Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 63 (2014) 7024 – 7042
Energy Procedia

GHGT-12

What lessons can hydraulic fracturing teach CCS about social acceptance?

Josh Wolff[a], Howard Herzog[a*]
[a]MIT Energy Initiative, 77 Massachusetts Avenue, Cambridge MA 02139, USA

Abstract

As with many technologies, carbon capture and storage (CCS) faces social acceptance challenges that can impact the pace of its development and deployment. Previous studies on the social acceptance of CCS have tended to rely on case studies of pilot projects or surveys of decision makers and the general public. Here, we take a different approach, using real world data about the social acceptance of hydraulic fracturing technologies to glean lessons for future carbon storage efforts. Hydraulic fracturing has many of the same operations, risks, and social narratives as carbon storage, making it a valid comparison. We conduct a statistical analysis on the relationship between various state demographic and economic factors and the stringency of state regulations governing the hydraulic fracturing industry. As a complement to this analysis, we conduct a comparative case study on the development of hydraulic fracturing regulations in New York and Pennsylvania. We find robust statistical evidence that familiarity with the oil and gas industry is associated with a decrease in regulatory variance among states where hydraulic fracturing takes place. Moreover, we identify a tension between regulatory control of hydraulic fracturing at the state level and regulatory control at the local level. This dynamic suggests that carbon storage policymakers and industrial leaders should emphasize local engagement in addition to state-level participation.

Peer-review under responsibility of the Organizing Committee of GHGT-12

Keywords: CCS Policy; Regulation; Hydraulic fracturing; Public acceptance; NIMBY

1. Introduction

Any emerging technology presents known and unknown risks that make stakeholders wary. CCS is no exception. Safety and efficacy concerns inherent to the carbon dioxide capture, transportation, and storage processes worry the public and their representatives, introducing the potential for siting and business development inefficiencies that

* Corresponding author. Tel.: +1-617-253-0688; fax: +1-617-253-8013
E-mail address: hjherzog@mit.edu

Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.736

could prevent the technology from taking root in the marketplace or reaching its full potential as a greenhouse gas mitigation strategy. Social acceptance is thus a dual challenge: not only might lack of acceptance prevent facility and storage siting for a mature CCS technologies, but it has already revealed its potential for scuttling pilot projects such as Barendrecht (Brunsting, et al., 2011) [1], threatening to prevent CCS from germinating in the marketplace at all.

References to social acceptance are often used synonymously with terms such as Not In My Backyard (NIMBY), but the concept is far broader and more multifaceted. While homeowners and communities are indeed important elements of social acceptance, so are the firms that carry out carbon storage and hydraulic fracturing, along with investors, regulators, politicians, voters, various interest groups, and even the media. In fact, rarely do social acceptance challenges take the form of protesters blocking bulldozers. For fossil fuel and mineral utilization processes—such as hydraulic fracturing and carbon storage—longstanding compensation practices and unitization regulations help to ensure that isolated opposition cannot stymie a project. More often, NIMBY manifests itself in the court of law or in the regulation-setting process.

It is therefore important to understand how grassroots acceptance or opposition to energy projects influences regulatory constraints on development. This study adds to the literature in two ways. First, it examines the U.S. hydraulic fracturing industry to uncover trends in social acceptance that are not yet apparent in the burgeoning carbon storage industry. Understanding how and why hydraulic fracturing regulations vary from state to state could serve as an important lesson for carbon storage. Second, it does so by studying how public acceptance is mediated through governance structures: the regulations, zoning laws, and public policies that affect new energy development efforts such as hydraulic fracturing and carbon storage. Public acceptance of sometimes risky energy infrastructure projects is itself difficult to measure, but past research has shown that familiarity with similar types of risks might be predictive of acceptance (Singleton, Ansolabehere, and Herzog, 2008) [2]. This new study therefore asks the question: "Is a state's level of familiarity with fossil fuel extraction predictive of its regulatory stringency with regards to hydraulic fracturing, and what might this tell us about future attempts to regulate carbon storage?"

This paper maintains the following structure. The background section explains the logic behind the use of hydraulic fracturing as a testbed for CCS social acceptance issues. The statistical analysis section explains the methodology and results of our assessment of regulatory differences between states that are relatively familiar with the fossil fuel industry and states that are relatively unfamiliar with it. The case study section relies on a comparative case study of New York State and Pennsylvania to tease out the more qualitative nuances that the statistical tests are unable to detect. Finally, we utilize the conclusions section to interpret our findings and relate them to future regulatory directions for carbon storage.

2. Background: Comparing hydraulic fracturing to CCS

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 social 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 a case study for assessing public acceptance of the transportation infrastructure that would be necessary for commercial-scale CCS (Marsden and Markusson, 2011) [3]. In our paper, we utilize the hydraulic fracturing industry as a case study for the social acceptance of carbon storage. In doing so, we take a broad view on what constitutes the process of hydraulic fracturing: as did Burger (2013), we define the practice 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.

While hydraulic fracturing is an imperfect proxy for carbon storage, the two processes have several similarities. In particular, 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 – 7,500 feet for hydraulic fracturing (NETL, 2009) [4] and about 5,500 feet for carbon storage (NETL, n.d.) [5]. 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 underground to storage sites below shale formations. Just as hydraulic fracturing operations utilize pipelines to transport natural gas away from the site, carbon storage operations would use pipeline infrastructure to move compressed 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 storage sites are typically sealed and monitored after site activity ceases.

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) [6][7][8]. Similar risks have been anticipated for CCS (Zoback and Gorelick, 2012) [9]. Unlikely but highly hazardous risks include irreversible drinking water pollution or catastrophic escape of carbon dioxide or methane from the site. Each of these risks have 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.

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, 2008) [10]. 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) [11]. Meanwhile, some opponents view the technologies as a wasteful and polluting use of resources that could be more productively spent on truly “clean” forms of energy such as wind or solar (Markusson et al., 2012) [12]. 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) [12]. Lastly, hydraulic fracturing often takes place in regions unfamiliar with fossil fuel operations (Deutch, 2012) [13]—a characteristic that carbon storage is likely to share—differentiating it from another close proxy: enhanced oil recovery (EOR).

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 social 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.

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 (NEPA-2005) initiated sweeping changes to the energy industry (U.S. Congress, 2005) [14], 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—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. Statistical analysis

3.1. Analysis methodology

The analysis portion of the study seeks to answer the question: Is there an association between familiarity with the oil and gas industry and regulations for shale gas production? This methodology subsection describes the process we used to answer the question.

Our statistical analysis relied on a 2013 dataset of U.S. state-by-state regulatory stringency for the shale gas industry. In 2013, Richardson et al. [15] 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 1.

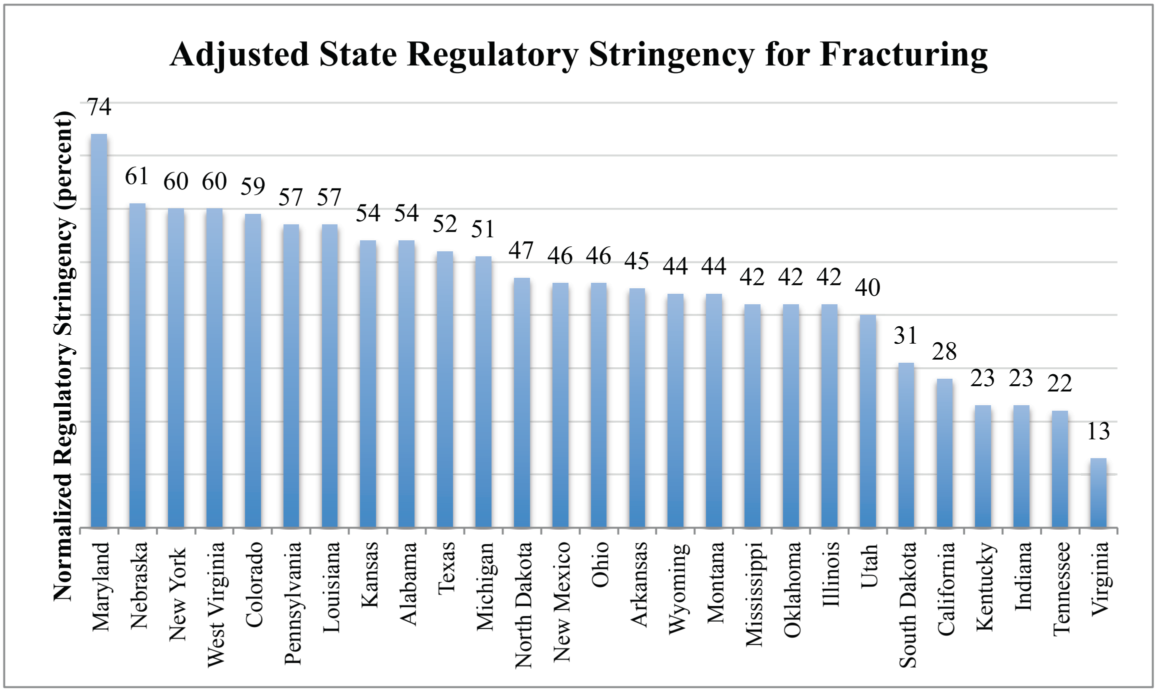


Fig. 1. Regulatory stringency of hydraulic fracturing. Each state's score represents the percent of fracturing operation elements that state regulates out of the total possible population of elements.

In their study, Richardson, et al., 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, noted that the degree of regulatory heterogeneity for hydraulic fracturing appeared largely arbitrary. We sought to build on these findings by examining 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.* Our analysis built on theirs by including more comprehensive measures of familiarity with the oil and gas industry. We relied on four variables as proxies for familiarity: oil production from 1989-2000 (EIA Crude Oil Data, 2014) [16], natural gas wells active between 1989 and 2000 (EIA Gas Data, 2014) [17], percent of resident workers employed in the oil and gas industry in 2011(American Petroleum Institute, 2013) [18], and percent of state GDP due to oil and gas in 2011 (Ibid). We chose these variables based on data availability and because we felt 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. We wanted to analyze 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 we needed to truncate the familiarity dataset to the years before hydraulic fracturing accelerated in the early 2000s. We could not obtain data on oil and gas sector workforce and revenue characteristics from the 1990s; future extensions of this study include reproducing our analysis with such datasets.

In addition to familiarity data, we analyzed regulatory stringency against 2012 population density (Census.gov population estimates, 2012) [19] and "conservative advantage" (Gallup, 2014) [20] 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 (Ibid). We hypothesized that sparsely populated states and conservative states would have lower and less variable regulatory stringency.

Following RFF's methodology, we began our analysis by using regression to identify how particular levels of familiarity were associated with stringency of shale gas regulations in each state. Like RFF, we did not find evidence of robust associations. Figure 2 illustrates the relationship between familiarity with oil production from 1989-2000 and regulatory stringency for shale gas in 2013. The blue trend line shows little evidence of a relationship, and indeed our simple regression analysis could not find an association with 90 percent statistical confidence. Additional plots are available in Appendix A.

We noticed, however, 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. In Figure 2, for example, 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 prompted us to modify our original question to instead ask: Do states that are more familiar with the oil and gas industry tend towards a common level of regulatory stringency?

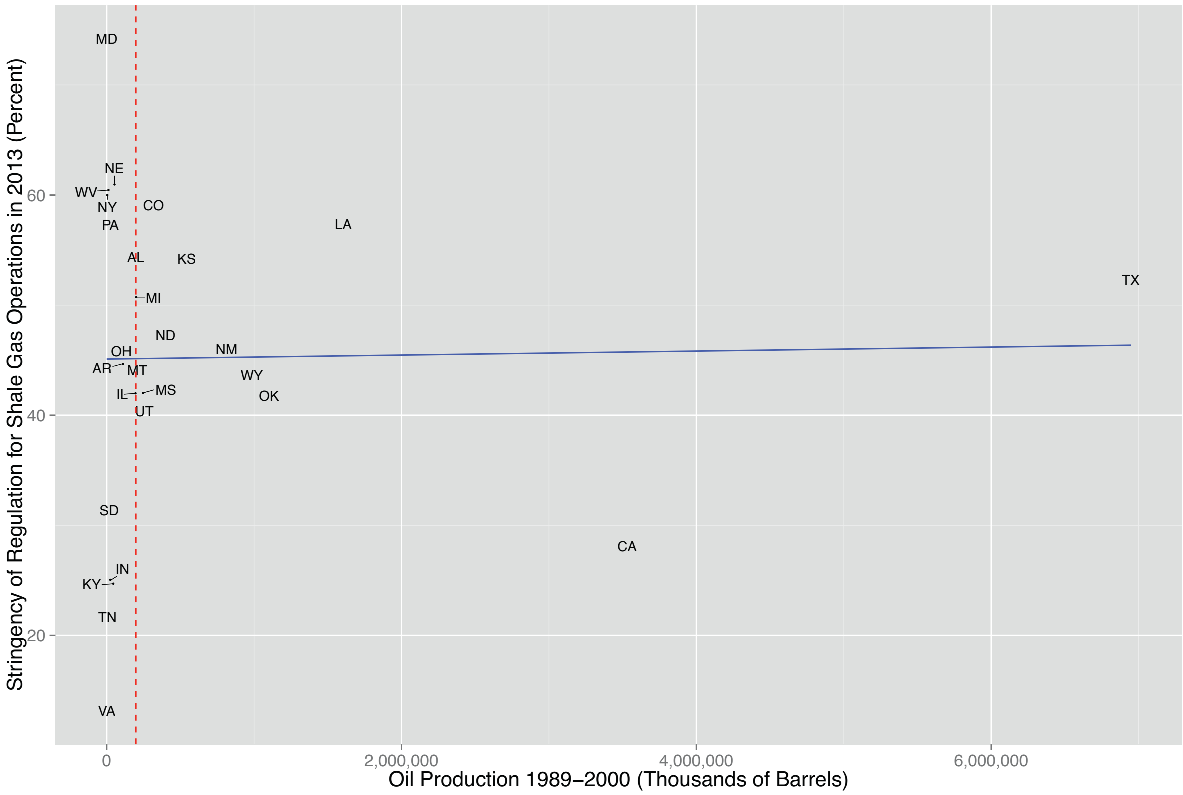


Fig. 2: Regression results- oil production vs. regulatory stringency for shale gas

Ultimately, we relied on statistical analyses to detect relationships between independent variables and the level of variance (or consistency) in regulatory stringency *among* states. We analyzed the association between familiarity and regulatory stringency by performing 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 (RFF's dataset contained an odd number of states, making a 50/50 comparison impossible). We hypothesized that, for each test, the high familiarity group of states would have a lower variance of regulatory stringency than low familiarity group. Note that this could be true even if the mean level of regulatory stringency was identical between the two groups. The six scatterplots in Appendix A display the data we sought to analyze for each of our variance tests.

We used two statistical tests 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, we used the F-test 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, we conducted an additional statistical test called Levene's tests. 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.

3.2. Analysis results

We found a robust relationship between familiarity with the oil and gas industry and the variance of regulatory stringency across states. For each of our 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 1 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, we found that relatively rural states had a lower variance for regulatory stringency than did the group of more urban states. Conservative advantage and cross-state regulatory consistency showed some indication of an association, but only for Levene's tests. Detailed results from the tests are displayed in Table B1 in Appendix B.

Table 1: 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

We also constructed violin plots 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 3 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, we ranked states according to total oil production between 1989 and 2000 and then placed the bottom half of states 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 C.

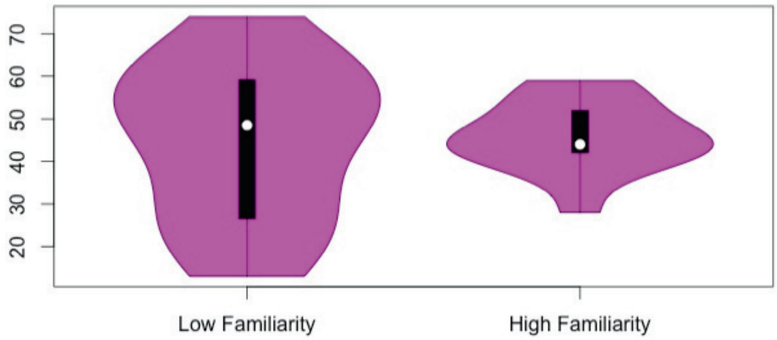


Fig. 3. Distribution of shale gas regulatory stringency (percent) for states familiar and unfamiliar with oil extraction

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. Case study: Hydraulic fracturing in Pennsylvania and New York State

4.1. Case study methodology

To complement the preceding statistical analysis, we conducted a comparative case study on the development of hydraulic fracturing regulations and industries in states of New York and Pennsylvania. These case studies allowed us to investigate the more nuanced and less quantifiable aspects of social acceptance, and also afforded us the chance to identify potential causal mechanisms that could lead to high or low regulatory stringency. Finally, unlike our statistical analysis of 2013 shale gas regulations, the case studies allowed us to track the development of regulations over time. In summary, we relied on the case study to characterize the process by which a state develops a particular level of regulatory stringency.

We chose to compare New York State and Pennsylvania for two reasons. First, both states lay over the Marcellus shale play, which is perhaps the nation's richest deposit of trapped natural gas (EIA Natural Gas Weekly Update, 10 July 2014) [21]. 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) [22]. The combination of similar geomorphology and dissimilar hydraulic fracturing governance strategies sets the stage for an interesting comparison. Second, due to the wealth of natural gas locked in the Marcellus shale, fracturing policy developments the Marcellus shale region have been widely reported on and documented. The existence of this relatively large trove of case data makes the comparison of New York State and Pennsylvania more comprehensive than comparisons of other states. This paper is certainly not the first to compare how regulatory strategies for hydraulic fracturing differ between Pennsylvania and New York State (Krancer, Hill, and Tamulonis, 2014; Goho, 2012) [23][24]. However, to our knowledge it is the first attempt 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.

4.2. Comparison of hydraulic fracturing in New York State and Pennsylvania

The governance structures for hydraulic fracturing in New York State and Pennsylvania are dynamic. One common thread between both 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 4).

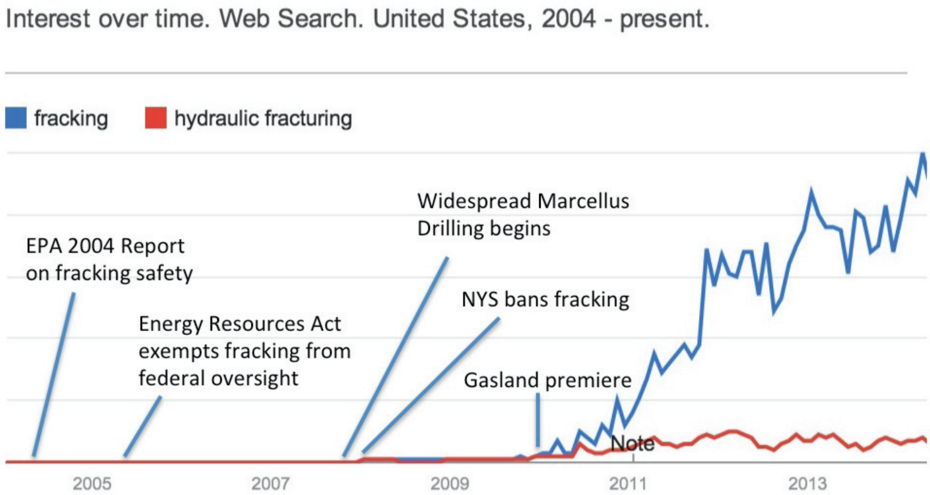


Fig. 4: Relative increase in US Google searches for terms “fracking” and “hydraulic fracturing” over time. Note that many of the pivotal decisions for shale gas development occurred before the issue received heavy internet attention. Internet searches for information on hydraulic fracturing did not pick up until after the premiere of the documentary film “Gasland” in 2010. Graph made using Google Trends.

4.3. National Energy Policy Act of 2005

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) [25]. In response to a 1997 groundwater pollution incident caused by a coalbed 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 coalbed 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.

4.4. Development of hydraulic fracturing regulations in Pennsylvania

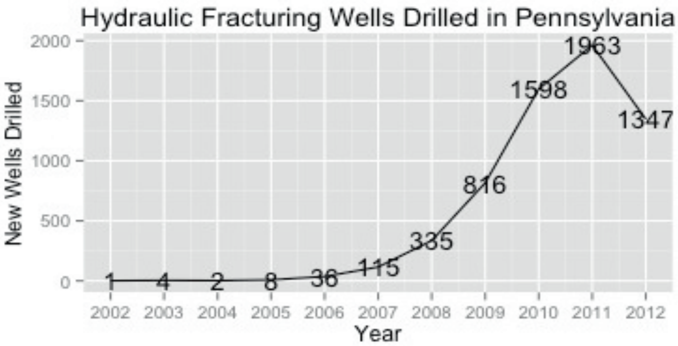


Fig. 5: New hydraulic fracturing wells in PA, by year. Data from fractracker.org [26]

Hydraulic fracturing did not become a major industry in Pennsylvania until around 2008, as is evident from Figure 5. 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) [27]. 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) [28].

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.) [29]. 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) [30]. 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) [31]. 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 constitutional provisions called "home rules" granting municipalities regulatory authority over matters of local concern (Goho, 2012) [24]. 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 (Constitution of the Commonwealth of Pennsylvania) [32]. 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) [33]. 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) [24]. 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) [31]. Almost immediately, Pennsylvania's state government faced lawsuit from a group of municipalities, individuals, and interest groups in *Township of Robinson v. Commonwealth* (Krancer, Hill, and Tamulonis, 2014) [23]. 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) [34]. 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 RFF 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?

4.5. Development of hydraulic fracturing regulations in 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) [34]. 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) [35]. 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) [36]. 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 (ibid). 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) [36]. 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) [23]. 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 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) [36]. 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) [23]. The resulting moratorium, the complaint alleged, represented an unconstitutional "taking" of mineral rights, an unauthorized seizure of private property (ibid). The group sued in 2014, calling for New York State to expedite the SGEIS process (Moody, 2014) [37].

The latest legal action on fracturing may render the statewide moratorium moot and put New York State on a similar regulatory track as Pennsylvania. 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) [38]. 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. 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) [39]. The case legitimizes the large number of local fracturing regulations emerging across New York State: as of mid-2012, 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) [40]. As in Pennsylvania, fracturing regulations in New York State are moving to the local level.

5. Conclusions

Four patterns emerge from this study and provide ample takeaways for a future carbon storage industry. First, by all of our measures of familiarity and past experience with oil and gas, our 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. Carbon storage firms should try to initially locate in states familiar with oil and gas extraction. These states are more likely to have developed a sustainable and predictable balance of regulatory power.

Second, municipalities are increasingly taking legal action to ensure a high degree of local regulatory control over hydraulic fracturing. As states with home rules cede some of their regulatory power, they may appear to decrease in regulatory stringency, even as the municipalities within them introduce increasingly strict local regulations. This process could explain why states that are relatively familiar with oil and gas tend to converge on a medium level of regulatory stringency: these states may have reached equilibrium between regulation at the state level and at the local level. The lesson for the carbon storage industry is clear: don't assume that siting will be easy because a state's oil and gas act appears lax. Municipal ordinances may matter as much or more than state regulations.

Moreover, cities and towns in both New York State and Pennsylvania 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 turn, courts 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. 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 affecting regulations at the state level, 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.

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 fracking 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: regulatory consistency over large areas may help eliminate the inefficiencies of patchwork regulations, but it creates a situation in which anti-CCS policies 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 social acceptance of hydraulic fracturing—the ERA of 2005, the exponential increase in shale extraction in Pennsylvania, New York State's moratorium—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. The ERA of 2005 set the stage for state and local regulation of hydraulic fracturing, and an overarching federal rule is now unlikely. 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. Carbon storage firms should be prepared to identify and engage decision makers and regulators early, before the issue reaches the national stage. Additional research should characterize how the policymaking process changes as issues garner broader public attention.

Acknowledgements

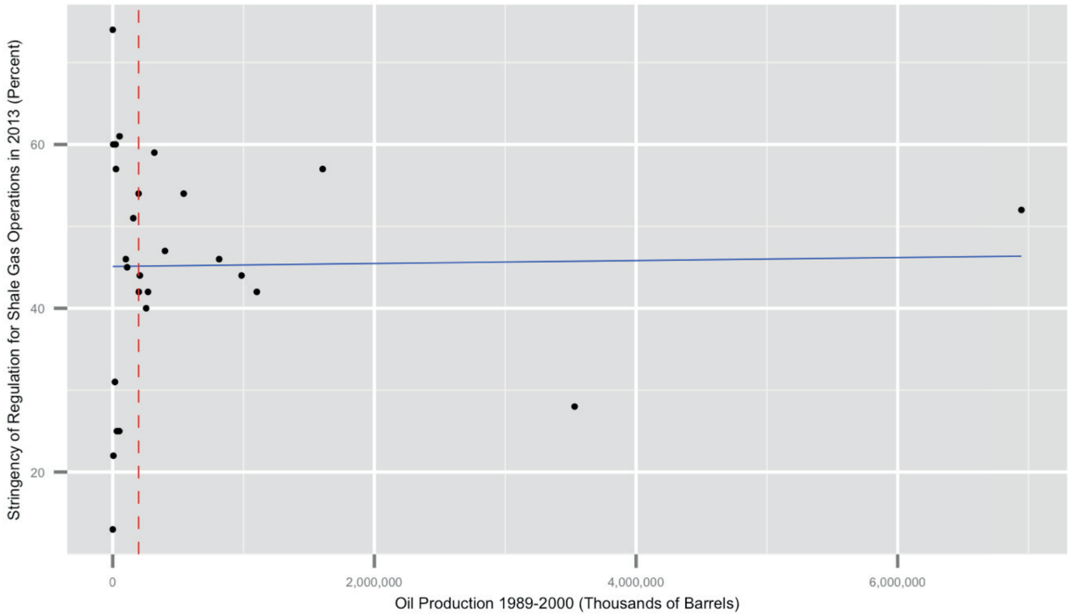
We would like to acknowledge the MIT Carbon Sequestration Initiative for their financial support of this research. The list of member companies can be found at http://sequestration.mit.edu/CSI/csi_participants.html.

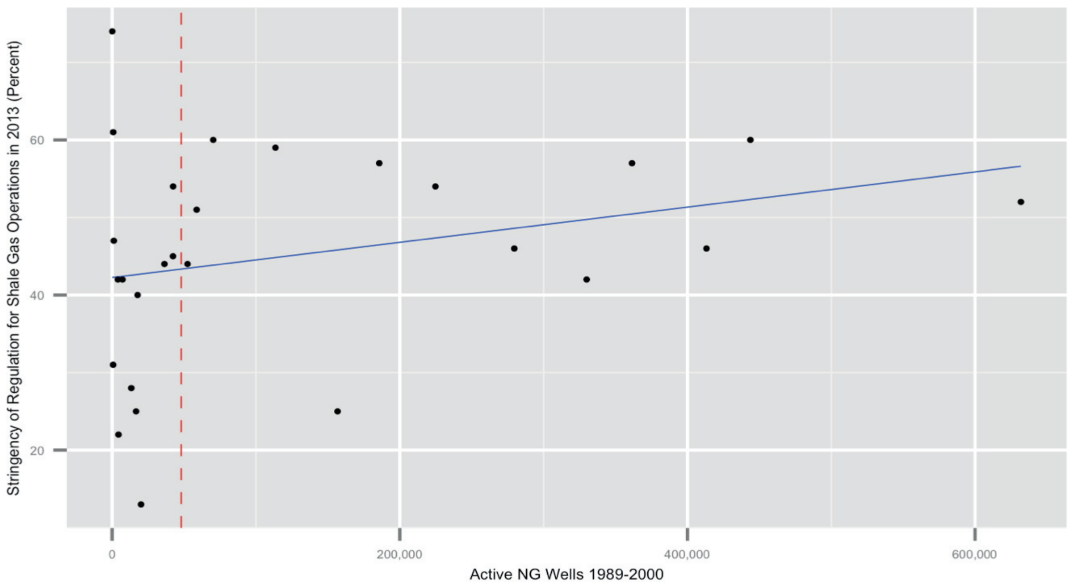
References

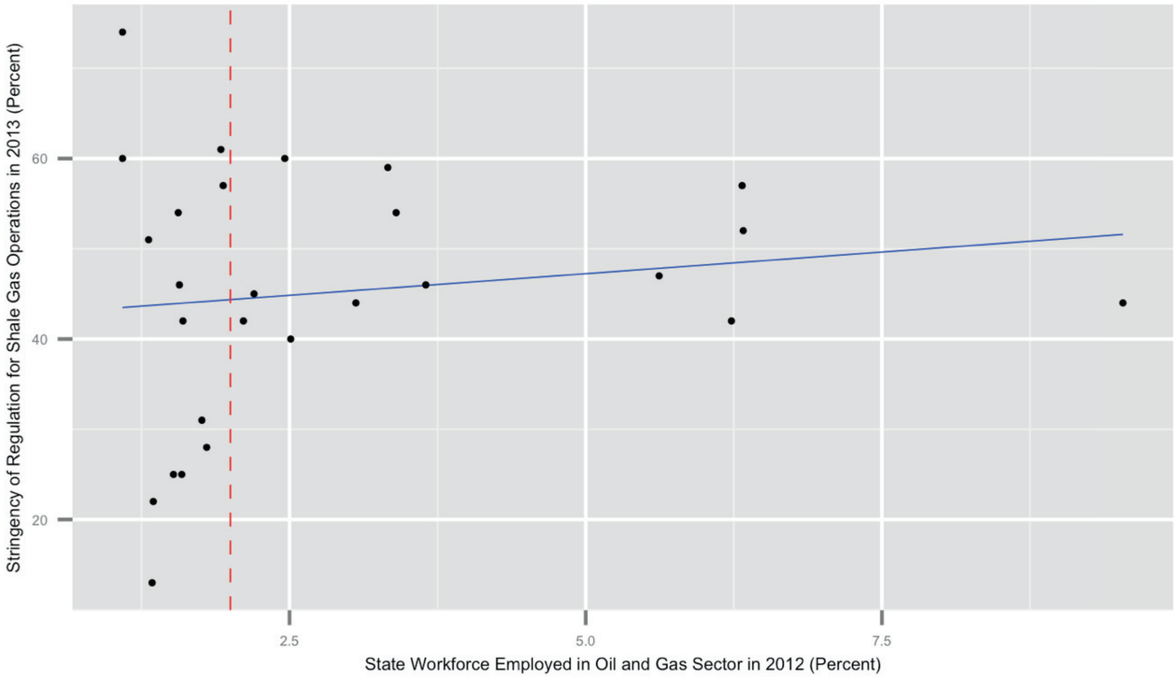
[1] Brunsting S, de Best-Waldhober M, (Ynke) Feenstra, C. F. J., Mikunda T. Stakeholder participation practices and onshore CCS: Lessons from the Dutch CCS case Barendrecht. Energy Procedia, 2011; 4, 6376–6383.
[2] Singleton G, Herzog H, Ansolabehere, S. Public risk perspectives on the geologic storage of carbon dioxide. International Journal of Greenhouse Gas Control. 2009; 3(1), 100–107.
[3] Marsden W and Markusson. Public acceptance of natural gas infrastructure development in the UK 2000-2011. UK Energy Research Centre. 2011.
[4] NETL. Modern Shale Gas Development in the US: A Primer. Department of Energy, National Energy Technology Laboratory. 2009. http://energy.gov/fe/downloads/modern-shale-gas-development-united-states-primer
[5] NETL. What are the characteristics of a storage site? Carbon Dioxide Storage Site. http://www.netl.doe.gov/research/coal/carbon-storage/Carbon-Storage-FAQs/carbon-dioxide-storage-site
[6] Ellsworth W. Injection-Induced Earthquakes. Science 2013; 341; 6142
[7] Horton S, 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.
[8] Keranen K, Weingarten M, Abers G, Bekins B, Ge S. Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection. Science 2014.
[9] Zoback M, Gorelick S. Earthquake triggering and large-scale geologic storage of carbon dioxide. PNAS; 109.26; 10164-10168.
[10] Marston P, Moore P. From EOR to CCS: the evolving legal and regulatory framework for carbon capture and storage. Energy LJ 2008; 29; 421.
[11] CarbonTracker. Unburnable Carbon 2013: Wasted capital and stranded assets. 2013.
[12] Markusson N, et al. A socio-technical framework for assessing the viability of carbon capture and storage technology. Technological Forecasting and Social Change 2012; 79.5; 903-918.
[13] Deutch J. The US Natural-Gas Boom Will Transform the World. The Wall Street Journal 2012.
[14] Congress, U. S. "Energy Policy Act of 2005." Public Law 2005; 109.58; 42.
[15] Richardson N, Gottlieb M, Krupnick A, Wiseman H. The State of Shale Gas Regulation. Resources for the Future 2013.
[16] EIA. Crude Oil Production. United States Department of Energy: Energy Information Administration 2014. Available at: https://www.census.gov/popest/data/state/totals/2012/
[17] EIA. Natural Gas Drilling. United States Department of Energy: Energy Information Administration 2014.
[18] American Petroleum Institute. Economic impacts of the oil and natural gas industry on the US Economy in 2011. 2013.
[19] Census.gov. Population Estimates 2012. Available at: https://www.census.gov/popest/data/state/totals/2012/
[20] Gallup. Conservative Advantage Poll. State of the States 2014.
[21] EIA. Natural Gas Weekly Update. United States Department of Energy: Energy Information Administration 2014.
[22] Kuzmich C. Assembly passes fracking moratorium bill. The Legislative Gazette. June 17, 2014.
[23] Krancer M, Hill M, Tamulonis F. Who's on first. A tale of two states on hydraulic fracturing and the constitution. Blank Rome LLP 2014.
[24] Goho S. Municipalities and hydraulic fracturing: Trends in state preemption. Planning & Environmental Law 2012; 64; 3-9.
[25] Rahm D. Regulating hydraulic fracturing in shale plays: The Case of Texas. Energy Policy 2011; 39;2974-2981.
[26] Fractracker.org. New unconventional wells drilled in Pennsylvania. 2013.
[27] Krauss C. There's gas in those hills. April 8, 2008.
[28] EIA. Top 5 Producing States' Combined Marketed Natural Gas Output Rose in 2011. Natural Gas Gross Withdrawals and Production. U.S. Department of Energy: Energy Information Administration 2012.
[29] Food&WaterWatch. Local actions against fracking.
[30] Detrow S. Corbett: Keep local zoning restrictions in the impact fee. NPR State Impact 2012.
[31] State of Pennsylvania. House Bill 1950: Act 13. 2012.
[32] Constitution of the Commonwealth of Pennsylvania. http://www.pahouse.com/pa_const.htm
[33] Conserveland.org. Environmental Rights Amendment. 2014.
[34] J-127A-D-2012. Township of Robinson et al., vs. Commonwealth of Pennsylvania. Pacourts.us. 2012.
[35] NYDEC. SEQR: Environmental Impact Assessment in New York State. New York State Department of Environmental Protection. 2014.
[36] Ayala S. The story of NYS's fracking moratorium. Examiner. 2011.
[37] Moody R. Landowners sue the state over fracking moratorium. Leglislative Gazette 2014.
[38] Mufson S. How two small New York towns have shaken up the national fight over fracking. The Washington Post. July 2, 2014.
[39] State of New York Court of Appeals. Norse Energy Corp vs. Town of Dryden. 2014. http://www.riverkeeper.org/wp-content/uploads/2014/06/APL-2013-00245_-Norse-Energy-Corp.-USA-v.-Town-of-Dryden_-Amici-Curiae-B....pdf
[40] Fractracker.org. New York State bans and moratoria. 2014.

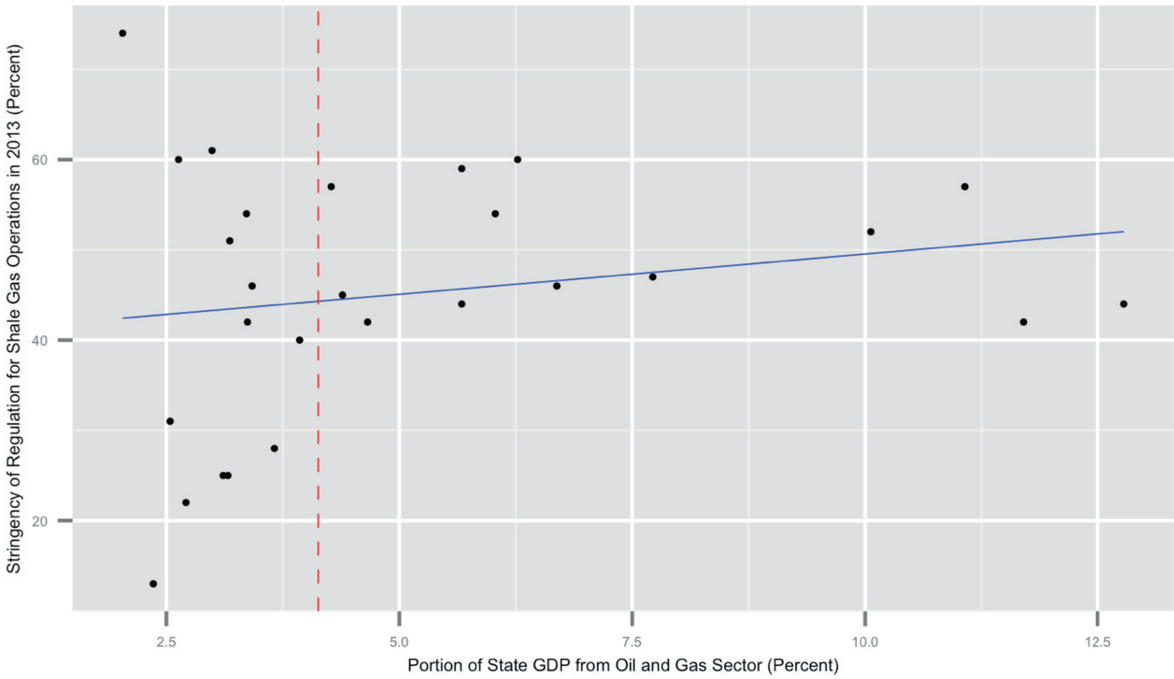
Appendix A. Datasets for Variance Tests

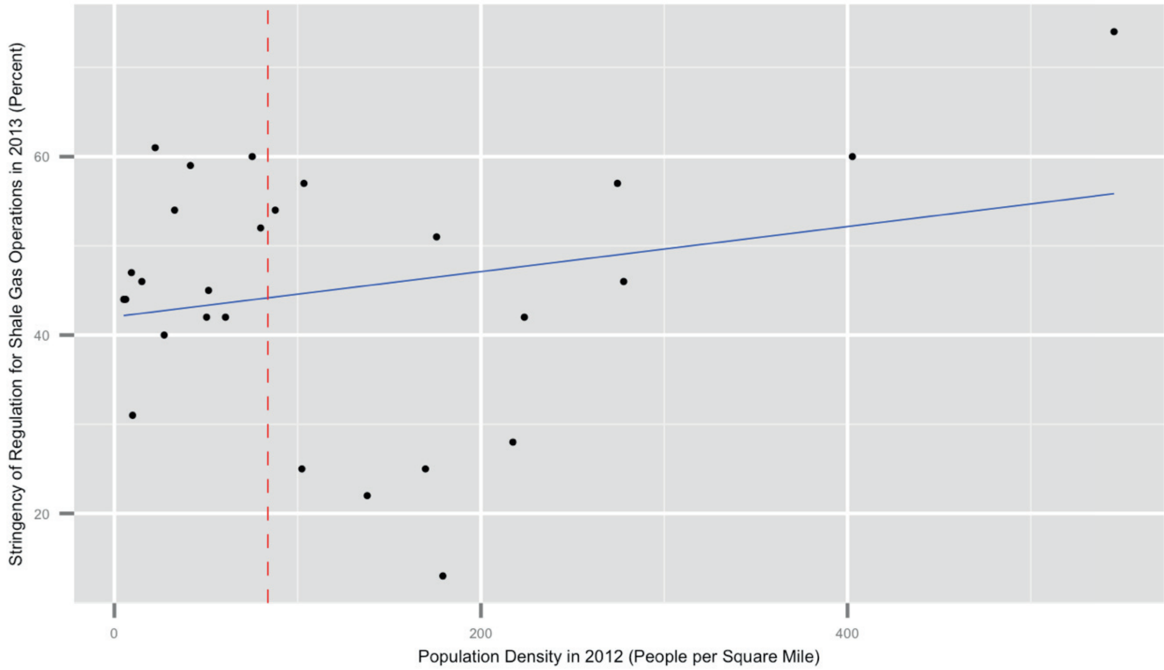
The scatterplots below display the data we analyzed with each of our variance tests. Each state's relative level of regulatory stringency for shale gas development is plotted against the various familiarity and demographic variables discussed previously. The vertical line on each plot, colored red and 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.

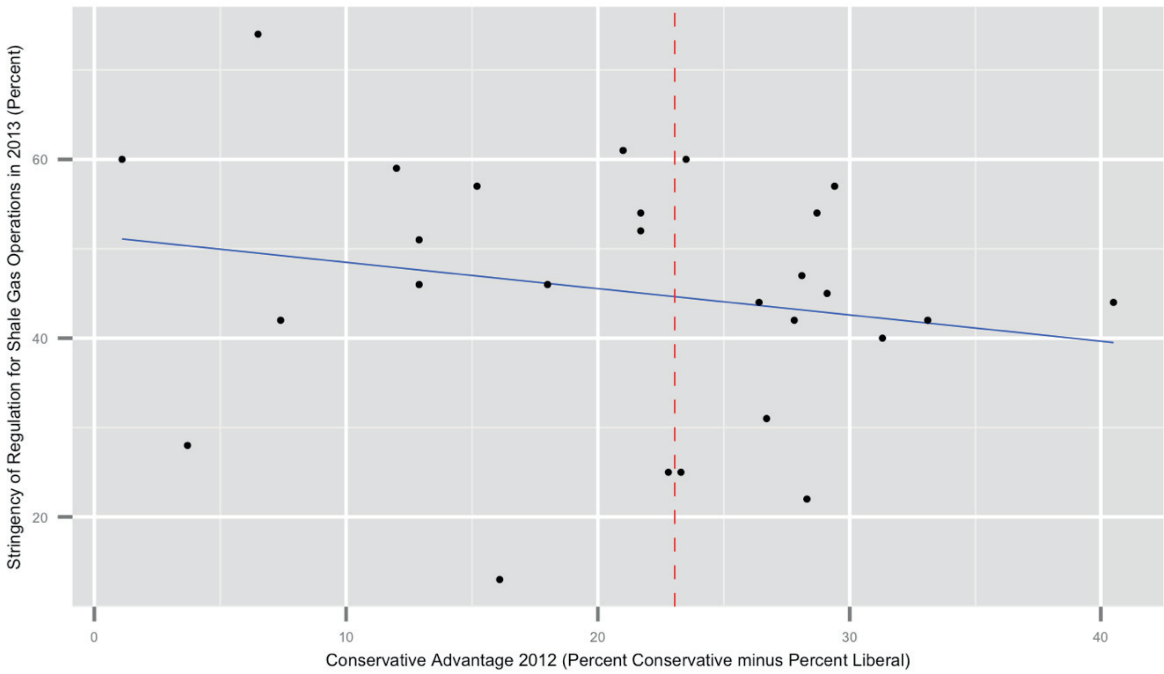





Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
60
40
20
2.5
5.0
7.5
State Workforce Employed in Oil and Gas Sector in 2012 (Percent)


Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
60
40
20
2.5
5.0
7.5
10.0
12.5
Portion of State GDP from Oil and Gas Sector (Percent)


Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
20
40
60
0
200
400
Population Density in 2012 (People per Square Mile)


Stringency of Regulation for Shale Gas Operations in 2013 (Percent)
20
40
60
0
10
20
30
40
Conservative Advantage 2012 (Percent Conservative minus Percent Liberal)

Appendix B. F-Test and the Levene's Test Results

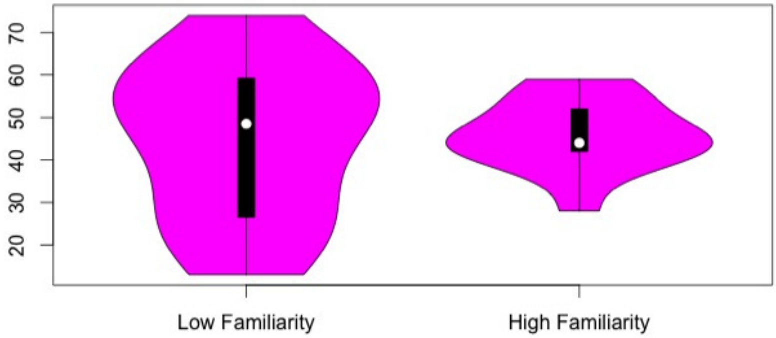
Table B1: Tests results for difference in variance of regulatory stringency between high and low familiarity groups

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**

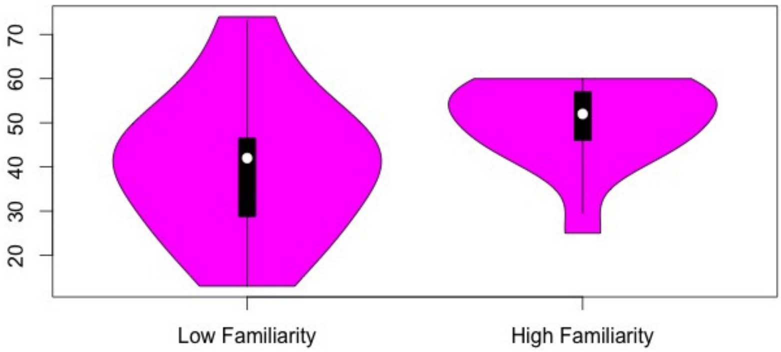
*	Statistically significant with 90 percent confidence
**	Statistically significant with 95 percent confidence
***	Statistically significant with 99 percent confidence
'	Not statistically significant

Appendix C. Violin Plots

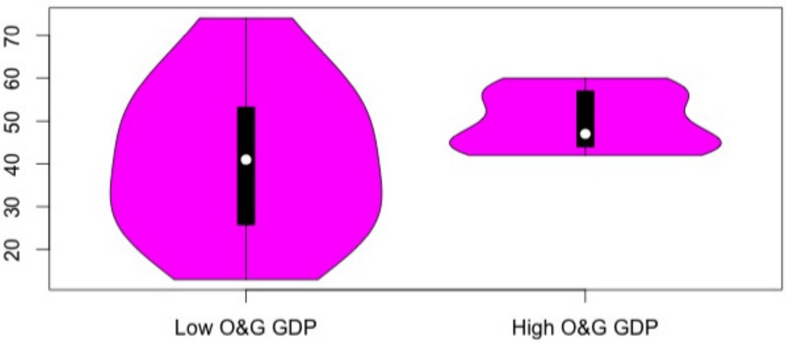
Distribution of shale gas regulatory stringency (percent)
for states familiar and unfamiliar with oil extraction



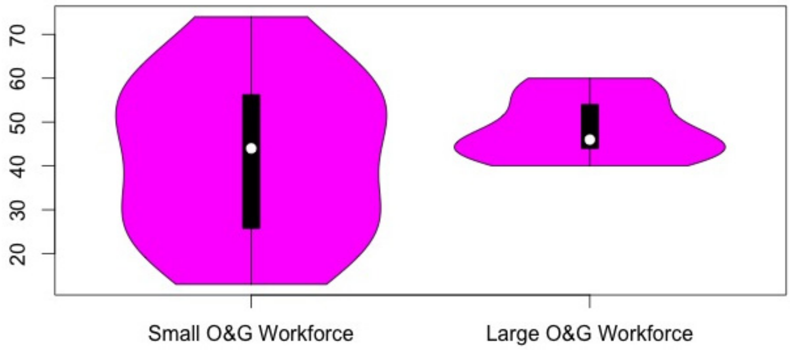
Distribution of shale gas regulatory stringency (percent)
for states familiar and unfamiliar with natural gas extraction



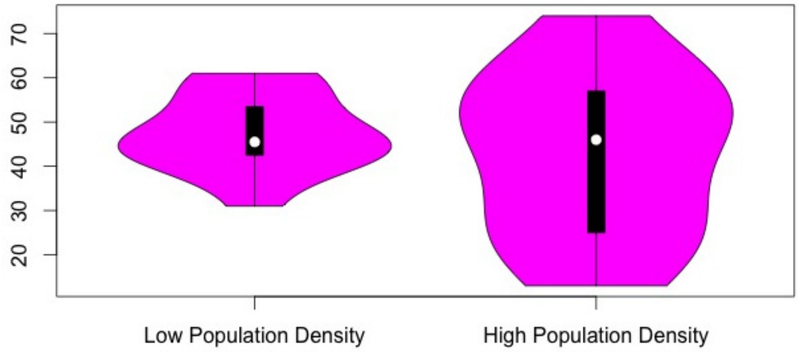
Distribution of shale gas regulatory stringency (percent)
for states with lower GDP share from O&G industry
and with higher GDP share from O&G industry



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