be a good technological analogue for studying public acceptance of geologic storage in the US. Survey responses indicate that US respondents both accept hydraulic fracturing—outright or after negotiation—at rates similar to geologic storage and that they are more familiar with hydraulic fracturing than with CCS.

Policymakers and developers may therefore be able to look to each state's hydraulic fracturing history to anticipate how residents in the area may react to geologic storage projects.

Second, a number of factors are correlated with local acceptance of hydraulic fracturing and geologic storage technologies, but mapping of precise relationships has proved quite complicated. Familiarity and acceptance are at best weakly correlated. Respondents who were relatively familiar with hydraulic fracturing and CCS showed acceptance rates similar to those of less knowledgeable respondents. While several demographic variables—including gender, age, and internet access—are strongly correlated with acceptance, they have limited predictive power. A logistic regression model relying on demographics to predict acceptance performs no better than simply assuming that all residents will accept compensation. Acceptance of geologic storage is only mildly associated with views on economic and environmental tradeoffs and with opinions on climate change mitigation policies, although the association between hydraulic fracturing acceptance and these factors was stronger. These findings allude to the complexities involved with predicting acceptance of an unknown technology such as geologic storage.

Third, compensation appears to be effective in incentivizing acceptance of local geologic storage and hydraulic fracturing infrastructure. Increasing compensation offers appear to have moderate effects on acceptance levels—among US respondents, the highest compensation offer of $5,000 had a 20 percent higher acceptance rate than the lowest compensation offer of $500. However, due to the existence of pooling regulations, even small improvements in public acceptance could enable successful siting of hydraulic fracturing or geologic storage infrastructure. Most jurisdictions within the United States utilize "compulsory pooling" regulations to ensure that a small minority of holdouts cannot prevent drilling for oil and natural gas (Handlan and Sykes, 1984). If a certain percentage of a community agrees to development, then it moves forward. The same rules may govern future efforts to exploit underground pore space for geologic storage of CO_2. However, compulsory pooling is only triggered after a certain percentage of residents agree to development. Ohio, for example, has a compulsory pooling threshold of 90 percent of residents (Ohio DNR, 2015). While the compensation curve in Figure 17 reflects diminishing returns on compensation, those returns may help push local acceptance past the threshold necessary to trigger compulsory pooling. Moreover, the threat of compulsory pooling may convince some residents to accept compensation packages.

Fourth, broad differences exist between UK and US respondents, though some of these may be due to differences in survey design. Both populations showed moderate differences in values toward environmental and economic tradeoffs and toward climate change mitigation strategies. Most significantly, however, UK respondents' reactions to compensation offers for three different energy technologies indicated that they might think of hydraulic fracturing more like nuclear power than like CCS. This alludes once more to the idea that policymakers and developers should tailor communications and compensation offers to local populations, rather than attempting to devise global solutions to public acceptance.

6.6 Key Chapter Findings

- Survey results indicate that hydraulic fracturing may be a good technological analogue for studying public acceptance of geologic storage.
- Prediction of public acceptance of nearby geologic storage is difficult. However, several variables such as gender, age, internet access, views on environmental and energy issues, and views on climate change mitigation are associated with willingness to accept compensation for nearby project siting.
- Compensation appears to have some effect in incentivizing acceptance of local geologic storage projects.
- A comparison of surveys conducted in the US and UK suggests that populations in these nations may hold differing views toward local siting of hydraulic fracturing and carbon storage infrastructure.

Chapter 7: Conclusions

This thesis investigates two questions related to public acceptance of geologic storage:

- What are the factors associated with public acceptance of CCS?
- How can communities, regulators, and stakeholders increase public acceptance of geologic storage of CO_2 so that CCS technologies can be deployed both safely and efficiently?

Additionally, the thesis assesses and validates the use of hydraulic fracturing as a technological analogue for anticipating public acceptance issues related to geologic storage of CO_2. Characterization of regulatory, stakeholder, and community acceptance of both hydraulic fracturing and geologic storage resulted in the findings and recommendations discussed below.

7.1 Hydraulic fracturing as a technological analogue for CCS

- Hydraulic fracturing is technologically similar to CCS but is better known by the general public, and therefore could serve as an analogue for anticipating future trends related to public acceptance of geologic storage.
- Survey data indicate that the US public has similar perceptions toward both hydraulic fracturing and geologic storage.

Public acceptance will continue to play an important role in siting of geologic storage projects, but is notoriously difficult to anticipate for relatively unknown emerging technologies such as CCS. Nevertheless, prediction of the public's response to geologic storage projects will continue to be an important part of the technology development process. Investigators and developers can better understand how regulators and communities might react to future geologic storage projects by examining how these parties have reacted to recent hydraulic fracturing projects. Hydraulic fracturing also represents an analogy through which the public can better understand the technology. Developers may choose to reference hydraulic fracturing in their explanations about the technical operations and risks of geologic storage. Finally, it provides a model for regulators to anticipate and mitigate risks related to the injection component of CCS, and helps them to identify the appropriate level of financial incentives, such as carbon taxes, for incentivizing development of CCS technologies.

7.2 Regulatory Aspects of Public Acceptance

- Evidence from state regulations for hydraulic fracturing indicates that geologic storage might face a more predictable, more moderate level of regulatory stringency in areas already familiar with the fossil fuel industry. These represent ideal locations for demonstration projects.
- The legal and regulatory history of hydraulic fracturing suggests that geologic storage will increasingly face pressure from municipal-level regulators and policymakers.

States with a long history of oil and gas development show a more moderate, "middle-of-the-road" approach toward regulating hydraulic fracturing. The CCS industry should expect a similar reaction to CCS. In fact, states with resident populations that are relatively familiar with hydraulic fracturing might be excellent locations for CCS demonstration projects. Nevertheless, in every state where hydraulic fracturing is taking place, some municipalities are increasingly passing stricter zoning and public health ordinances to minimize development. CCS developers should prepare for pushback from municipalities, even in states where policymakers see value in hosting projects. Additional research is necessary to understand common municipal policy responses to infrastructure siting. In particular, future research should focus on creating a typology of municipal reactions to hydraulic fracturing and CCS infrastructure projects so that developers can efficiently anticipate and respond to local opposition.

7.3 Stakeholder Aspects of Public Acceptance

- Challenging public opposition costs developers resources in the form of delays, court fees, and public relations campaigns. Natural gas developers demonstrate a willingness to engage with and challenge communities that actively oppose development, but they have a large financial incentive to do so. CO_2 prices corresponding to current natural gas prices equate to nearly $100 per ton.

Current Henry Hub prices are about $5 per mmBtu of natural gas. This price incentivizes developers to initiate new projects and defend them against public opposition. This corresponds to a CO_2 price of at least $100 per ton. At this price, natural gas and CO_2 would have similar financial values for a given unit of volume. Even still, this price does not account for the added cost of capture and purification, which far exceed the price of processing natural gas. Thus, CO_2 prices may need to be even higher in order to encourage development. Without a high CO_2 price, developers are unlikely to expend resources to safeguard projects against public opposition. The implications for policymakers are two-fold. First, without market incentives such as carbon prices, developers are unlikely to expend resources to engage with communities on local siting issues. Second, politically feasible carbon prices might still be too low to unilaterally create CCS development on par with current development of hydraulic fracturing infrastructure. Policymakers should therefore pair market policies with other regulatory tactics such as subsidies and changes in zoning laws.

7.4 Community Aspects of Public Acceptance

- Compensation appears to be a viable approach for improving public acceptance of geologic storage activities.
- Several factors are associated with effectiveness of compensation, including age, gender, access to the internet, and views on the economy, the environment, and climate mitigation. However, none of these factors proved particularly predictive of public acceptance for geologic storage.
- Residents in the UK appear to view hydraulic fracturing and CCS as quite different technologies, while the US views them as relatively similar.

The results from our survey indicate that increased amounts of compensation are associated with increases in public acceptance for both geologic storage and hydraulic fracturing. However, there appear to be diminishing returns on high levels of compensation for siting of these technologies. Survey respondents in the UK appear to consider siting of hydraulic fracturing more similar to siting of nuclear power than to CCS, and perceive compensation accordingly. Policymakers and developers should view compensation as an important tool for shoring up local support for CCS infrastructure. Both surveys indicated that a number of factors are associated with willingness to accept compensation for hydraulic fracturing and CCS. Younger residents, males, and those with internet access are more likely to accept nearby siting, as are residents who prioritize the economy over the environment and residents who prioritize climate change mitigation strategies focusing on technological change over strategies focusing on lifestyle change. Nevertheless, while these factors demonstrated high significance, they lacked predictive power. For now, policymakers and developers may choose to focus on assessing local public acceptance of geologic storage qualitatively.

7.5 Closing

This investigation found that familiarity with similar technologies and industries may indeed be predictive of public acceptance for geologic storage of carbon dioxide. One resulting implication of this is that hydraulic fracturing may be a suitable analogue for understanding public acceptance for geologic storage. Another is that geologic storage development should initially be located in states with a history of underground resource exploitation. Even in areas abundantly familiar with similar technologies, however, CCS developers may face pushback from individual communities and landowners. They should be prepared to offer compensation in such cases, as financial incentives appear to be effective in shoring up public acceptance. In order to encourage developers to expend resources on public acceptance and engagement practices, policymakers must implement robust market mechanisms such as carbon prices.

Chapter 8: References

American Petroleum Institute. (2013) "Economic impacts of the oil and natural gas industry on the US Economy in 2011."

Anderson C, Schirmer J, Abjorensen N. (2012). "Exploring CCS community acceptance and public participation from a human and social capital perspective." Mitigation and Adaptation Strategies for Global Change, 17, 687–706.

Anderson O. (2009). "Geolgoic CO2 Sequestration: Who Owns the Pore Space?" Wyoming Law Review, 9, 97.

Ayala S. (2011). "The story of NYS's fracking moratorium." Examiner. 2011.

Baumstark, K. (2015). "New Colorado Methane Emissions Rules." KBH Center for Energy, Law & Business.

Burger M. (2013). "Fracking and Federalism Choice." University of Pennsylvania Law Review. 161: 150. 2012.

CarbonTracker. (2013) "Unburnable Carbon 2013: Wasted capital and stranded assets." 2013.

Carley S, Krause R, Warren D, Rupp J, Graham J. (2013). "Early public impressions of terrestrial carbon capture and storage in a coal-intensive state." Environmental Science and Technology 46(13):7086–7093.

CCS Browser. (2013). "A guide to CO_2 capture and storage."

Census.gov. (2013). "Population Estimates 2012." *State Totals: Vintage 2012.*

City of Longmont. (2014). "Longmont succeeds in critical oil and gas case." New from the City of Longmont. October 14, 2014.

City of Longmont. (2015). "Oil and Gas Regulations in Longmont." Longmont Oil and Gas Information.

Clark V and Herzog H. (2014). "Can 'stranded' Fossil Fuel Reserves Drive CCS Deployment?" Energy Procedia 63: 7261-7271.

CO Code Regs. § 404-1:205A(b)(2)(A). (2011). Modifications to the Colorado Oil and Gas Conservation Commission Regulations. December 2, 2011.

COGA. (2012). "The Niobrara." Colorado Oil and Gas Association. Fast Facts.

COGCA. (2014). "Oil and Gas Conservation Act Title 34, Article 60." Colorado Oil and Gas Conservation Act.

Conserveland.org. (2014). "Environmental Rights Amendment." 2014.

Cuomo Administration. (2015). "Governor Cuomo Holds Cabinet Meeting." Discussion of Health Commission Findings on Hydraulic Fracturing in New York State. December 17, 2014.

Curry T. (2004). "Public awareness of carbon capture and storage: a survey of attitudes toward climate change mitigation." MIT Masters Thesis. June 2004.

Dammel J, Bielicki J, Pollak M, Wilson E. (2011)."A tale of two technologies: hydraulic fracturing and geologic carbon sequestration." Environmental science & technology 2011; 45; 5075-5076.

Detrow S. (2012). Corbett: Keep local zoning restrictions in the impact fee. NPR State Impact 2012.

Deutch J. (2012). "The US Natural-Gas Boom Will Transform the World." The Wall Street Journal. 2012.

EIA. (2012). "Top 5 Producing States' Combined Marketed Natural Gas Output Rose in 2011." Natural Gas Gross Withdrawals and Production. United States Department of Energy: Energy Information Administration 2012.

EIA. (2014a). "Crude Oil Production." United States Department of Energy: Energy Information Administration 2014. Available at: https://www.census.gov/popest/data/state/totals/2012/

EIA. (2014b). "Natural Gas Drilling." United States Department of Energy: Energy Information Administration 2014.

EIA. (2014c). "Natural Gas Weekly Update." United States Department of Energy: Energy Information Administration 10 July 2014.

EIA. (2015). "Henry Hub Natural Gas Spot Price." United States Department of Energy: Energy Information Administration. April 2015.

Ellsworth W. "Injection-Induced Earthquakes." Science 2013; 341; 6142

Fischel W. (2001). "Why are there NIMBYs?." Land economics 77.1 144-152.

Food&WaterWatch. (n.d.). "Local actions against fracking."

Fractracker.org. (2014). "New York State bans and moratoria." As of July 2014.

Freyman M. (2014). "Hydraulic fracturing and water stress." Ceres. February 2014.

Gallup. (2014). "Conservative Advantage Poll." State of the States. 2014.

Goho S. (2012). "Municipalities and hydraulic fracturing: Trends in state preemption." Planning & Environmental Law 2012; 64; 3-9.

Goldberg K. (2013). "Colo. methane rules could be a national model." Law360. November, 22, 2013.

Gough C, Taylor I, Shackley S. (2009). "Burying Carbon Under the Sea: An Initial Exploration of Public Opinions." Energy & Environment, 13, 883–900.

Handlan A and Sykes K. (1984). "Pooling and unitization: legal and ethical considerations." Tulsa Law Review. 19,3.

Healy J. (2015). "Heavyweight Response to Local Fracking Bans." New York Times. January 3, 2015.

Heddle G, Herzog H, Klett M. (2003). "The Economics of CO2 Storage," M.I.T. LFEE 2003-003 RP, August (2003).

Horton S. (2012). "Disposal of hydrofracking waste fluid by injection into subsurface aquifers triggers earthquake swarm in central Arkansas with potential for damaging earthquake." Seismological Research Letters 2012; 83; 250-260.

Huijts N, Midden C, Meijnders A. (2007). "Social acceptance of carbon dioxide storage." Energy Policy, 35(5), 2780–2789.

Interagency Working Group on the Social Cost of Carbon. (2013). "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis." United States Government. Technical Support Document Under Executive Order 12866. November 2013.

IPCC (2005) "Special Report on Carbon Dioxide Carbon Capture and Storage." Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2013) "Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

J-127A-D-2012. Township of Robinson et al., vs. Commonwealth of Pennsylvania. Pacourts.us. 2012.

Jenkins-Smith H, Silva C, Nowlin M, deLozier G. (2011). "Reversing nuclear opposition: Evolving public acceptance of a permanent nuclear waste disposal facility." Risk Analysis 31.4: 629-644.

Kahneman D, Knetsch J, Thaler R. (1991). "Anomalies: The endowment effect, loss aversion, and status quo bias." The journal of economic perspectives: 193-206.

Kahneman D, Tversky A. (1979). "Prospect Theory: An Analysis of Decision under Risk". Econometrica 47 (2): 263.

Kasperson R, Ram B. (2013). The Public Acceptance of New Energy Technologies. Daedalus, 142(1), 90–96.

Kasperson R, Renn O, Slovic P, Brown H, Emel J, Goble R, Kasperson J, Ratick S. (1988). "The social amplification of risk: A conceptual framework." Risk analysis, 8(2), 177-187.

Kenworthy T. (2012). "Local-State Clashes over Oil and Gas Drilling." Center for American Progress. Novenber 1, 2012.

Keranen K, Weingarten M, Abers G, Bekins B, Ge S. (2014). "Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection." Science 2014; 345; 448-451.

Kerr R. (2010). "Natural Gas from shale bursts onto the scene." Science. News Focus. 328: 1624-1626.

Kraeusel J, Möst D. (2012). "Carbon Capture and Storage on its way to large-scale deployment: Social acceptance and willingness to pay in Germany." Energy Policy, 49, 642–651.

Krancer M, Hill M, Tamulonis F. (2014). "Who’s on first. A tale of two states on hydraulic fracturing and the constitution." Blank Rome LLP 2014.

Krause R, Carley S, Warren D, Rupp J, Graham J. (2014).“Not in (or Under) My Backyard: Geographic proximity and public acceptance of carbon capture and storage facilities." Risk Analysis 34(3): 529-540.

Krauss C. (2008). "There’s gas in those hills." New York Times. April 8, 2008.

Kuzmich C. (2014). "Assembly passes fracking moratorium bill." The Legislative Gazette. June 17, 2014.

L’Orange Seigo S, Dohle S, Siegrist M. (2014). "Public perception of carbon capture and storage (CCS): A review." Renewable and Sustainable Energy Reviews. 38, 848–863.

Litvak A. (2014). "Uncommon legal concept may surface in New York after fracking ban." PowerSource. December 23, 2014.

Markusson N, Kern F, Watson J, Arapostathis S, Chalmers H, Ghaleigh N, Heptonstall P, Pearson P, Rossati D, Russell, S. (2012). "A socio-technical framework for assessing the viability of carbon capture and storage technology." Technological Forecasting and Social Change 2012; 79.5; 903-918.

Marsden W and Markusson N. (2011). "Public acceptance of natural gas infrastructure development in the UK 2000-2011." UK Energy Research Centre. 2011.

Marston P and Moore P. (2008). "From EOR to CCS: the evolving legal and regulatory framework for carbon capture and storage." Energy LJ 2008; 29; 421.

Midden C, Huijts N. (2009). "The role of trust in the affective evaluation of novel risks: The case of CO2 storage." Risk Analysis, 29(5): 743–751.

MIT CCS Project Database. (2015). MIT Carbon Capture and Sequestration Technologies Program.

Moody R. (2014). "Landowners sue the state over fracking moratorium." Leglislative Gazette 2014.

Mufson S. (2014). "How two small New York towns have shaken up the national fight over fracking." The Washington Post. July 2, 2014.

NETL. (2009). "Modern Shale Gas Development in the US: A Primer." Department of Energy, National Energy Technology Laboratory. 2009.

Nickerson R. (1998). "Confirmation bias: A ubiquitous phenomenon in many guises." Review of General Psychology, 2(2): 175–220.

NYDEC. (2014). "SEQR: Environmental Impact Assessment in New York State." New York State Department of Environmental Protection. 2014.

NYS Court of Appeals. (2014). "Norse Energy Corp. v. Town of Dryden." New York State Court of Appeals. Opinion. June 2014.

NYS Department of Health. (2014). "A public health review of high volume hydraulic fracturing for shale gas development." New York State Department of Health. December 2014.

O’Hare M. (2010). "NIMBY and ROW." Working Paper No. CEPP003.. UCB Center for Environmental Public Policy, Goldman School of Public Policy University of California, Berkeley.

Ohio DNR. (2015). "Mandatory Pooling." Ohio Department of Natural Resources Division of Oil and Gas Resources.

Olson M. (2009). The logic of collective action. Vol. 124. Harvard University Press.

Oltra C, Sala R, Sola R, Di Masso M, Rowe G. (2010). "Lay perceptions of carbon capture and storage technology." International Journal of Greenhouse Gas Control, 4(4): 698-706.

Oltra C, Upham P, Riesch H, Boso A, Brunsting S, Dütschke E, Lis A. (2012). "Public Responses to CO2 Storage Sites: lessons from five European cases. Energy & Environment, 23(2): 227–248.

PA Act 13 HB 1950. (2012). State of Pennsylvania. House Bill 1950: Act 13. 2012.

Palmgren C, Morgan G, Bruine de Bruin W, Keith D. (2004). "Initial public perceptions of deep geological and oceanic disposal of carbon dioxide." Environmental Science and Technology. 38: 6441-6450.

Pennsylvania Constitution, Article I, Section 27.

Politico. (2011). "Governor John Hickenlooper." Politico Magazine: The Arena.

Rahm D. (2011). "Regulating hydraulic fracturing in shale plays: The Case of Texas." Energy Policy 2011; 39;2974-2981.

Renn O. (1998). "The role of risk perception for risk management." Reliability Engineering and System Safety. 59: 49-62.

Richardson N, Gottlieb M, Krupnick A, Wiseman H. (2013). "The State of Shale Gas Regulation." Resources for the Future 2013.

Rochat S. (2014). "Boulder Country judge strikes down Longmont fracking ban." Longmont Times Call News. July 24, 2014.

Ruben J, Hager B, Herzog H. (2012). "No geologic evidence that seismicity causes fault leakage that would render large-scale carbon capture and storage unsuccessful." Proceedings of the National Academy of Sciences 109.52: E3623-E3623.

Schively C. (2007). "Understanding the NIMBY and LULU phenomena: Reassessing our knowledge base and informing future research." Journal of planning literature 21(3): 255-266.

Singleton G, Herzog H, Ansolabehere, S. (2009). "Public risk perspectives on the geologic storage of carbon dioxide." International Journal of Greenhouse Gas Control. 2009; 3(1), 100–107.

Singleton G. (2007). "Geologic Storage of Carbon Dioxide: Risk Analysis and Implications for Public Acceptance." MIT Masters Thesis. June 2007.

Sjöberg L. (2000). "Perceived risk and tampering with Nature." Journal of Risk Research. 3(4): 353-367.

Slovic P. (1987). "Perception of risk." Science 236(4799): 280-285.

Stark P. (2013). "US Tight Oil Plays." IHS inc. Available at: http://blog.ihs.com/us-tight-oil-plays-spotlight-on-the-learning-curve

Starr C. (1969). "Social benefit versus technological risk: what is our society willing to pay for safety?" Science. 165: 1232-1238.

Stedman R, Jacquet J, Filteau M, Willits F, Brasier K, McLaughlin D. (2012). "Environmental reviews and case studies: Marcellus shale gas development and new boomtown research: Views of New York and Pennsylvania residents." Environmental Practice 14(04): 382-393.

Streater S. (2013). "Colorado okays groundwater sampling rule derided by industry, environmentalists," E&E, January 8, 2013.

ter Mors E, Terwel B, Daamen D. (2012). "The potential of host community compensation in facility siting." International Journal of Greenhouse Gas Control 11: S130-S138.

ter Mors E, Weenig M, Ellemers N, Daamen D. (2010). "Effective communication about complex environmental issues: Perceived quality of information about carbon dioxide capture and storage (CCS) depends on stakeholder collaboration." Journal of Environmental Psychology. 30(4): 347–357.

Terwel B, Daamen D. (2012). "Initial public reactions to carbon capture and storage (CCS): differentiating general and local views." Climate Policy 12(3): 288-300.

Terwel B, Harinck F, Ellemers N, Daamen D. (2009). "Competence-based and integrity-based trust as predictors of acceptance of carbon dioxide capture and storage (CCS)." Risk Analysis, 29: 1129-1140.

Terwel B, Harinck F, Ellemers N, Daamen D. (2010). "Voice in political decision-making: the effect of group voice on perceived trustworthiness of decision makers and subsequent acceptance of decisions." Journal of Experimental Psychology: Applied 16(2): 173-186.

Tokushige K, Akimoto K, and Tomoda T. (2007). "Public perceptions on the acceptance of geological storage of carbon dioxide and information influencing the acceptance." International Journal of Greenhouse Gas Control 1(1): 101-112.

U.S. Congress. (2005). "Energy Policy Act of 2005." Public Law 2005; 109.58; 42.

Upham P, Roberts T. (2011). "Public perceptions of CCS: Emergent themes in pan-European focus groups and implications for communications." International Journal of Greenhouse Gas Control, 5(5): 1359–1367.

USGS. (2012). "Map of Assessed Shale Gas in the United States, 2012." United States Geologic Survey. National Assessment of Oil and Gas Project. Digital Data Series DDS-69-Z.

Van der Horst D. (2007). "NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies." Energy policy 35(5): 2705-2714.

van Os H, Herber R, Scholtens B. (2014). "Not Under Our Back Yards? A case study of social acceptance of the Northern Netherlands CCS initiative." Renewable and Sustainable Energy Reviews 2014; 30; 923-942.

Visschers V, Siegrist M. (2012). "Fair play in energy policy decisions: Procedural fairness, outcome fairness and acceptance of the decision to rebuild nuclear power plants." Energy Policy, 46: 292-300.

Wallquist L, Seigo S, Visschers V, Siegrist M. (2012). "Public acceptance of CCS system elements: A conjoint measurement." International Journal of Greenhouse Gas Control, 6: 77–83.

Wallquist L, Visschers V, Siegrist M. (2010). "Impact of knowledge and misconceptions on benefit and risk perception of CCS." Environmental Science and Technology, 44(17): 6557–6562.

Wolff J and Herzog H. (2014). "What lessons can hydraulic fracturing teach CCS about social acceptance?" Energy Procedia 63: 7024-7042.

Wolsink M. (2007). "Planning of renewables schemes: Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation." Energy Policy 2007; 35; 5; 2692-2704.

Wong-Parodi G, Dowlatabadi H, McDaniels T, and Ray I. (2011). "Influencing Attitudes toward Carbon Capture and Sequestration: A Social Marketing Approach." Environmental Science & Technology, 45: 6743–6751.

Wüstenhagen R, Wolsink M, Bürer M. (2007). "Social acceptance of renewable energy innovation: An introduction to the concept." Energy Policy 2007; 35; 2683-2691.

Zaal M, Terwel B, ter Mors E, Daamen D. (2014). "Monetary compensation can increase public support for the siting of hazardous facilities." Journal of Environmental Psychology, 37:21–30.

Zoback M, Gorelick S. (2012). "Earthquake triggering and large-scale geologic storage of carbon dioxide." Proceedings of the National Academy of Sciences; 109.26; 10164-10168.

Appendix A: Discussion of EPA Class VI Well Regulations

On October 8, 2014, at the GHGT12 conference in Austin, Texas, dozens of researchers and industry leaders gathered to hear a panel talk entitled "Permitting Storage Sites in the US: Lessons Learned and Paths Forward." Sean McCoy from the International Energy Agency moderated the panel, which included Mary Rose Bayer, co-leader of the Geologic Sequestration team in the U.S. Environmental Protection Agency's (EPA's) Office of Ground Water and Drinking Water; Sallie Greenberg, associate director of the Advanced Energy Technology Initiative at Illinois State Geological Survey; Dwight Peters, business manager at Schlumberger Carbon Services; and Bob Van Voorhees, executive director of the Carbon Sequestration Council. The panel reflected on lessons learned about EPA's Class VI permitting process and implications for the workability of future geologic sequestration projects. This article summarizes their discussion and the pertinent comments expressed by attendees.

Background on EPA's Class VI well rule

EPA's Class VI well rule for carbon dioxide sequestration represents the first new well class since the Agency implemented the five initial well classes to protect underground sources of drinking water (USDWs). In 2007, EPA initiated the development of a new regulatory framework for geologic sequestration. The Agency proposed the new Class VI rule in 2008 and promulgated the final rule in 2010. Carbon dioxide injection for enhanced oil recovery still falls under the Class II rule, but Class II wells intended for geologic sequestration must apply for a Class VI well permit when there is an increased risk to USDWs compared to Class II operations. EPA's criteria for Class VI wells include extensive requirements related to site characterization, well construction, monitoring procedures, post injection site care, emergency response, and financial responsibility.

To date, EPA has approved a total of six Class VI well permits, awarding four well permits to FutureGen 2.0 in Morgan County, Illinois, on August 29, 2014, and two well permits (one final, one draft) to Archer Daniel Midland's (ADM's) Illinois Industrial CCS Sources project in Decatur, Illinois, on September 23, 2014. Note that the FutureGen project has since been cancelled.

The panelists focused on these main topics:

- Technical collaboration between EPA and permit applicants.
- Causes and effects of the long permit processing timeframes.
- Aspects of successful projects.
- The relationship between Class VI wells and other well types.

EPA as a technical collaborator for Class VI wells

Throughout the GHGT12 panel session, Mary Rose Bayer stressed that EPA intended the Class VI well regulations to foster technical collaboration between permit applicants and the Agency. She cautioned that applicants should not look at the permit as a simple box checking exercise, but instead as an opportunity to engage with technical staff at EPA. This collaborative paradigm means that each well permit requires significant investments of expertise, time, and money from both EPA and the applicant.

These investments, however, reflect the Rule's ability to adapt to individual project sites. Moreover, they will help improve the regulatory decisions over time, particularly in areas related to risk quantification and assessment, over-pressurized injection formations, and plume monitoring. Finally, as Bob Van Voorhees noted, EPA's collaborative approach toward the Class VI permit has led to a helpful separation between well data collected for research purposes and data collected to satisfy the permit requirements. Applicants have been pleasantly surprised that well data collections intended solely for research purposes have not adversely affected the permitting process.

A lengthy permit review period

Perhaps the most common topic of discussion was the length of time required for permit approval. When asked about the biggest surprises in the permitting process, Sallie Greenberg immediately cited the permitting timeframe. Citing a similar example for gaining a Class I non-hazardous permit prior to the Class VI rule, she explained that her team had expected the process to take six months, but it ultimately took three years. The delay significantly affected project budgeting and management. Similarly, Bob Van Voorhees cautioned that future permitting cannot be allowed to take 12 to 36 months, and pointed toward the past delays as costing the industry experimental and scientific opportunities.

Mary Rose Bayer said that EPA is aware of sensitivities around the permitting timeline. She explained that the permitting process necessarily relies on significant "information sharing" between EPA and each permit applicant. The Agency is interested in ensuring that it receives Class VI project data that supports the permit applicant's decision-making, allows EPA to determine regulatory compliance, and facilitates transparent communication with stakeholders. Future applicants can speed up the permitting process by, for example, communicating the rationale behind choosing particular locations for monitoring wells. Still, given EPA's responsibility as the permitting authority to review all information submitted and to ensure the permit applicant is in compliance with Federal regulations, it will continue to take time to evaluate permit applications and ensure that protective permits are issued.

Aspects of successful projects

All geologic sequestration wells must meet Class VI permit criteria, but successful projects will need to exceed many of the rule's regulations. While the permitting delay negatively affected some aspects of project management for the first Decatur well, it had one interestingly positive effect: it led to a more comprehensive environmental baseline. Sallie Greenberg anticipates that the extended baseline will pay dividends during future monitoring efforts. Dr. Greenberg explained that establishing environmental baselines and conducting environmental monitoring are two areas where successful project developers must exceed permit requirements.

Stakeholder engagement is another such area. Dr. Greenberg cautioned that developers who adhere too closely to the minimum public participation parts of the permitting process will fail to begin community meetings early enough in the process and will likely face significant opposition. Successful developers must initiate stakeholder engagement long before the permitting process starts. For example, Decatur project managers began meeting with the community in 2003, five years before submitting their 2008 Class VI permit application. Engagement activities included science fairs, public meetings, hearings, focus groups, and school appearances.

Dwight Peters agreed but warned future applicants to remember that anything written into the permit becomes a legal requirement. For example, a facility that commits to two community meetings per week is then compelled to host the meetings each week, regardless of whether stakeholders show up.

The relationship between Class VI wells and other well types

The final discussion theme revolved around how Class VI wells might relate to wells used for enhanced oil recovery (EOR) or research activities. One attendee asked whether EPA allows for easy conversion of a well's type from Class II EOR to Class VI. Dwight Peters answered that such a change would likely not be pursued while EOR operations are ongoing. This is because EOR operators are focused on producing oil at minimum cost, not sequestering carbon dioxide.

Regarding research wells, Bob Van Voorhees pointed out that the stringent requirements of Class VI permits create disincentives for many types of activities. Of particular concern is the 50 year mandatory PISC, which is likely to be unnecessary for most research operations. Mr. Van Voorhees suggested that EPA revisit its initial strategy to permit research wells as Class V experimental technology wells. Mary Rose Bayer, however, indicated that EPA is interested, instead, in focusing on collaboration with permit applicants in an effort to work toward adapting the Class VI well requirements to enable research projects.

Advice for future well operators

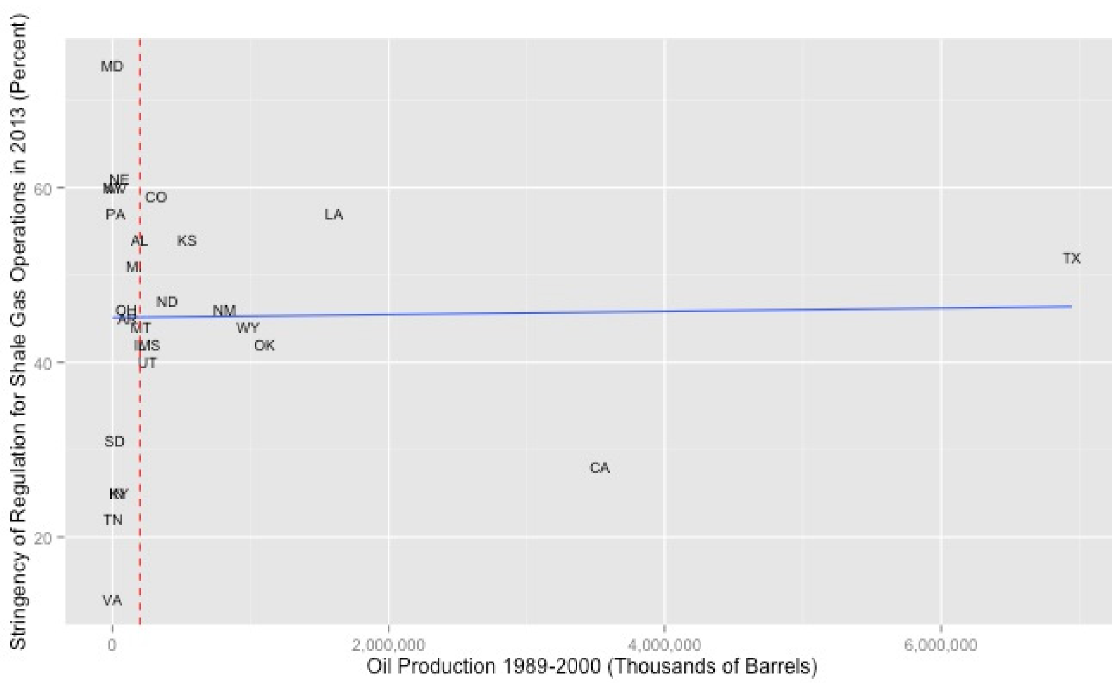
As the panel came to a close, the moderator asked each panelist to share final words of advice with future permit applicants.

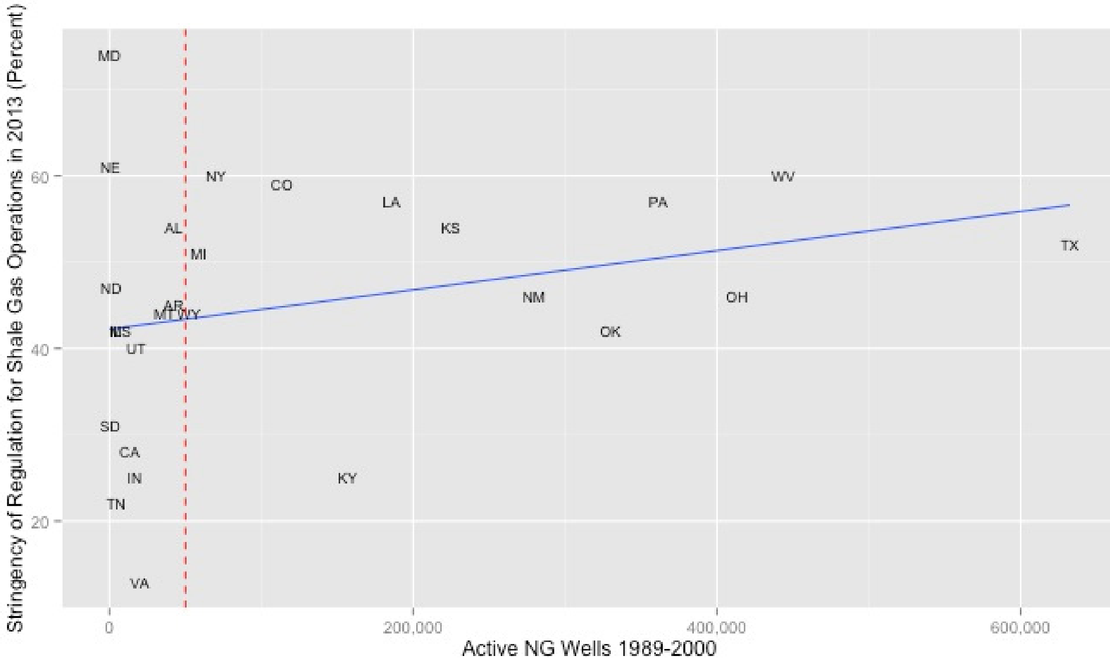
- *Mary Rose Bayer*: EPA is committed to partnering with applicants through early engagement and technical collaboration. Please don't view EPA simply as reviewers and the permitting process as a "box checking exercise." EPA is focused on making technical, risk-based permitting decisions.
- *Sallie Greenberg*: Look to successful projects as models for your own wells. Begin working with EPA as soon as possible. Plan to exceed permit requirements in certain areas to support best practices and build prior and informed consent.
- *Bob Van Voorhees*: EPA designed the regulation to allow for a reasonable amount of flexibility, but the Agency cannot identify best practices; that is the job of the research community and injection well operators.
- *Dwight Peters*: Begin the permitting process as early as possible. CCS projects are complex and require many other permits in addition to Class VI well approval. You wouldn't want to pursue a capture permit until you are sure you're sure you'll get a permit for storage. Pretty soon you're looking a decade into the future.

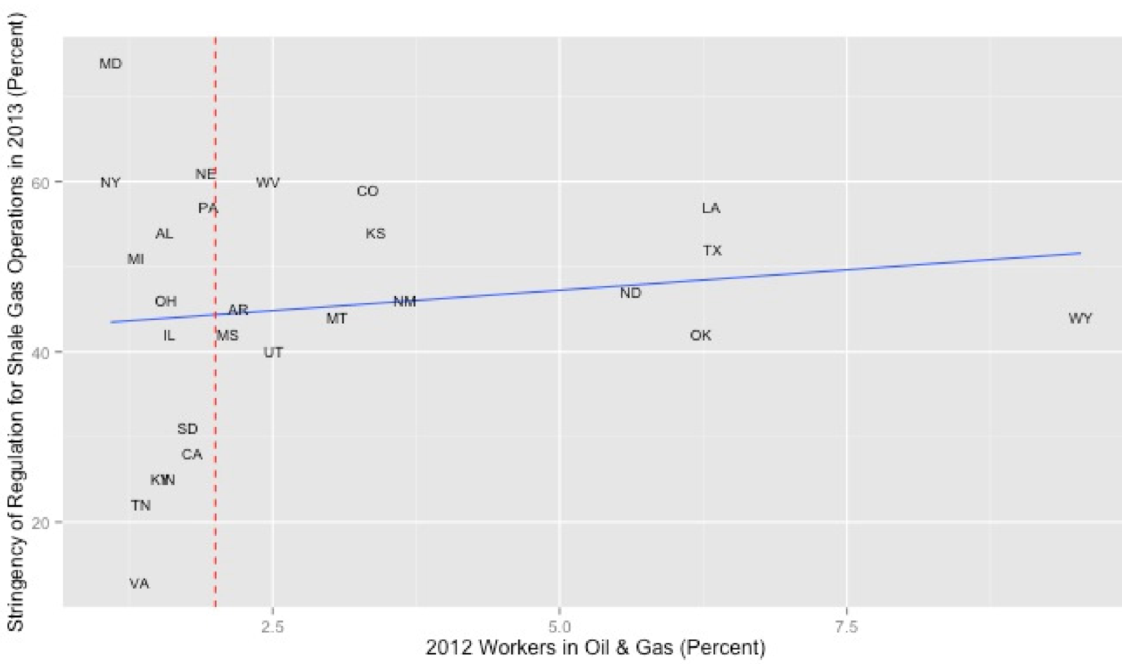
Appendix B: Additional Results from State Regulatory Analysis

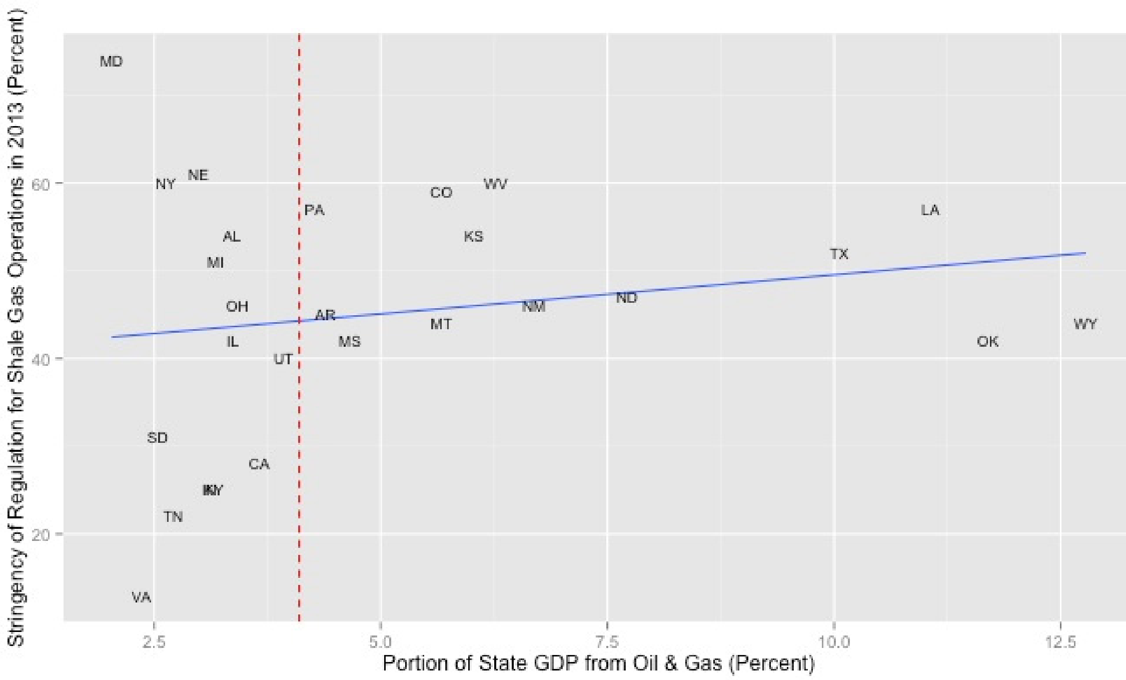
Additional scatterplots

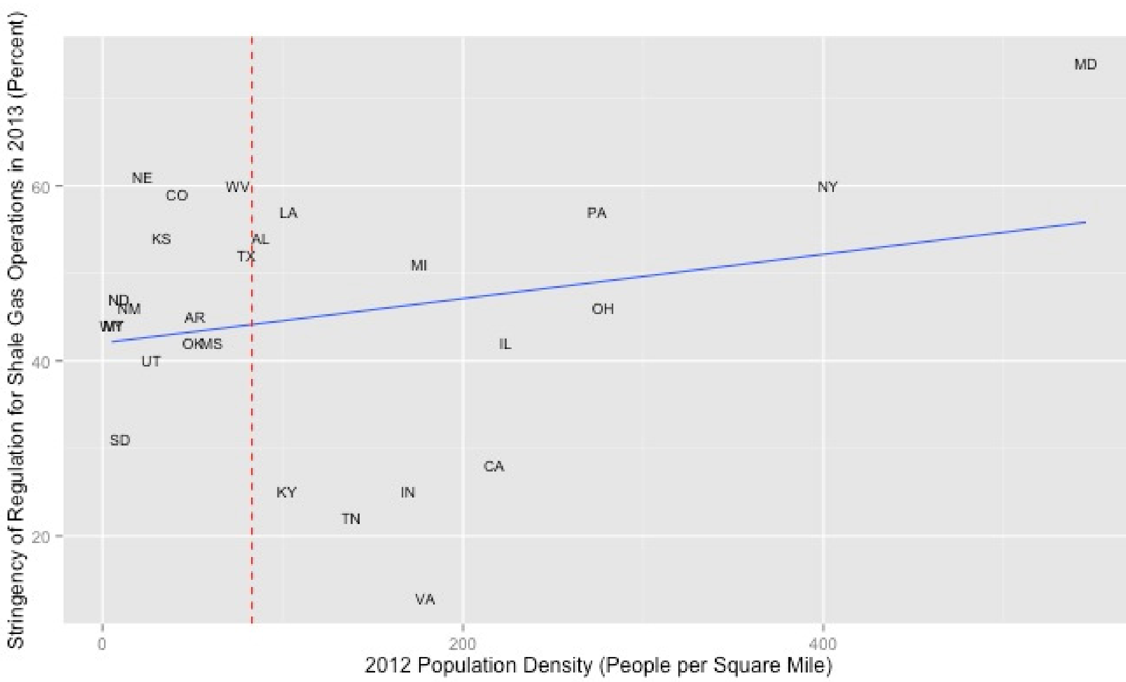
The scatterplots below display the data we analyzed with each of our variance tests. Each state's relative level of regulatory stringency for shale gas development is plotted against the various familiarity and demographic variables discussed previously. The vertical line on each plot, colored red and dashed, denotes the demarcation between test groups one and two. For the familiarity variables—historic gas wells, historic oil production, percent of workforce in oil and gas, and percent of GDP based on oil and gas—this line marks the division between the low familiarity and high familiarity groups. For the population density variable, it marks the division between rural and urban states. For the conservative advantage states it marks the division between relatively liberal and relatively conservative states. The solid blue line represents the results of a simple regression test, which is displayed here to illustrate trends in the data.

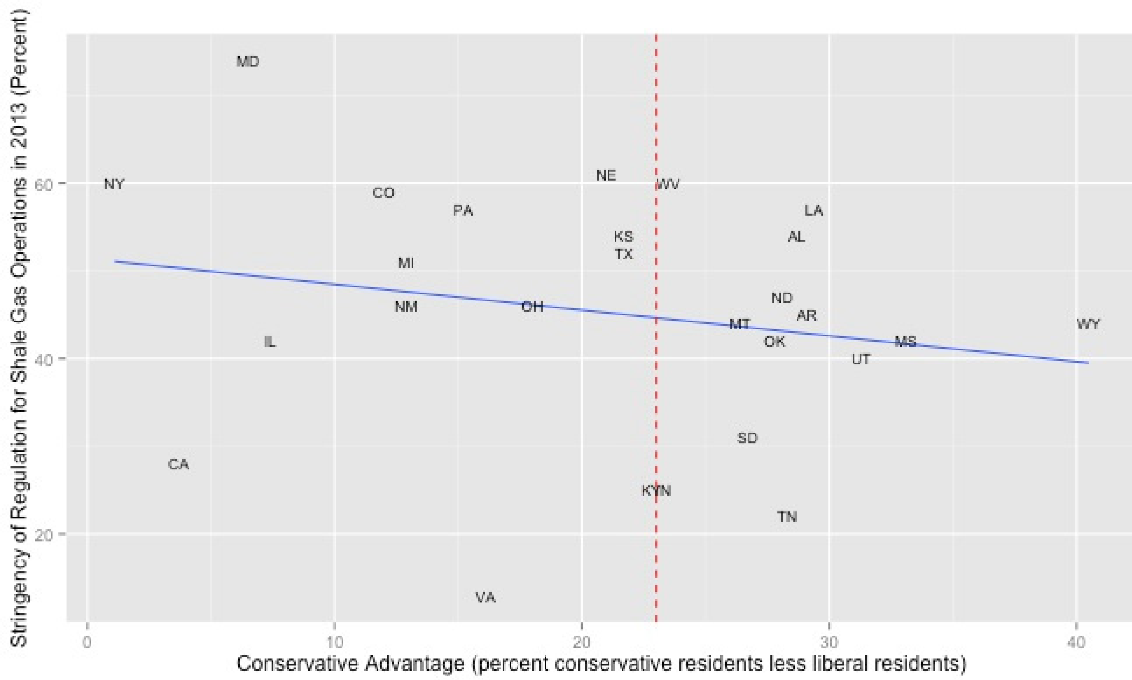



Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
Active NG Wells 1989-2000
0
200,000
400,000
600,000
20
40
60
MD
NE
NY
CO
LA
KS
AL
MI
ND
AR
MT
WY
MS
UT
SD
CA
IN
TN
VA
KY
WV
PA
TX
NM
OH
OK


Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
2012 Workers in Oil & Gas (Percent)
2.5
5.0
7.5
20
40
60
MD
NY
NE
WV
CO
PA
AL
KS
MI
LA
TX
OH
AR
NM
ND
MT
WY
IL
MS
OK
UT
SD
CA
TN
VA


Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
Portion of State GDP from Oil & Gas (Percent)
MD
NY
NE
PA
CO
WV
KS
LA
AL
MI
TX
OH
AR
NM
ND
MT
WY
IL
MS
OK
UT
SD
CA
TN
VA
20
40
60
2.5
5.0
7.5
10.0
12.5


Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
2012 Population Density (People per Square Mile)
MD
NE
CO
WV
NY
LA
PA
KS
AL
TX
MI
ND
NM
OH
AR
OKMS
IL
UT
SD
CA
KY
IN
TN
VA
20
40
60
0
200
400



F-Test and the Levene's test results for statistical differences between groups

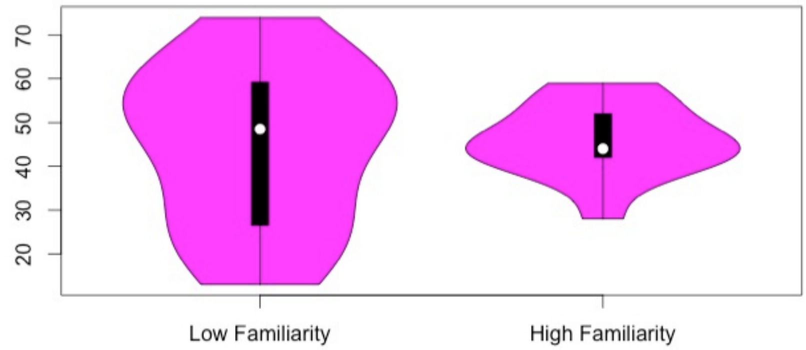
Tests results for difference in variance of regulatory stringency between high and low familiarity groups

Stringency vs…	Variance	F-Test Result	Levene's Test Result
Oil extraction '89-'00	Low oil familiarity: 335 High oil familiarity: 67	F = 4.98 p-value =0 .0088***	Test Statistic = 11.642 p-value = 0.000714***
Gas wells '89-'00	Low gas familiarity: 261 High gas familiarity: 96	F = 2.7058 p-value = 0.0945*	Test Statistic = 5.97 p-value = 0.007259***
State GDP from O&G	Low O&G GDP: 313 High O&G GDP: 46	F= 6.847 p-value = 0.0021***	Test Statistic = 4.8357 p-value = 0.01432**
Workforce in O&G	Low O&G employment: 332 High O&G employment: 48	F = 6.919629 p-value = 0.0019***	Test Statistic = 8.2447 p-value = 0.002431***
Population Density	Low pop density: 73 High pop density: 337	F = 0.2177623 p-value = 0.0105**	Test Statistic = 16.08 p-value = 0.000217***
Conservative Advantage	Low conservative ad.: 265 High conservative ad.: 129	F= 2.060249 P=value= 0.2205`	Test Statistic = 3.9624 p-value = 0.02637**

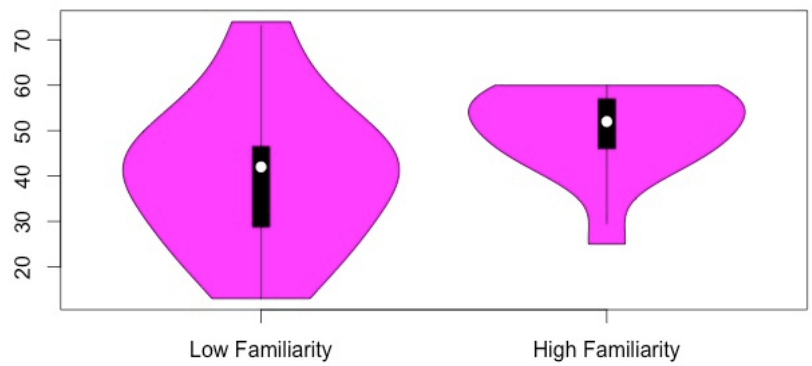
* Statistically significant with 90 percent confidence
** Statistically significant with 95 percent confidence
*** Statistically significant with 99 percent confidence
` Not statistically significant

Additional violin plots

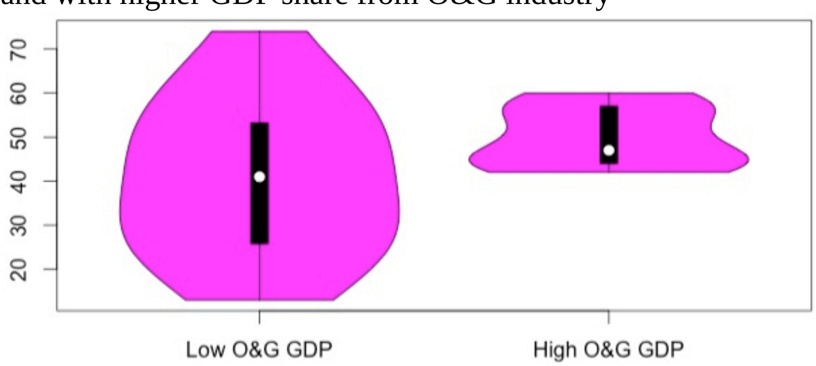
Distribution of shale gas regulatory stringency (percent)
for states familiar and unfamiliar with oil extraction



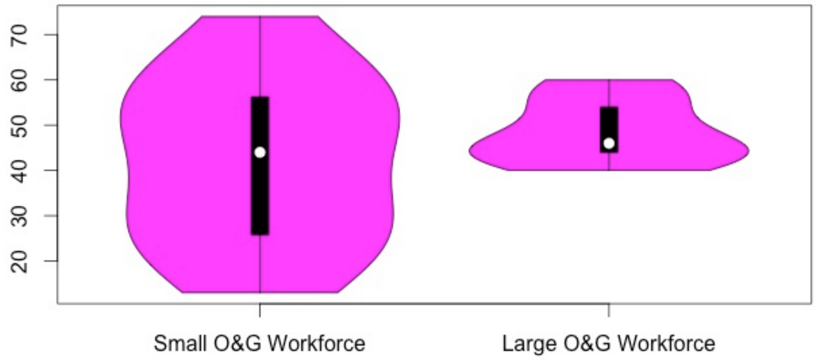
Distribution of shale gas regulatory stringency (percent)
for states familiar and unfamiliar with natural gas extraction



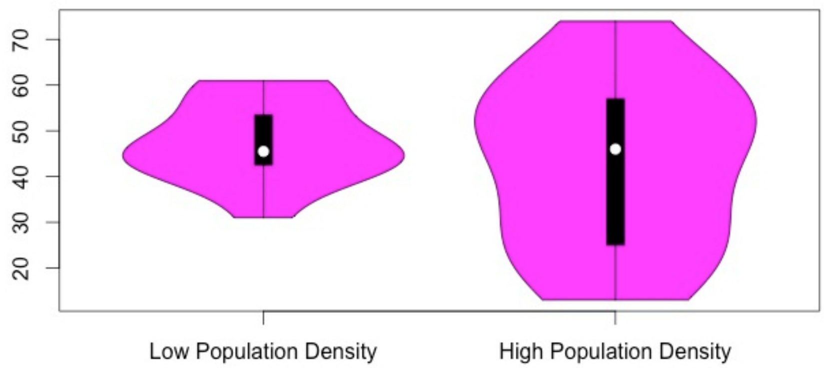
Distribution of shale gas regulatory stringency (percent)
for states with lower GDP share from O&G industry
and with higher GDP share from O&G industry



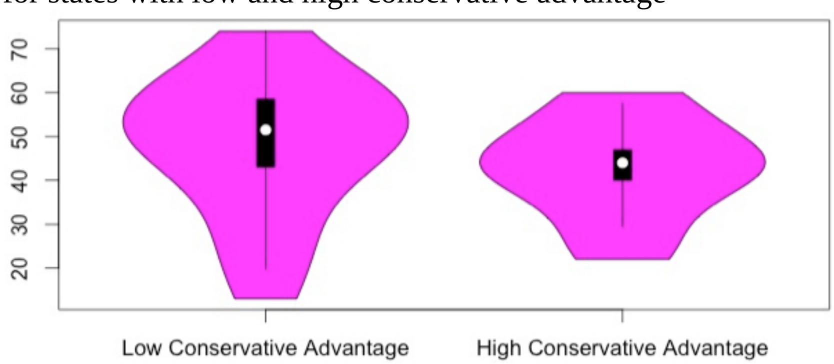
Distribution of shale gas regulatory stringency (percent)
for states with small O&G workforces and with large O&G workforces



Distribution of shale gas regulatory stringency (percent)
for states with low and high population density



Distribution of shale gas regulatory stringency (percent)
for states with low and high conservative advantage



Appendix C: Reiner survey data and more detailed analysis

US Survey Questions

1. Have you heard of or read about any of the following in the past year? (Select all that apply.)

[Randomize list]

1. More efficient appliances
2. Hybrid cars
3. Hydrogen cars
4. Hydraulic fracturing
5. Nuclear energy
6. Bioenergy/biomass
7. Carbon sequestration
8. Solar energy
9. Carbon capture and storage
10. Wind energy
11. Fracking
12. Iron fertilization
13. Clean coal
14. Shale gas
15. None of these

2. Many environmental issues involve difficult trade-offs with the economy. Which of the following statements best describes your view? (Select only one response.)

[Rotate order. Half of sample gets order 1-4. Other half gets order 4-1]

1. The highest priority should be given to protecting the environment, even if it hurts the economy.
2. Both the environment and the economy are important, but the environment should come first.
3. Both the environment and the economy are important, but the economy should come first.
4. The highest priority should be given to the economy even if it hurts the environment.
5. Not sure

3. Which statement comes closest to your views on how the problem of global warming should be addressed? (Select only one response.)

[Randomize list]

1. I believe that firms and government researchers should develop new technologies to solve the problem.
2. I believe we should change our lifestyles to reduce energy consumption.
3. I believe we should adapt to a warmer climate.
4. I believe we should do nothing since global warming is not a problem.

[Split sample. HALF SAMPLE shown Q4A. HALF SSAMPLE shown Q4b]

4a. Hydraulic fracturing, or “fracking,” is a way to extract natural gas from shale rocks found deep underground. The hydraulic fracturing process pumps millions of gallons of sand, water, and chemicals deep underground to break apart rocks that contain the natural gas. The produced natural gas is used to help generate electricity, heat homes, and power industry. As a fossil fuel, natural gas is cleaner than coal and less expensive than oil.

Imagine that an energy company approaches you about beginning hydraulic fracturing operations in your area. The company asks to lease your mineral rights in return for a royalty payment.

Would you be willing to accept hydraulic fracturing near your home if you got a royalty of [START PAYMENT AT 500, THEN, 1000, 2500, 5000 UNTIL PERSON ACCEPTS] per MONTH for the active lifetime of the well?

programmmer: show 500 first (yes/no response), then 1000, 2500, 5000. Once a respondent says yes skip to next question.

	Yes	No
$500	1	2
$1000	1	2
$2500	1	2
$5000	1	2

4b. Carbon capture and storage (CCS) is a way to reduce carbon dioxide emissions in response to climate change concerns and is compatible with our current fossil energy infrastructure. CCS technologies “capture” carbon dioxide from the exhaust of fossil fuel-fired power plants and other industrial facilities, and then pump it deep underground into safe and permanent storage areas at least a half mile below the earth’s surface. Many studies show that the use of CCS technologies will reduce the overall costs of meeting carbon dioxide emissions reduction goals.

Imagine that an energy company approaches you about beginning carbon storage operations in your area. The company asks to lease your mineral rights in return for a royalty payment.

Would you be willing to accept carbon storage near your home if you got a royalty of [START PAYMENT AT 500, THEN 1000, 2500, 5000 UNTIL PERSON ACCEPTS] per MONTH for the active lifetime of the project?

programmmer: show 500 first (yes/no response), then 1000, 2500, 5000. Once a respondent says yes skip to next question.

	Yes	No
$500	1	2
$1000	1	2
$2500	1	2
$5000	1	2

UK Survey Questions

<u>Instructions</u>

Question 1 – Random order (a)-(m); select up to three
Question 2 – Ask question as it is
Question 3 – Random (a)-(e)/(e)-(a)
Question 4 – Random order (a)-(k); select up to three
Question 5 – Random (a)-(d)/(d)-(a)
Question 6 – Ask question as it is
Question 7 – Random (a)-(g)/(g)-(a)
Question 8 – Random order for all except (q); multiple responses
Question 9 – Random order
Question 10 – Random order
Question 11 – Ask question as it is
Question 12 – Ask question as it is
Question 13 – Ask question as it is
Question 14 – Random order
Question 15 – Random order
Question 16 – Random (a)-(e)/(e)-(a)
Question 17 – Open-ended
Question 18 – Random (a)-(e)/(e)-(a)
Question 19 – Random (a)-(e)/(e)-(a)
Question 20 – Ask question as it is
Question 21 – Random (a)-(e)/(e)-(a)
Question 20 – Random (a)-(g)/(g)-(a)
Question 21 – Random order
Question 22 – Random order (a)-(d)
Question 23 – Random order (a)-(e)
Question 24 – Random order
Question 25a-25c – Rotate order and

Question 1

Which of the following do you think are the most important issues facing the country at this time? Please tick up to three.
<1>Health
<2>Immigration & Asylum
<3>Crime
<4>The economy
<5>Tax
<6>Pensions
<7>Education
<8>Family life & childcare
<9>International conflicts
<10>The environment
<11>Europe
<l2>Energy prices
<13>Transport
<14 fixed xor>None of these
<15 fixed xor>Don't know

[We'll only show the three respondents select]
Of these, please select which you believe to be the single most important issue facing the country.
<1>Health
<2>Immigration & Asylum
<3>Crime
<4>The economy
<5>Tax
<6>Pensions
<7>Education
<8>Family life & childcare
<9>International conflicts
<10>The environment
<11>Europe
<l2>Energy prices
<13>Transport
<14 fixed xor>None of these
<15 fixed xor>Don't know

Question 2

We currently assist other nations through international aid. Do you think we should increase international aid, let it stay the same, decrease international aid or remove it entirely?

(a) Increase
(b) Stay the same
(c) Decrease
(d) Remove it entirely
(e) Don't know

Question 3

To what extent do you agree or disagree with the following statement: Science and technology are making our lives healthier, easier, and more comfortable

(a) Strongly Agree
(b) Agree
(c) Neither agree nor disagree
(d) Disagree
(e) Strongly disagree
(f) Don't know

Question 4

Consider the following environmental problems. Which would you say are the most important problems facing the UK today? Please select up to three.

(a) Toxic waste
(b) Ozone depletion
(c) Endangered species
(d) Climate Change
(e) Acid rain
(f) Smog
(g) Green Spaces
(h) Water pollution
(i) Overpopulation
(j) Destruction of ecosystems
(k) Resource depletion
(l) None of these
(m) Don't know

Question 4a.

Of these, please select the environmental problem you believe to be the single most important problem.
(a) Toxic waste
(b) Ozone depletion
(c) Endangered species
(d) Climate Change
(e) Acid rain
(f) Smog
(g) Green Spaces
(h) Water pollution
(i) Overpopulation
(j) Destruction of ecosystems
(k) Resource depletion
(l) None of these
(m) Don't know

Question 5

Many environmental issues involve difficult trade-offs with the economy. Which of the following statements best describes your view?

(a) The highest priority should be given to protecting the environment, even if it hurts the economy.
(b) Both the environment and the economy are important, but the environment should come first.
(c) Both the environment and the economy are important, but the economy should come first.
(d) The highest priority should be given to the economy even if it hurts the environment.
(e) Not sure

Question 6

Compared to most people how knowledgeable would you say you are about how energy is produced, delivered and used?

(1) (2) (3) (4) (5)

Not at all Knowledgeable	Very knowledgeable

Question 7

How would you describe energy prices today?

1. Unreasonably low
2.
3.
4.
5.
6.
7. Unreasonably high
8. Don't know

Question 8

Have you read about any of the following in the past year? Check all that apply.

(a) More efficient appliances
(b) More efficient cars
(c) Hydrogen cars
(d) Nuclear energy
(e) Bioenergy/biomass
(f) Deforestation/Reforestation
(g) Solar energy
(h) Carbon capture and storage
(i) Wind energy
(j) Iron fertilisation
(k) Land reification
(l) Geoengineering
(m) Ocean acidification
(n) Shale gas
(o) Enhanced oil recovery
(p) Hydraulic fracturing (Fracking)
(q) None of the above

Question 9

To what extent do you trust information about energy related issues from each of the following sources?

Sources	**1 Not at all**	**2**	**3**	**4**	**5**	**6**	**7 Totally**	**Don't know**
(a) The UK government								
(b) Regional/ local government								
(c) The European Union								
(d) Electricity, gas and other energy companies								
(e) University scientists								
(f) Journalists								
(g) Major political parties								
(h) Environmental protection organizations								

Question 10

Which, if any, of the following activities have a significant impact on levels of carbon dioxide in the atmosphere?

	Yes, increases carbon dioxide	Yes, decreases carbon dioxide	No impact	Not sure
(a) Cars				
(b) Home heating				
(c) Coal burning power plants				
(d) Nuclear power plants				
(e) Windmills				
(f) Trees				
(g) Oceans				
(h) Factories (e.g. steel mills)				
(i) Breathing				

Question 11

From what you know about climate change, which of the following statements comes closest to your opinion?
(a) Climate change has been established as a serious problem and immediate action is necessary.
(b) There is enough evidence that climate change is taking place and some action should be taken.
(c) We don't know enough about climate change and more research is necessary before we take any actions.
(d) Concern about climate change is unwarranted.
(e) Not sure

Question 12

How much change do you think is needed to our general lifestyle and consumption habits to stop the effects of climate change happening? Choose the answer that is *closest* to your opinion

(a) We need to radically alter our behaviour
(b) We need to dramatically alter our behaviour to be more energy efficient, but solutions to climate change must come through the development of clean energy sources
(c) Changing our behaviour on such a large scale is not feasible; therefore we need to rely on technological development of cleaner energy sources.
(d) Neither behaviour change nor widespread use of cleaner energy technology will stop climate change happening
(e) Climate change is not a problem at all

Question 13

How familiar are you with carbon capture and storage (CCS) technologies?

(a) Never heard of this
(b) Heard before, but not at all familiar
(c) Not very familiar
(d) Neither familiar nor unfamiliar
(e) Somewhat familiar
(f) Very familiar

Question 14

Do you think "Carbon capture and storage" or CCS can or can not reduce each of the following environmental concerns?

	Can reduce this environmental concern	Can NOT reduce this environmental concern	Not sure
(a) Toxic waste			
(b) Ozone depletion			
(c) Climate change			
(d) Acid rain			
(e) Smog			
(f) Water pollution			
(g) Resource depletion			

Question 15

The following technologies have been proposed to address climate change. If you were responsible for designing a plan to address climate change, which, if any, of the following technologies would you use?

[For each, the respondent may choose *Definitely Use, Probably Use, Neutral, Probably Not Use, Don't Know]*

(a) Bioenergy/biomass: Producing energy from trees or agricultural wastes.
(b) Aforestation/reforestation: Planting trees to absorb carbon dioxide from the atmosphere.
(c) Carbon capture and storage with gas power: Capturing carbon dioxide from natural gas-fired power plant exhaust and storing it in underground reservoirs.
(d) Carbon capture and storage with coal power: Capturing carbon dioxide from coal-fired power plant exhaust and storing it in underground reservoirs.
(e) Iron fertilisation of oceans: Adding iron to the ocean to increase its uptake of carbon dioxide from the atmosphere.
(f) Energy efficient appliances: Producing kitchen and household appliances that use less energy to accomplish the same tasks.
(g) Energy efficient cars: Producing cars that use less energy to drive the same distance.
(h) Nuclear energy: Producing energy from a nuclear reaction.
(i) Solar energy: Using the energy from the sun for heating or electricity production.
(j) Wind energy: Producing electricity from the wind, traditionally in a windmill.
(k) Cool roof: Painting rooftops white to reflect sunlight
(l) Aerosols: Spraying small particles into the upper atmosphere to reflect sunlight
(m) Fuel switching: Replace coal-fired power plants with natural gas fired power plants that produce half as much carbon dioxide as coal

Question 16

The UK Government plans to spend £1 billion to support the demonstration of carbon dioxide capture and storage (CCS) technologies, which would capture carbon dioxide from a large power plant and store it under the North Sea. To what extent do you support or oppose this commitment?

(a) Strongly support
(b) Tend to support
(c) Neither support nor oppose
(d) Tend to oppose
(e) Strongly oppose
(f) Not sure/DK

Question 17

The UK has narrowed down funding for these CCS projects to two main proposals. One project is meant to be in Yorkshire and the other in Scotland. Can you name either of these projects or any of the companies involved? IF you cannot name either of these projects or the companies involved, please skip this question, please do not look up the answer, this question will automatically skip forward in 1 minute.

Question 18

How effective or ineffective do you think environmental regulations are in protecting the environment in your local community?

(a) Very effective
(b) Somewhat effective
(c) Neither effective nor ineffective
(d) Somewhat ineffective
(e) Very ineffective
(f) Not Sure/Don't Know

Question 19

Would you say yourexperience with the development of new infrastructure (transport links, waste facilities, etc) in your community was mainly positive or negative?

(a) Very positive
(b) Somewhat positive
(c) Neither positive nor negative
(d) Somewhat negative
(e) Very negative
(f) Not Sure/Don't Know

Question 20

How familiar are you with hydraulic fracturing (fracking)?

(a) Never heard of this
(b) Heard before, but not at all familiar
(c) Not very familiar
(d) Neither familiar nor unfamiliar
(e) Somewhat familiar
(f) Very familiar

Question 21

Based on what you know or have heard, please indicate the degree to which you support or oppose hydraulic fracturing (fracking) in the extraction of fossil fuels:

(a) Strongly oppose
(b) Somewhat oppose
(c) Oppose neither support nor oppose
(d) Somewhat support
(e) Strongly support
(f) Don't know

Question 22

Which, if any, of the following would you say were the main benefits of hydraulic fracturing or fracking for shale gas?

(a) Less reliance on imported energy
(b) Compensation for local communities
(c) Lower natural gas prices
(d) More jobs in the region
(e) Other: ________
(f) There are no major benefits

Question 23

And which, if any, of the following would you say were the major risks of hydraulic fracturing or fracking for shale gas?

(a) Increased likelihood of earthquakes
(b) Impact on drinking water
(c) Effect on house prices
(d) Increased trafic associated with operations
(e) Impact on local air quality
(f) Other: ________
(g) There are no major risks

Question 24

What impact, if any, do you believe the following would have on your future energy bills?

	Large drop in energy bills	Small drop in energy bills	No impact	Small rise in energy bills	Large rise in energy bills	Don't know
(a) Building more onshore wind farms						
(b) Building more offshore wind farms						
(c) Recent agreement to build a new nuclear power plant						
(d) Conducting fracking (drilling for shale gas) onshore						
(e) Building coal or gas plants with carbon capture and storage (CCS)						
(f) Improving the insulation in your home						

For questions 25a-25c, randomise the order which the respondent receives the question. Moreover, the starting value X should be a random value drawn from a uniform distribution over the interval [£1, £10]*2000. Based on the answer, a second value is chosen: X-1000 if X was accepted (yes) or X+1000, if X was not accepted.

Question 25a

[Split sample for half give distance as 1 mile, for other half give distance as 50 miles]

The government supports drilling for shale gas (fracking) in the UK, which would require onshore exploration. Would you be willing to accept [£X] to have an onshore fracking well within [1 mile/50 miles] of your home? (a) Yes (b) No

(a) Yes
(b) No

If no, then offer £1000 more, i.e., Would you be willing to accept [X+£1000] to have an onshore fracking well within [1 mile/50 miles] of your home?

If yes, then offer £1000 less, i.e., Would you still be willing to accept [X-£1000] to have an onshore fracking well within [1 mile/50 miles] of your home?

Question 25b

[Split sample for half give distance as 1 mile, for other half give distance as 50 miles]

The government supports building new nuclear power plants in the UK. Would you be willing to accept [£X] to have a nuclear power plant located within [1 mile/50 miles] of your home? (a) Yes (b) No

(a) yes
(b) no

If no, then offer £1000 more, i.e., Would you be willing to accept [X+£1000] to have a nuclear power plant located within [1 mile/50 miles] of your home?

If yes, then offer £1000 less, i.e., Would you still be willing to accept [X-£1000] to have a nuclear power plant located within [1 mile/50 miles] of your home?

Question 25c

[Split sample for half give distance as 1 mile, for other half give distance as 50 miles]

The government has committed to supporting carbon dioxide capture and storage (CCS) projects in the UK. It will be necessary to build a pipeline from the plant where the carbon dioxide (CO_2) is captured and thence transported to a storage site, which in the UK would be offshore. Would you be willing to accept [£X] to have a CO_2 pipeline within [1 mile/ 50 miles] of your home?

(a) Yes
(b) No

If no, then offer £1000 more, i.e., Would you be willing to accept [X+£1000] to have a CO_2 pipeline located within [1 mile/50 miles] of your home?

If yes, then offer £1000 less, i.e., Would you still be willing to accept [X-£1000] to have CO_2 pipeline located within [1 mile/50 miles] of your home?

Comparison of UK and US demographic variables

Demographic Variable	**US**	**UK**
Age	X	X
Education Level	X	X
Education Years		X
Employment Industry		X
Employment Responsibility (e.g., manager, laborer)		X
Employment Status	X	X
Gender	X	X
Head of Household Status (Y/N)	X	X
Income, Household	X	X
Income, Personal		X
Internet Access	X	
Marital Status	X	X
Number of Children in Household	X	X
Number of People in Household	X	X
Political Party		X
Race/Ethnicity	X	X
Region	X	X
Social Grade		X
Type of Housing (e.g., own, rent)	X	X
Vote in 2010		X