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Mitigating Risks From Fracking-Related Earthquakes: Assessing State Regulatory Decisions

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ABSTRACT

Public concern about earthquakes linked to wastewater injection from fracking operations is rising. However, few have examined how “induced seismicity” is acted upon by state officials. For some, an incremental response to smaller quakes can be viewed as an acceptable risk policy orientation because of the sizeable economic benefits that accompany drilling activities while others prefer risk mitigation policies (such as the use of “threshold policies”) as a better way to address quake-related problems. To account for state response to induced seismicity impacts, we examine three factors: the emergence of quakes as focusing events, the economic importance of oil and gas to state jobs and revenue, and selected characteristics of earthquakes as a policy issue, i.e., complexity and categorical precedence. Using information drawn from documentary sources, we consider which factors are most helpful in accounting for agency decisions aimed at reducing seismic risks linked to nearby injection wells.

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Introduction

U.S. natural gas production has increased considerably over the past few years because of industry’s embrace of hydraulic fracturing (fracking) combined with horizontal drilling. Saundry (2009) defines fracking as a “drilling technology that injects a mix of water and chemicals at high levels of pressure into deep underground shale deposits in order to dislodge gas. Once the rock formation is fractured, the gas can flow to the well where it is pumped out of the ground.”

While oil and gas companies narrowly construe “fracking” as the process of extracting gas from shale, we follow Evensen et al. (2014) in adopting a broader view of the term that covers drilling activities from the exploration phase to the eventual disposal of wastewater associated with fracking operations.

Fracking’s supporters highlight a number of potential benefits. First, proponents argue that fracking offers access to an abundant source of domestic energy that reduces U.S. dependence upon imported oil and gas from politically unstable or unfriendly countries (IHS Global Insight 2009). Second, using natural gas to generate electricity results in fewer CO₂ emissions than coal over time, and may contribute to a reduction in greenhouse gas emissions (Engelder 2011). Third, fracking operations result in an economic boon by

creating infrastructure, well-paid jobs, revenues, and taxes for affected local governments (Sovacool 2014; Fisk 2016).

Yet greater use of fracking to increase oil and gas production is not without its critics. Environmentalists contend that fracking harms nearby residents' quality of life and surrounding areas in a variety of ways. This includes noise and traffic congestion that accompany drilling operations (Jacquet 2014), negative impacts on air and water quality (Vengosh et al. 2014), the depletion of groundwater resources for use in fracking operations (Sovacool 2014), adverse health effects for people living in close proximity to drilling sites (Adgate, Goldstein, and McKenzie 2014), and the link between the underground injection of fracking wastewater and the emergence of earthquakes (McGarr 2014).

State policymakers are often in a difficult position of developing policies that retain the economic benefits of oil and gas production while mitigating some of the environmental costs associated with fracking. In some states, legislators have taken action. State regulators, however, are the central actors in responding to the threats posed by induced seismicity. Thus, our main objective in this exploratory article is to consider why the administrative responses in six states—Arkansas, Colorado, Ohio, Kansas, Oklahoma, and Texas—varied between 2008 and 2015.

An Overview of Earthquake Risks

More than 2 billion gallons of fluid has been injected into underground disposal wells. Yet most of the 144,000 Class II UIC underground injection wells in the United States are relatively benign (Kiger 2014).¹ Scientists have connected a small number of wells to increasing seismic activity, a process many scientists refer to as *induced seismicity*.

Ellsworth (2013), for example, explains that injection wells are often drilled to depths deeper than traditional oil and gas wells and can receive billions of gallons of fluid over their lifetime. Additionally, they may also be located in areas in which there is little to no mapping of the known and unknown fault lines. Again, while the exact causal process for each well is unknown, Ellsworth (2013) concluded that for some wells, the injected wastewaters act as a lubricant to exert high pressures on fault lines, causing them to slip—that is, cause an earthquake (see also Keranen et al. 2014; McGarr 2014; Vengosh et al. 2014). Keranen et al. (2013) reached a similar conclusion in their analysis of increasing rates of seismicity in Oklahoma. High pressures emanating from injection wells placed pressures on nearby fault lines, which, in turn, triggered a series of small earthquakes. Despite identifying a relationship, they cautioned that their findings were not predictive and were specific to the areas included in their study.

Literature Review

In our exploratory effort to account for the administrative differences in state responses to induced seismicity, there is little direct research to draw upon. Thus, we decided to consider the insights drawn from three distinct literatures. The first is from policy scholars who examine the politics of hazards and other natural disasters. The second addresses the tension between energy and environmental policy goals that confronts many elected officials. The third examines policy type and the degree to which regulators have prior experience in addressing similar issues.

Focusing Events

Our first possible explanation relates to the pervasive political effects of focusing events.

Research by Baumgartner and Jones (2009) and Kingdon (1995) suggests that focusing events can be strategically used by groups and entrepreneurs during the political push for policies that alter the status quo and for plans that lead to significant changes in organizational behavior (Stone 2012; Zahariadis 2014). According to Birkland (1997), earthquakes are particularly likely to receive news coverage since damages tend to be concentrated in a small geographical space.

Events can also shape what appears on the institutional and decision-making agendas of state lawmakers. Agency officials or groups, following a shock, can “crowd” out other topics or questions or push their issues (or particular understanding of an issue) to the top of the agenda, narrowing the possible pool of issues that are debated and acted upon by policymakers (Baumgartner and Jones 2009). Finally, human-made focusing events may raise an issue’s salience in the minds of some policymakers but narrow it for others, especially if such events were inadvertent or produced unintended consequences (Stone 2012).

Economic Importance

A second possibility in linking state-induced seismicity policy decisions is derived from research that examines the prospective importance of oil and gas production within the state’s economic context. The emergence of “induced” earthquakes can reduce state officials’ incentives for seeking policies that place restrictions on drilling practices, since the damages or costs of quakes are localized while the job-related benefits of oil and gas production may extend well beyond seismic hotspots, perhaps statewide (Sovacool 2014). Case analyses of states like Texas (Rahm 2011), Pennsylvania (Rabe and Borick 2013) and Colorado (Heikkila et al. 2014) suggest that the relationships between regulatory agencies and energy companies are not adversarial. Indeed, oil and gas trade associations may play a prominent role in pushing for industry-friendly outcomes in regulatory decisions, as well as offering campaign funding for pro-drilling candidates for state elective positions (Holland 2015).

Earthquake-prone states vary across indicators of fiscal dependency and receptiveness to environmental protection relative to oil and gas production. Some states, like Oklahoma and Texas, not only rank high as major oil and gas producers but also are more likely to receive and depend upon severance tax revenues to fund public services. This, in turn, has allowed higher producer states to more easily deal with recessionary pressures (Rabe and Hampton 2015).

It is thus plausible to suggest that economic factors such as dependency on oil and gas as a source of jobs or revenue may lessen the likelihood of public demands for immediate regulatory responses to quakes (Konisky and Woods 2012).

Categorical Precedence and Perception

A third source of influence examines how regulators may react to “induced seismicity” as a problem based on categorical precedence, or the extent to which they address a problem like seismicity because of prior experience or knowledge about agency responses to similar issues (Cobb and Ross 1997). This could be particularly vexing for regulators in states newly engaged in fracking operations with little knowledge of fracking-related operations

or earthquakes. It might also lead to decisions with unintended consequences if an inexperienced official responds immediately to seismic events in an effort to mollify anxious residents. On the other hand, state officials with prior experience in reacting to a particular hazard can be expected to rely on precedent and adaptive management to shape policy decisions (Nie and Schultz 2012).

Methods

Case Selection


Our article focuses on the six states identified by the U.S. Geological Survey (USGS) as having experienced increasing rates of induced seismicity. To address why state administrative responses differed, we employed a content analysis that enabled us to compare the regulatory responses taken by each state's primary oil and gas regulatory authority: that is, decisions that reveal whether a state is more inclined to choose a risk acceptance or risk mitigation approach. For each state, we identified the primary agency that is responsible for overseeing wastewater injections: the Railroad Commission of Texas, the Kansas Corporation Commission, the Oklahoma Corporation Commission, the Arkansas Oil and Gas Commission, the Colorado Oil and Gas Conservation Commission, and the Ohio Department of Natural Resources. Although we note that other agencies have authorities and abilities that would allow them to influence fracking activities (e.g., environmental agencies or state courts), we limit our study to each state's primary administrative agency that is vested with the authority to regulate the oil and gas industry. We searched each site with the following search queries: fracking and earthquake, earthquake, seismicity, induced seismicity and injection wells, injection wells, hydraulic fracturing and earthquake.

Our decision to focus exclusively on Arkansas, Colorado, Ohio, Kansas, Oklahoma, and Texas is based on research conducted by the USGS indicating that these states are home to the preponderance of seismic activity linked to fracking-related injection wells (Petersen et al. 2015). The combined number of seismic events registering R3 or more (the minimal threshold on the Richter scale that can lead to injury or property loss) surpassed 300 in these states from 2010 through 2012. By 2014, seismologists recorded more than 650 seismic events in these states. During 1967–2000, by comparison, these states averaged only 21 R3 quakes annually (Ellsworth 2013).

Dependent Variable

We limit our focus to administrative actions adopted by state regulatory officials, rather than legislation pushed by lawmakers (Wozniak 2014). We do so for several reasons. First, our focus on the administrative actions taken by the primary oil and gas regulatory agency permits us to make comparisons across states and to examine whether our independent variables have any explanatory power relative to administrative decisions regarding induced seismicity. Second, governors and legislators must grapple with a high degree of technological uncertainty when recommending regulatory or legislative solutions, and in the case of induced seismicity have often relied on administrative actions to address public concerns (King 2014). Third, it makes sense to focus on what administrators are doing since they have the expertise to make regulatory decisions and are less likely to be swayed by short-term political concerns.

Table 1. State administrative responses to oil and gas' injection well earthquakes.

Most lenient regulatory response (high risk acceptance)					Most stringent regulatory response (high risk mitigation)
Status quo/do nothing	Requiring additional information Texas, Oklahoma	Additional seismic monitoring	Implementation of stoplight rules Colorado, Oklahoma	Temporary suspension of injection wells Oklahoma, Kansas	Permanent suspensions of injection wells Ohio, Arkansas

Note. From state regulatory agency websites.

We identified six possible administrative responses to induced seismicity, which we posit range from a strong risk acceptance orientation to one that is best described as a high commitment to risk mitigation. As shown in Table 1, state regulators may opt to remain silent and rely on the status quo. This, we believe, is the most lenient response, that is, risk acceptance to induced seismicity, since no additional actions are required of the industry or of state personnel. Moving toward the continuum's center are administrative actions that require industry or the applicable state agency to engage in additional monitoring or data collection. Despite allowing continued injections, we consider such responses as somewhat closer to risk mitigation because they impose additional regulatory, personnel, or technical costs.

State regulators may also opt to rely on stoplight approaches. Here, regulators identify thresholds such as a clustering of quakes, the number of seismic events in a specific time window or area, or the severity of earthquakes. The passing of a threshold then triggers a range of options, including temporary or permanent bans on injections at a site. A stoplight approach, we argue, is more stringent than additional information because it does signal that regulators are willing to take significant actions to mitigate risks posed by human-made quakes. Finally, permanent suspensions or bans and even temporary moratoriums on injections are the most severe regulatory options available to state administrative officials. The decision to pause injection, either permanently or temporarily, will force the state to forgo fees and may very well harm nearby oil and gas operations.

Independent Variables and Expectations

Based on the literature reports cited, the exploratory nature of the study, and our limited sample size, we limited our analysis to three different independent variables: focusing events, economic dependence, and categorical precedence. The focusing-event literature notes that shocks are often fleeting and that they do not inherently lead to nonincremental policy change via legislation. After an event, groups may adopt a number of political strategies that ultimately lead to administrative actions.

Groups may believe, for example, that state regulators have sufficient authority and expertise to act. They may also believe that state administrators are more inclined to issue new policies as compared to state elected officials. Moreover, state legislators may not be in session, have the expertise, or have the inclination to consider new legislation. They may also indicate their support for administrative responses. Regardless of the reason, after an induced seismic event, administrative action might be the only course of action. We operationalize focusing events with available count data for earthquakes rated 3 or higher.

1. States faced with a greater number of focusing events like seismic shocks (rated 3 or more on the Richter scale) are more likely to adopt risk-mitigation type policies to reduce earthquake risks.
2. States faced with a greater number of focusing events in population centers (rated 3 or more on the Richter scale) are more likely to adopt risk-mitigation type policies to reduce earthquake risks.
3. Stakeholders participating in the fracking debate have defined the practice in environmental terms. Other prefer to frame fracking as more closely related to energy and economic development (Davis and Fisk 2014). As an industry, oil and gas production supports thousands of jobs, remits millions in state and local taxes, and generates billions of dollars of economic output. Therefore, how a state's administrative leadership prioritizes and relies upon energy development in comparison with other industries likely influences receptivity to calls for additional degrees of regulatory oversight. We measure economic dependence by calculating the percentage of the state's gross domestic product (GDP) that originates from oil and gas operations.
4. States that are less economically dependent on oil and gas revenues will enact more risk-mitigation type policies to reduce earthquake risks than states that are more dependent on oil and gas operations.
5. Our literature review also indicated that the previous experiences of regulators in addressing similar policy problems could influence how administrative decisions were made (Cobb and Ross 1997). Regulators in states new to developing oil and gas resources may have limited information to guide responses to earthquakes and may prefer to do nothing. Conversely, a lack of experience might also lead to administrative decisions designed to quickly mitigate earthquake threats. Those state officials with previous experience in responding to a related hazard are expected to rely on precedent and to adopt more middle-group approaches, such as stoplight measures. We measure categorical precedence by determining whether the state was an early or later participant in the hydraulic fracking boom.
6. States with less experience dealing with oil and gas operations will enact more risk-mitigation type policies to reduce earthquake risks oversight policies than states with more experience dealing with oil and gas operations.
7. States with a lesser percentage of regulators with oil and gas background will enact more risk-mitigation type policies to reduce earthquake risks oversight policies than states with more experience dealing with oil and gas operations.

Case Studies

Colorado

Decision-making responsibility in Colorado for addressing seismicity problems linked to oil and gas fracking operations lies with the Colorado Oil and Gas Conservation Commission (COGCC), an agency located within the Department of Natural Resources. Under Rule 25 within the state's regulatory code, COGCC is in charge of regulating induced seismicity linked to injection wells with input from geologists within the Colorado Geological Survey. Whenever oil and gas companies seek agency approval to drill, COGCC staff attempt to determine whether the affected site has seismic potential and its proximity

to existing faults before issuing any permits (Colorado Oil and Gas Conservation Commission [COGCC] 2011).

Colorado's experience with seismic activity dates back to the early 2000s when natural gas was extracted from coal seams located in the western and less populated areas of the state. An increase in gas production within that region's San Juan Basin in 2011 along with a corresponding increase in the volume of injected water led to a substantial rise in tremors detected by USGS geologists, culminating with a magnitude 5.3 earthquake. However, the agency position that injected water was related to seismic activity was initially dismissed by Colorado State Geologist Vince Matthews, who suggested that "these cowboys from USGS [are] jumping to conclusions" (Soraghan 2014).

Over the past few years, COGCC regulators and Governor John Hickenlooper have taken a more proactive stance designed to convince front-range residents that public safety concerns would carry equal weight with energy production. In 2014, regulators dealt more decisively with earthquake incidents in northern Colorado. Two smaller but significant quakes (magnitude 2.6 and 3.4, respectively) struck near injection wells located a few miles from Greeley, prompting COGCC officials to direct company officials to temporarily halt injection activities as a precautionary measure (Weaver 2015).

Additional steps were taken to monitor and evaluate other disposal wells in the area. In effect, a "stoplight" risk-management plan was adopted (see Table 1), although Colorado regulators stopped short of acknowledging any connection between the underground injection of produced waters and the rising number of quakes. However, these actions, though limited, were consistent with our expectation that a seismic shock occurring near a populated area would lead to a policy response with a caveat: No additional laws or regulations have been enacted to address seismicity issues (Weaver 2015). Instead, regulators have chosen to retain the option to exercise discretionary judgment in determining what actions to take.

Oklahoma

Decision-making responsibility for addressing seismicity problems linked to oil and gas fracking operations lies with the Oil and Gas Division within the Oklahoma Corporation Commission (OCC), a regulatory body that oversees public utilities, the oil and gas industry (exploration, drilling, production and waste disposal), motor carrier transport, and petroleum products. The OCC receives decisional support from the Oklahoma Geological Survey (OGS).

Oklahoma has a history of seismic activity that predates the accelerated use of fracking. Between 1975 and 2008 the state averaged between one and three earthquakes annually that registered 3 or more on the Richter scale (the minimum threshold for injury or property damage). However, thanks to the rising number of underground injection wells containing produced waters from fracking operations, the number of R3 quakes rose to 20 in 2009, more than 100 in 2012, and more than 800 in 2015, giving Oklahoma the dubious honor of becoming the most seismically active state (Soraghan 2015a; 2015b). Most have been inconsequential, but in 2011, a magnitude 5.7 quake shook the town of Prague, resulting in injuries to two people and the destruction of 14 homes (Wertz 2013).

Despite the surge in R3 quakes and the growing consensus among geophysicists that a strong relationship exists between the underground injection of produced waters and the incidence of seismic activity (Ellsworth 2013), elected officials and OCC regulators were initially reluctant to suggest the possibility of a link between the two. The political sensitivity

of the issue is apparent in a state where one of every six jobs is based on the production and distribution of oil and gas. Seismicity issues are often couched within the context of multiple contributing factors including injection wells, but care is taken to avoid language that might imply culpability on the part of nearby drilling operations (Lee 2014).

How have state officials responded to the surge of seismic events in Oklahoma? Following a significant rise in the number of R3 and R4 quakes in 2013, Governor Mary Fallin formed an interagency committee to study the relationship between injection wells and seismic events (Lee 2014). OCC then issued new rules in September 2014 requiring companies to provide more information about daily volume and pressure associated with injection activities (see Table 1). Regulators increasingly scrutinized proposed injection activities within designated “areas of interest”: that is, a 6-mile zone surrounding the location of quakes measuring 4.0 or more. Another new requirement was the decision to adopt the “traffic light” system that calls for restrictions including the possibility of well shutdowns if risks based on staff reviews of proximity to faults and area seismicity are revealed (Oklahoma Corporation Commission [OCC] 2014). An early test of the new approach occurred in October 2014 when the OCC shut down several injection wells near Cushing, a town housing a complex of both pipelines and storage tanks (Soraghan 2014). These activities are consistent with our expectations that states experiencing more serious quakes and quakes located closer to populated areas are more likely to adopt risk mitigation strategies.

More recently, Oklahoma state officials finally acknowledged within an OGS report that the growing number of injection wells associated with oil and gas drilling may be associated with the increase in R3 and R4 earthquakes. The Fallon Administration reinforced the message by creating a new website titled “Earthquakes in Oklahoma” with an interactive map that plots locations of both quakes and injection wells (Wines 2015). However, OCC and both state and industry officials continue to insist that that any suggested links between fracking operations and the incidence of quakes are tenuous and not yet scientifically supportable.

Texas

Prior to the early 2000s, Texas sensors did not show much in terms of seismic activity. However, as the number of producing wells has continued to grow, Texas seismographs are also showing signs of increased “shaking.” The community of Azle, located atop the Barnett Shale plat, for example, reported two earthquakes between 1970 and 2007. However, the same region experienced 74 relatively small seismic events in 2008 alone and 16 in November of that year (Railroad Commission of Texas [RCT] 2013).

In 2014, following a prolonged period of public and substate (cities) pressure, the Texas Railroad Commission (RCT) issued new rules addressing induced seismicity and hired a state seismologist. The rules mandate that companies submit data (for a 100-mile radius) about the region’s historical levels of seismicity when seeking to drill an injection well. The rules also expanded the RCT’s authority. RCT regulators may halt, slow, or modify wastewater injections if the well is linked to seismic events. As Table 1 indicates, they may also require operators to share information more frequently about the pressures and volumes of the fluids being injected (Sakelaris 2014). David Pearson, the state’s seismologist, described the RCT’s approach as somewhat similar to a stoplight approach, but “[halting injections] would be an option of last resort ... what we envision is modification of the permit.” For a state that is quite dependent upon the production of oil and gas for both energy and

revenue, these steps signaled that RCT was coping in a limited way with an uptick in seismic shocks without acknowledging that wastewater injection practices might be associated with earthquake risks.

The RCT passed the rules despite not finding a conclusive link between injection wells and earthquakes. It noted: “Whether there is a definitive link or not between disposal wells and seismic activity in Texas has not been determined ... as our agency continues to work with the scientific community to coordinate an exchange of information ... we have seen a need for laying the groundwork for some basic industry best practices” (Nye, quoted in Baker 2014).

Arkansas

The Arkansas Oil and Gas Commission (AOGC) is the primary regulator of state fracking operations. State lawmakers created the agency in 1939 and authorized it to oversee oil and gas operations including production, wastewater injection wells, and issues related to seismicity. The legislature, moreover, has charged the AOGC with protecting the correlative rights of owners’ subsurface property rights, ensuring the safe and orderly development of the state’s natural resources (including oil and natural gas) and with safeguarding the environment.

The AOGC originally consisted of seven members with “industry knowledge” as a key eligibility requirement. In 1985, lawmakers expanded the commission’s membership by two, and specified that members are no longer required to have industry ties (Bengal 2014). An executive director oversees the organization’s daily functions.

Much like other states that have enjoyed the natural gas renaissance, Arkansas has also experienced some of the costs of development. Seismic events rose dramatically in 2010 and 2011. This included a swarm of 700 quakes representing a 20-fold increase as compared to 2009 and culminating in major shocks measuring R4.7 and R3.6 near Greenbrier, about 37 miles north of Little Rock. The AOGC responded by passing an indefinite moratorium on injection wells in July 2011 (see Table 1). The moratorium shut down injection wells in a 1,200-square-mile area encompassing Faulkner, Cleburne, Van Buren, Conway, and White counties, including four that were located within the Fayetteville Shale Play. This is consistent with our expectation that states with more shocks would be more likely to respond with a risk mitigation policy.

Consequently, the number of quakes dropped precipitously in 2012 and 2013 (AOGC n.d.). With the closure of these wells, operators found it necessary to ship the produced wastewaters to other injection wells in Arkansas, Oklahoma, or Texas. And in 2014, the AOGC passed rules that established buffer distances for injection wells for wells located in the rest of the state. New wells must be located at least 1 mile from known fault lines, and gas operators are required to submit additional information to the AOGC relative to the volumes and pressures of their injections (AOGC n.d.).

Kansas

The state legislature established the Kansas Corporation Commission (KCC) in 1933 and authorized it to oversee oil and gas development, motor carriers, public utilities, pipelines, railroads, and telephone services. The Oil and Gas Conservation division, part of the KCC, oversees the safe and efficient production of natural gas, the protection of citizen and

landowner correlative rights, and waste prevention. Three commissioners (appointed by the governor and approved by the state senate) head the KCC and serve staggered 4-year terms. An executive director oversees the agency's daily operations (Kansas Corporation Commission [KCC] 2014). The KCC develops policies with input from another state agency, the Kansas Geological Survey (KGS).

While state leaders are touting the economic and employment benefits of expanded natural gas production, increasing levels of seismicity are raising public awareness and concern. Between 2003 and 2012, the state recorded five total seismic events throughout the state. Earthquake activity beginning in 2013, however, has increased dramatically, totaling more than 30 quakes in 2013 and more than 100 in 2014 (Kansas Geological Survey [KGS] 2015). Kansas initially responded by adopting a wait, see, and understand approach when it came to issues related to induced seismicity and injection wells. In 2014, Governor Brownback appointed a Kansas Seismicity Task Force (KSTF) and charged it with studying the relationship between injection wells and seismicity and with creating a state action plan (Kansas Seismicity Task Force [KSTF] 2014).

The task force's findings stopped short of identifying a causal relationship between seismicity and wastewater injection. Task force members and the interim director of the Kansas Geological Survey, Rex Buchanan, summarized the group's position as "there is data that point to a possible correlation between fluid injection and seismic activity ... we need to assess that data, get more information through seismic monitoring, and understand why the area has experienced increased seismic activity recently" (Kansas Seismicity Task Force [KSTF] 2014).

The state action plan initially emphasized the need for greater monitoring and data collection, including the installation of a strategically placed network of sensors. It also incorporated a response plan based on data pertaining to the earthquake's magnitude, its risks to adjacent and nearby properties, local and regional clustering, and timing/frequency within a 24-hour period (Kansas Seismicity Task Force [KSTF] 2014).

More recently, the continuing rise of seismic activities in southern Kansas has led state regulators to adopt a more proactive approach. Following the detection of more small quakes in November 2014, the state deployed its mobile fleet of sensors to more closely monitor local impacts (Winter 2014). Things escalated further in March 2015, when the KCC responded to property damage complaints brought by a local resident in Harper County by issuing an order that dramatically slowed down the pace of well injection activities connected to nearby operations for 6 months (see Table 1). Commission officials cited an "immediate danger" to public safety as the main justification for the order—a decision that offers a sharp contrast with more measured responses taken by Oklahoma regulators (Soraghan 2015c). The test period concluded in September 2015. State regulators felt free to act on the basis of the best available information, in part, because of the lack of prior experience with fracking-related earthquakes. In addition, they were less constrained by the possibility of political pushback owing in part to a lesser economic dependency on oil and gas production than in oil patch states.

Ohio

Decision-making responsibility in Ohio for addressing seismicity problems linked to oil and gas fracking operations lies with the Division of Oil and Gas Resources Management

within the state's Department of Natural Resources (ODNR). It was established as a stand-alone division by the state legislature in 2011 to better handle the challenges of developing the in-state shale plays. In addition, division regulators receive decision-making support from a technical advisory council and from the ODNR's Division of Geological Survey, an agency that is responsible for monitoring seismic activities and conducting research (Ohio Division of Oil and Gas Resources Management [ODNR] 2015).

Ohio has a history of weak but naturally occurring seismic activities associated with known fault lines, but things changed with onset of fracking in Mahoning County along with the corresponding rise in the issuance of permits to use of saltwater injection wells in late December 2010. Between March and December 2011, a dozen seismic events occurred in or around Youngstown, the county's largest city. While most were minor unnoticeable events, the last of these was a 4.0 magnitude earthquake that shook the city and received national attention. On December 31, Governor Kasich placed a moratorium on the development or use of injection wells within a 7-mile radius of the quake's location (see Table 1).

Other short-term actions aimed at improving emergency response procedures included the adoption of new ODNR rules in July 2012 requiring companies to provide more data prior to issuing permits for constructing new injection wells, and an increase in the frequency of unannounced inspections. In 2013, agency monitoring capabilities were strengthened thanks to the acquisition and use of portable seismic units (Brown 2015). The willingness of state officials to take action is consistent with the notion that more people were at risk, given the proximity of quakes to Youngstown. Nor were they constrained by the economic concerns to the same degree as higher production states like Oklahoma or Texas.

The most recent wave of seismic activities occurred in March 2014, when 77 small earthquakes in Mahoning County were triggered by fracking operations—not underground injection wells—near a previously unmapped and undetected geologic fault. This highly unusual incident led to ODNR's imposition of a temporary shutdown in drilling activities followed by the enactment of stricter rules for fracking activities near faults (Downing 2015).

Discussion

In examining between-state differences in state responses to the mitigation of earthquakes, it is important to note that overall variance is fairly small (see Table 1). Except for Arkansas and Oklahoma, oil- and gas-producing states have not suffered much in terms of injury or property losses that could be attributed to induced seismicity. State regulators have generally tended to adopt approaches that are both cautious and incremental. Another reason that differences have not been more pronounced is that state officials have been more open to sharing policy-relevant information aimed at reducing seismic risks. In 2014, oil- and gas-producing states became involved with the States First initiative, an information exchange program that has coordinated meetings with regulators from earthquake-prone states to develop suggested standards for measuring earthquakes and to determine the type of equipment needed to monitor seismic activities (States First 2014).

A typical reaction by regulators to increased seismic activity from regulators in all six states is to request additional (sometimes proprietary) information about the volume and

content of produced waters/wastewaters released into injection wells. A key rationale is the belief that further study could add to increased scientific understanding of when and under what conditions injection activities might be allowed to continue or halted because of unacceptable risk (McGarr et al. 2015). This was often accompanied by decisions to restrict injection activities located at or near quake sites, especially in states that have adopted stoplight approaches. However, the prior reluctance to avoid admitting a potential causal connection between wells and seismicity has nearly gone away, especially in Arkansas, Kansas, and Ohio.

How can we account for some of the differing policy responses found among the six states? First, the number of focusing events has been quite small but they did result in some administrative shifts, especially when citizens/groups were prepared to push for changes. Larger earthquakes occurred in Arkansas, Ohio, and Oklahoma in 2011, events that were reported in national media outlets. These resulted in immediate shutdowns of injection wells in Arkansas and Ohio. This coincides with our expectation that states with little prior experience in addressing fracking-related risks associated with quakes will react more quickly to mitigate problems.

Smaller, more localized, earthquakes occurred in Azle, TX, and in south central Kansas. Despite the vocal expression of discontent along with pleas for policy reform by Azle residents, the RCT chose not to respond with administrative actions to restrict wastewater injection by oil and gas companies in nearby wells. Instead, RCT commissioners chose to respond by hiring a state seismologist, and the agency later adopted rules identifying conditions under which restrictions on fracking-related wastewater disposal might be imposed. On the other hand, several seismic events that shook Kansas in March 2014 seemingly contributed to the state's decision to impose strict limitations on wastewater wells in areas near the earthquake's epicenter (Hendrick 2015). These results generally support our hypothesis that seismic incidents (focusing events) that take place in close proximity to populated areas lead to the adoption of more risk-mitigation administrative policies.

It also appears that the lack of a categorical precedent (to overall oil and gas development) matters to states that have been more proactive in mitigating seismic risks. This can be observed in the earlier 2011 actions taken by regulators in Arkansas and Ohio, but it also accounts for more forceful measures adopted by Kansas regulators. None of these states had previously encountered seismicity issues in close proximity to fracking operations or injection wells. It is also instructive to note that administrators in Ohio and Kansas may have also been unaware of financial liability issues arising from statements acknowledging the possible relationship between injection well activities and earthquakes.

We found less of a relationship between categorical precedent (on an individual level) and the presence of regulatory measures geared toward risk mitigation. The two states (Ohio and Arkansas) that banned wastewater injections at specific wells reported that more than 40% or more of their oil and gas commissioners had oil and gas ties (although both had little prior experience with hydraulic fracturing technology). By comparison, Texas has not had any commissioners with a required background in oil and gas production and was the state with the strongest orientation toward risk acceptance (see Table 2).

The economic importance of oil and gas production to a state's GDP also affects policy decisions in terms of timing and a more risk-averse stance from state officials. States with little or no revenue from oil and gas severance taxes, like Arkansas and Ohio, took action to address earthquake risks more rapidly than did states like Oklahoma and Texas that are more dependent on these sources for energy supply, jobs, and revenue that supports public

Table 2. Regulators' ties to industry.

State	Commissioner(s) with oil and gas ties (commissioners with ties/total number of commissioners)	Staff directors with oil and gas ties (director with ties/total number of directors)
Colorado	4/9	0/1
Kansas	0/3	1/1
Oklahoma	1/3	0/1
Ohio	2/5	0/1
Arkansas	7/9	0/1
Texas	0/3	0/1

Note. From Soraghan (2011).

programs. These two states rank highest in the percentage of state revenue derived from severance taxes on oil and gas (Rabe and Hampton 2015) as well as production. This provides an important political rationale for policymakers to avoid statements inferring a link between the injection of wastewater from fracking operations and the subsequent uptick in seismic actions that might lead to increasing legal liability concerns (Richards 2015).

For example, reaction to the large 2011 earthquake in Prague, OK, that injured two and destroyed 14 homes from state officials was surprisingly low key. According to OGS scientists, "We consider a rush to judgment about earthquakes being triggered [by wastewater injection] to be harmful to state, public, and industry interests. We are taking a measured and scientific approach to addressing issues so that any conclusion that earthquakes are linked to oil and gas activities can be scientifically defensible" (cited in Branstetter 2015).

Conclusions and Policy Implications

Public concern about health- and property-related risks from earthquakes linked to the underground injection of produced waters from oil and gas fracking operations has led state officials to consider how public safety can be balanced with industry health and well-paid jobs. Clearly all states have attempted to do both. State regulators have often proceeded cautiously; most have been reluctant to admit the possibility of a relationship between induced seismicity and quakes. However, all states have adopted increased monitoring requirements in response to earthquakes, several have imposed shutdowns or temporary moratoriums on injection wells near quake sites, and some have formally or informally enacted stoplight policies to guide postquake response decisions. While the link between focusing events and legislative action may occasionally be observed in energy policymaking, oil and gas regulators can often react to crises or events more promptly through administrative actions such as restrictions on the volume of injected wastewaters.

The number of cases is too small to allow major policy-related generalizations from our findings. However, we did conclude that stronger regulatory or policy actions seem to follow the emergence of earthquakes as focusing events on a national or even regional scale. A related and probably overlapping factor that was also associated with more pronounced administrative responses was the lack of categorical precedents, making it necessary for sometimes less experienced regulators to act decisively to reassure anxious residents and policymakers. Third, public officials in states that are more economically dependent upon oil and gas production for both jobs and revenue tend to act more slowly in responding to increased seismic activities and are also more reluctant to admit that increases in wastewater injection may be linked to the rising number of quakes in close proximity to fracking operations.

How can we build upon these findings research-wise? One possibility is to examine how focusing events associated with “induced seismicity” can lead to serious consideration of nonlegislative policy approaches to mitigate risks. This could include examining such events with an eye toward regulatory agencies as well as elected officials, since the former are more likely to be responsible for immediate decisional responses aimed at reducing seismic risks for affected residents. Recent tremblors occurring near Cushing, OK, also imply that our notion of earthquakes as “focusing events” need not be confined to risks affecting people or private property but could embrace critical infrastructure like pipelines or refineries as well.

Another potential line of inquiry assesses whether the combined effects of seismic incidents (i.e., focusing events) in or near more populated areas and the absence of prior experience in coping with energy-related disasters can lead to the adoption of policies that restrict an energy company’s wastewater disposal options. In addition, these concerns can be examined in relation to or compared with other higher risk policy issue areas like the regulation of pesticides or toxic substances.

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Note

1. There are approximately 30,000 oil and natural gas waste fluid injection wells in the United States.

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