Internalizing Externalities: Disclosure Regulation for Hydraulic Fracturing, Drilling Activity and Water Quality

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Abstract

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Keywords: Environmental regulation, Real effects, Transparency, Water pollution, Sustainability, Corporate Social Responsibility, Externalities, Unconventional oil & gas development, Fracking

JEL Classifications: D62, G38, K22, K32, L71, L72, M41, M48, Q53

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"Publicity is justly commended as a remedy for social and industrial diseases. Sunlight is said to be the best of disinfectants." (Justice Louis D. Brandeis, Harper's Weekly 1913)

1. Introduction

In this study, we pose the question in Brandeis' famous article and ask what publicity (or transparency) can do when it comes to environmental externalities. This question is highly relevant as transparency regulation has become a key policy tool in many areas (Weil *et al.*, 2006, Dranove and Jin, 2010, Weil *et al*., 2013, Leuz and Wysocki, 2016). Recently, disclosure requirements have been proposed for corporate GHG emissions and other sustainability issues (Christensen *et al.*, 2021, SEC, 2022). Targeting corporate environmental impacts with disclosure has a long tradition in the U.S., going back to the 1986 Emergency Planning and Community Right-to-Know Act (e.g., Oberholzer-Gee and Mitsunari, 2006). However, we still have relatively little evidence as to whether mandated disclosure works for behaviors with dispersed negative externalities as well as how it produces the intended effects.

We investigate these questions in the context of unconventional oil and gas (O&G) development, which combines horizontal drilling with hydraulic fracturing (HF) to extract shale gas and tight oil in deep formations. HF is considered the most important innovation in the energy sector since the introduction of nuclear energy, which has dramatically increased U.S. energy production and lowered consumer prices (e.g., Mason *et al.*, 2015, Bartik *et al.*, 2019, Black *et al.*, 2021). But the rise of HF has also been very controversial due to the associated health and environmental risks, including air and water pollution (e.g., Jackson *et al.*, 2014, Currie *et al.*, 2017, Bonetti *et al.*, 2021). Chief among them are concerns about the chemicals in the HF fluids (e.g., EPA, 2016, Vengosh *et al.*, 2017) and the large amounts of wastewater generated by HF (Vidic *et al.*, 2013, Vengosh *et al.*, 2014). In contrast, the industry maintains that environmental and health risks of HF are limited (API, 2017; 2019).

In an effort to shed light on HF practices and given the lack of federal regulation (Maule *et al*., 2013, Fink, 2019), many U.S. states have introduced mandatory disclosure rules for newly fractured wells starting around 2010. The rules require HF operators to disclose details on their drilling activity and the chemical composition of the HF fluids. These mandates were hailed as bringing more transparency to controversial practices of an industry with a long history of regulatory exemptions (Konschnik, 2014, Fink, 2019).[1] Yet, many voiced skepticism that the disclosure rules would make HF safer or reduce its environmental impacts, especially considering the trade secret exemptions and the lack of penalties for non- or misreporting (e.g., McFeeley, 2012, Maule *et al*., 2013, Konschnik, 2014, Tiemann and Vann, 2015).

Conceptually, the effect of state rules is not obvious either. On one hand, disclosure could enable stakeholders and the public to impose costs (or an implicit tax) on HF operators, which in turn should incentivize them to reduce pollution or to invest in cleaner practices (Pigou, 1920, Baumol and Oates, 1988, Goolsbee, 2004, Acemoglu *et al.*, 2012). On the other hand, whether disclosure is effective depends on the accessibility and dissemination of the information and the extent to which the publicity creates pressure or allows users to take actions that are costly to firms (Tietenberg, 1998, Weil *et al*., 2006, Weil *et al*., 2013).

Thus, our study analyzes the effectiveness of transparency targeting environmental externalities and the public pressure that disclosure regulation creates. The analysis provides the first empirical analysis of state disclosure rules for HF operators with respect to drilling activity and surface water pollution and, more generally, an assessment of the impact of HF on U.S. water quality over time. We focus on water pollution given its substantial environmental and social costs (Entrekin *et al.*, 2011, Keiser and Shapiro, 2019a, Keiser and Shapiro, 2019b, Hill and Ma, 2021). Further, several recent studies document the impact of HF wells and spills on water quality (Hill and Ma, 2017, Agarwal *et al.*, 2020, Bonetti *et al.*, 2021). Thus, rather than examining the required information or the composition of the HF fluids, which would

[1] For example, although the Underground Injection Control provision of the Safe Drinking Water Act (SDWA) normally regulates the use (and disclosure) of the fluids injected into the ground, HF is exempt from this provision (except when using diesel fuel).

limit our analysis to the post-disclosure period for most wells,[2] we analyze surface water quality to assess changes in the environmental impact and practices of unconventional O&G development resulting from the HF disclosure rules.

Our sample comprises a large geo-coded database of 154,324 HF wells from 16 states and 325,351 surface water-quality observations from 2,209 watersheds (HUC10s)[3] with and without HF activity. The sample spans 14 years (2006-2019). Our water quality analysis focuses on the concentrations of four ions: bromide (Br^-), chloride (Cl^-), barium (Ba) and strontium (Sr). These four ions are the likely mode of detection if and when surface water impact exists (Vidic *et al.*, 2013, Brantley *et al.*, 2014). For one, they are usually found in high concentrations in flowback and produced water from HF wells and therefore considered signatures (Vengosh *et al.*, 2014, Rosenblum *et al.*, 2017). Moreover, unlike some organic components of HF fluids, the four ions do not biodegrade, and their presence can and has been measured several years after HF spill events (Lauer *et al.*, 2016, Agarwal *et al.*, 2020). They are also measured in many locations with reasonable frequency, so that baseline chemical concentrations can be reliably estimated (Bonetti *et al.*, 2021).

The disclosure rules for HF wells were imposed by the states at different points in time allowing us to perform staggered difference-in-differences analyses for water quality and drilling activity. We estimate panel regressions with monitoring station fixed effects to control for differences in local water quality. In addition, we use state×month×year fixed effects or, alternatively, HUC8×month×year fixed effects to flexibly control for regional or sub-basin changes over time. Thus, the identification of the disclosure effects comes from differences in the pre- and post-disclosure evolution of ion concentrations between watersheds (HUC10) with

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2 Some operators provided chemical disclosures voluntarily before the mandates, which we exploit in one analysis. However, the sample of voluntary disclosures is limited and likely selected. See Fetter *et al.* (2018).

3 HUC10s (or watersheds) are homogenous geologic areas that drain or shed surface water into a specific waterbody. There are roughly 22,000 watersheds in the U.S. The average size of a watershed is 230 square miles. Prior work shows that the impact of HF wells on surface water are detectable at the watershed level (Agarwal *et al.,* 2020; Bonetti *et al.*, 2021), which is why we perform our analysis at this level.

HF activity and close-by control watersheds without HF activity that are in the same state or in the same sub-basin (HUC8). To further reduce heterogeneity between treatment and control watersheds, we also restrict the analysis to watersheds that are situated over shales.

We find that HUC10s with pre-disclosure HF activity exhibit a significant decrease in ion concentrations after the state disclosure mandates become effective. Based on the average ion concentrations in watersheds with HF activity, the estimated coefficients correspond to watershed-level decreases in chemical concentrations of 8,469.83 μg/l for Cl^-, 5.73 μg/l for Ba, and 20.59 μg/l for Sr. These effects imply meaningful declines in ion concentration levels relative to their baselines, ranging from 4.4 percent for Sr to 17.8 percent for Cl^-.

Reassuringly, we do not find such declines in three other water quality proxies (dissolved oxygen, phosphorus and fecal coliforms) that are not signatures for HF-related water impacts but should reflect changes in economic activity related to unconventional O&G development as well as other potential confounds, such as agriculture. In a similar spirit, we examine water quality changes related to conventional drilling, to which the HF disclosure rules do not apply, and find that the estimated effects do not mimic the results for HF wells. Additionally, we search for other state regulatory changes that apply to HF activity, such as wastewater management rules (e.g., on injection wells and pit lining) and HF drilling standards (e.g., for well casings and blowout controls). These other rules could confound our analysis of the disclosure rules, but we find that controlling for a broad range of other HF regulations, individually or jointly, does not alter our inferences with respect to HF disclosure regulation. We also perform extensive tests with respect to the timing of the state adoption dates, as it is an important source of identification.

Next, we analyze the margins along which HF operators adjust their practices after the disclosure mandate. We examine whether the documented improvements in water quality come from less HF drilling activity (extensive margin) or from changes in operator practices and technology that reduce the per-well impact on water quality (intensive margin). For the former, we find that the rate of new HF well entry declines by roughly 5 percent. This decline contributes roughly 14% of the overall decrease in water pollution in the post-disclosure period.

For HF operator adjustments along the intensive margin, we provide four sets of analyses to shed light on how operators adjust practices. First, we investigate whether wells spudded in the post-disclosure period exhibit smaller per-well effects on ion concentrations than wells spudded in the pre-disclosure period. We find that, after the disclosure mandates come into force, the per-well impact decreases. Even more convincingly, we see changes in the ion concentration patterns shortly after well spudding. Bonetti *et al.* (2021) document spikes in all four HF-related ion concentrations between 91 and 180 days after spudding. These spikes are not only an order of magnitude larger than the long-run impacts but also occur when HF wells generate large amounts of wastewater. We show that these concentration spikes are attenuated after mandatory disclosure.

Second, we analyze the environmental performance of O&G production, relating output to the ion concentration level by watershed. Consistent with our per-well analyses, which suggest improvements in HF practices, we find that O&G production per unit of water pollution increases after the disclosure mandates come into force. Third, we examine changes in the HF fluids around the introduction of the disclosure regulation. We document a decrease in the use of hazardous chemicals and chloride-related chemicals in HF fluids after the disclosure mandate, albeit relative to voluntary disclosures in the pre-period. Fourth, we study changes in HF-related incidents (e.g., spills, leaks and accidents related to wastewater), which are likely a key pathway by which HF wells affect water quality (Agarwal *et al.*, 2020; Bonetti *et al.*, 2021). The new disclosure requirements could make HF operators exercise more caution in their practices, including the handling of wastewater. Consistent with this idea, we detect a decline in the number of HF-related incidents, especially those related to the handling of wastewater and fracking pits. Taken together, our evidence suggests that, after mandatory disclosure, HF practices improve in material ways, reducing the surface water impact from new HF wells.

In our final set of analyses, we show more explicitly that targeted transparency operates through public pressure. This pressure can take many forms. Disclosure regulation can enable social movements, environmental groups, local communities, and the media to exert pressure on HF operators (Pargal and Wheeler, 1996; Freedman *et al.*, 2012, Johnson, 2020). For instance, social movements can shame operators for their use of toxic chemicals. Moreover, NGOs and watershed groups monitor surface waters and look for chemical signatures of HF flowback and produced water to identify contamination (Shale Network, 2020, Watson, 2022). They can also put pressure on regulators with respect to enforcement. In addition, HF disclosures can stimulate public debate about new stricter HF regulation, including bans, which in turn creates incentives for industry to improve HF practices.

Using several different proxies, we find that water quality improvements after the disclosure mandate are greater in areas where public pressure is higher. We find larger decreases in HF-related ion concentrations in areas with a greater presence of local environmental NGOs and in counties with more local newspapers. We show that public pressure, measured by media coverage and internet searches, intensifies after disclosure regulation and that the improvements in water quality are more pronounced in states with more news articles discussing HF and water pollution, and with more Google searches for HF after the disclosure mandate. Furthermore, we document larger ion declines in areas where a larger fraction of wells is owned by publicly traded firms, consistent with the idea that listed firms likely face more public scrutiny than private operators. We also find incremental water quality improvements when the dissemination of the HF disclosures to the public further improves after the state mandates are in place. All these results underscore the central role of public pressure created by disclosure regulation, as Justice Brandeis predicted for publicity.

To connect the reduced environmental impact with features of the disclosure mandates, we exploit variation in how easy it is to obtain trade secret exemptions or how quickly operators have to file the disclosures, as both features plausibly affect the effectiveness of the mandates.

Consistent with this notion, we find larger increases in water quality for states where disclosure mandates offer fewer trade secret exemptions and require timelier disclosure. This evidence is consistent with work in regulatory economics, highlighting the importance of implementation and enforcement for regulatory outcomes (Magat and Viscusi, 1990, Djankov *et al.*, 2003, Shleifer, 2005, Christensen *et al.*, 2016).

Our study makes two primary contributions. First, we contribute to a burgeoning literature studying the use of disclosure regulation in public policy, in particular, to drive changes in firm behavior (e.g., Weil *et al.*, 2006, Dranove and Jin, 2010, Christensen *et al.*, 2021).[4] Much of this literature examines information dissemination about "negative" firm behaviors, such as violations of standards or rules, mining accidents or tax avoidance (e.g., Bennear and Olmstead, 2008, Delmas *et al.*, 2010, Dyreng *et al.*, 2016, Christensen *et al.*, 2017, Chen *et al.*, 2018, Johnson, 2020, Rauter, 2020; Buntaine *et al.*, 2022) or quality disclosures to consumers, such as restaurant hygiene (e.g., Jin and Leslie, 2003). But disclosure rules do not always work as intended (e.g., Bui and Mayer, 2003, Dranove *et al.*, 2003, Weil et al, 2006). Moreover, it is not obvious that the real effects documented in prior studies carry over to settings where publicity targets corporate actions with dispersed negative externalities (such as air and water pollution), for which Coasian bargaining might be difficult.

In this regard, our paper is closer to recent studies on mandated disclosure of greenhouse gas emissions (GHG). Downar *et al.* (2021), Yang *et al.* (2021) and Tomar (2022) examine mandatory reporting of corporate GHG emissions in the UK and in the U.S., documenting reductions in GHG emissions between 7 and 15 percent. Tomar (2022) attributes the effects primarily to inter-firm benchmarking and learning. In our setting, the HF disclosure form does not reveal pollution per se. Instead, it provides transparency about the underlying activity and the question is whether such information can create sufficient pressure to alter corporate

4 There is also a growing accounting literature on the real effects of disclosure and reporting regulation. See Leuz and Wysocki (2016) and Roychowdhury *et al*. (2019) for extensive reviews of this literature.

behavior. Our study documents that transparency about the underlying activities contributes to the internalization of negative external effects. It also provides extensive evidence on how HF operators change their practices and the public pressure mechanism.

Second, our study presents new evidence on the environmental impact of HF on U.S. surface waters, covering an extended time period and much of the HF boom as well as documenting a post-disclosure reduction in this impact. Such evidence is not only important in light of the public controversy about HF, but also when considering its role for U.S. energy supply. This evidence complements other work in environmental economics showing that major regulatory initiatives, like the Clean Air Act or the Clean Water Act, have been effective at limiting environmental pollution (Greenstone, 2002, Greenstone, 2004, Keiser and Shapiro, 2019a, Keiser and Shapiro, 2019b). Our results are different and important because, unlike the aforementioned acts, mandating disclosure does not directly regulate quantities (e.g., economic activity or environmental pollution).

In terms of the setting, our paper is closely related to studies by Fetter (2017) and Fetter *et al.* (2018). The former shows that, after the introduction of the state disclosure rules, well operators report using fewer hazardous chemicals in their HF fluids, relative to prior voluntary disclosures. The latter examines whether the disclosure rules facilitate learning and imitation across operators, using the chemical mix of HF fluids. Fetter *et al.* (2018) find that firms' chemical choices converge to the mix of more productive wells. These findings are complementary to ours. However, convergence of operator practices does not necessarily imply lower environmental impact. Towards this end, we present evidence on water pollution, HF-related incidents and drilling activity.

2. Empirical Setting and Institutional Details

2.1 Hydraulic Fracturing and Water Quality

Unconventional development has tapped into large O&G reserves that sit in low-permeability formations and require HF for extraction. In the U.S., the production of shale gas and tight oil is projected to expand to 29.0 trillion cubic feet (tcf) by 2040, up from 13.6 tcf produced in 2015 (EIA, 2018). However, despite its important role for energy production and independence, unconventional development has been controversial due to its potential negative effects on human and ecological health (Colborn *et al.*, 2011, Entrekin *et al.*, 2011, Mason *et al.*, 2015, Currie *et al.*, 2017, Hill and Ma, 2022). Among the environmental risks, water pollution is a key concern for at least two reasons (McKenzie *et al.*, 2012, Vidic *et al.*, 2013, Vengosh *et al.*, 2014, EPA, 2016). First, aside from water and propping agents like sand, HF fluids contain a series of additives (e.g., friction reducers, surfactants, scale inhibitors, biocides, gelling agents, gel breakers, and inorganic acid), which are potentially toxic or harmful (Vidic *et al.*, 2013, Vengosh *et al.*, 2014). Second, HF wells produce large amounts of wastewater, initially the partial flowback of HF fluids and over time increasingly produced water from the deep formations. The latter brine is naturally occurring water into which organic and inorganic constituents from the deep formations have dissolved, resulting in very high salt concentrations (Rosenblum *et al.*, 2017).

In light of these concerns, the Environmental Protection Agency (EPA) reviewed and synthetized available scientific evidence concerning the impact of HF on U.S. water resources, following a request by the U.S. Congress. The final report concludes that “hydraulic fracturing activities can impact drinking water resources under some circumstances” (EPA, 2016). Contamination of groundwater has been ascribed to either cementing failures or the migration of stray gas and deep formation brines through faults (Osborn *et al*., 2011, Jackson *et al*., 2013, Darrah *et al*., 2014, Llewellyin *et al*., 2015). In Pennsylvania, Hill and Ma (2017, 2022) document increases in shale gas-related contaminants at ground-water intake locations of community water systems that are in close proximity and downstream to gas wells. For surface water, there are a number of studies documenting contaminations after spills and leaks (e.g., Lauer *et al.*, 2016, Maloney *et al.*, 2017, Agarwal *et al.*, 2020) and two large-scale studies on the link between unconventional O&G development and surface water quality. Olmstead *et al*.

(2013) estimate the effects of HF and wastewater treatment facilities on downstream chloride concentration and total suspended solids (TSS) in Pennsylvania. They find higher chloride concentration in surface water downstream from treatment facilities and that HF well density within a watershed is associated with increased TSS concentrations (but not chloride concentrations). Using a large geo-coded database of water quality observations and HF wells for the U.S., Bonetti *et al*. (2021) examine the association between new HF wells and ion concentrations in surface water that are specific to HF (barium, bromide, chloride and strontium). They find evidence of elevated ion concentrations for several shales (or states) and in many watersheds. The estimated association is larger for wells with large amounts of produced water, for wells located in areas with high-salinity formations and for wells that are located upstream and in proximity of water monitoring stations. Potential pathways for surface water contamination are accidents, leaks and spills of HF fluids, flowback or produced water (on-site, related to HF pits or brine trucking), and the direct disposal of untreated wastewater from HF operations (unauthorized or permitted) (Vidic *et al.*, 2013, Vengosh *et al.*, 2014, EPA, 2016, Agarwal *et al.*, 2020, Bonetti *et al.*, 2021).

2.2 HF Chemicals Disclosure Regulation

Although HF is subject to the Clean Water Act, it is exempted from the SDWA provision on underground injections, which regulates monitoring, recordkeeping and reporting requirements for any injection of chemicals endangering drinking water sources (except for diesel fuel). Because of this exemption, granted by Section 322 of Energy Policy Act (2005), HF operators had no obligation to disclose the components used in the HF fluids. As public concerns about the environmental and health effects of HF grew, some operators started voluntarily disclosing the composition of the HF fluids. Beginning in 2010, several states mandated the disclosure of the chemical components used in HF on a well-by-well basis. There are currently eighteen states with significant hydraulic fracturing activity and chemical disclosure laws for the HF fluids (Konschnik and Dayalu, 2016).[5] These rules were adopted at different points between 2010 and 2015 (Table 1, Panel A and Figure 1).[6]

The HF forms require information on the operator, well identification number, exact location (state, county, latitude, longitude), job start and end dates, some drilling information, such as the vertical well depth and the volume of water used, as well as details on HF fluids. The required fluid information varies only slightly across states. Typical disclosures are the ingredient name (plus trade name if applicable), the chemical abstract service number, the concentration in the fluid (typically the maximum concentration in any fracturing stage), and the supplier name (see Appendix for an example). All states allow operators to obtain trade secrets exemptions for chemicals that are considered confidential business information under the Uniform Trade Secrets Act. The prerequisites and procedures to obtain such exemptions vary across states (McFeeley, 2012, Jiang, 2022).[7] If granted, the form still discloses the chemical concentration, but the name and chemical abstract service number are omitted.

The disclosure forms have to be filed with a state agency or, predominantly, with the FracFocus registry,[8] which is a web-based database created by the Groundwater Protection Council and the Interstate Oil and Gas Conservation Commission. State rules stipulate when the disclosure must be made, typically between 30 and 120 days after the spudding or the completion of the HF well. In addition, all states require HF operators to submit well

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5 California and Michigan have disclosure rules but are not included in our sample because we lack water quality data (California) or data on drilling activity (Michigan). Our well databases provide information for only 18 wells in Michigan. In California, our databases include 212 wells, but all of them are located in two watersheds without water quality observations.

6 In Pennsylvania, operators had to report *to the regulator* information on the chemicals used in the drilling process starting 14 months before the adoption of the public disclosure rules. In Colorado, beginning from April 2009, operators had to keep a record of the chemicals used in the drilling process and the regulator had the right to access to these records during inspections. In the other states, we are not aware of such reporting requirements by the regulators.

7 The prerequisites and procedures to claim a trade secret exemption can entail the following: (1) a formal request is required; (2) the submission requires a factual justification; (3) operators have to provide supporting information; (4) there is a process for evaluating the trade secret claim; (5) operators must follow a specific standard to show that the trade secret exemption is justified. We provide more details on states' trade secret exemptions in the Online Appendix OA4.

8 State rules specify where the HF disclosures must be filed. In our sample, only Arkansas and New Mexico require operators to file with the state agency without mentioning FracFocus, although the majority of operators in these states still submit their forms also to FracFocus (Konschnik and Dayalu, 2016).

completion reports to their respective state agencies. These reports include the well identification number, location, completion date, and basic information on the drilling process. Many states introduced this requirement prior to the HF disclosure mandate, but initially the filings were difficult to access (e.g., as hard copies at the state agencies) and it was not until later that they moved to online portals.[9]

In sum, the state disclosure mandates substantially change the public information environment for HF activities in three ways. First, the mandates make it much easier and quicker for the public to obtain information about the location and timing of drilling activity and the operator identity. Second, the disclosure forms reveal the composition of the HF fluids and, in particular, provide information about potentially harmful chemicals used in HF fluids. Third, the public dissemination of this information via FracFocus is much wider. All these changes imply that the transparency of HF activities substantially increases.

2.3 Disclosure Regulation and Public Pressure

Unlike traditional regulatory approaches to pollution control, disclosure regulation does not restrict or prescribe specific practices. Instead, the idea of targeted transparency is to enlist market forces and public pressure to change corporate behavior (Weil *et al*., 2013), which goes beyond right-to-know policies justified on ethical grounds (Tietenberg, 1998). Viewed through this lens, HF disclosure requirements could change the behavior of HF operators and the environmental impact of HF wells by increasing transparency and enabling stakeholders or the public to impose pressure and ultimately costs on HF operators, which in turn could incentivize operators to drill less, change the composition of the HF fluids or to operate in a cleaner and safer fashion.

[9] Three states (Colorado, Montana, and Utah) made these filings available online around the same time as the HF fluid disclosures. For them, the two disclosure changes are essentially bundled. Four states (Arkansas, Kentucky, Ohio, and Pennsylvania) introduced online completion reports after their HF disclosure mandates. The remainder provided them earlier. In robustness analyses, we explore whether online well completion reports play a role in the water quality effects. We find little evidence of that, which is not surprising as they are even more technical and did not receive much public attention.

However, for disclosure rules to work in this way, they need to provide relevant information about the environmental risks, they need to disseminate or publicize the information widely and finally users need to be able to act on this information (Tietenberg, 1998; Weil *et al*., 2006). As discussed in Section II.B, the HF disclosure rules likely satisfy the first two criteria. But it is not obvious that the rules create enough pressure for HF operators to change their practices. Conceptually, public pressure can arise in a number of ways.

First, given the contentious public debate about HF, operators could expect the public to react negatively to the disclosure of toxic chemicals in the HF fluids. For instance, the well-specific disclosures could facilitate protests nearby HF activity by local communities and environmental NGOs (see Pargal and Wheeler, 1996; for community influence). Public pressure can impose reputational costs on HF operators (e.g., shaming) as well as increase regulatory enforcement (see Johnson, 2020; Leonelli, 2022; for workplace safety violations). In addition, NGOs monitor surface waters and look for the chemical signatures of HF flowback and produced water (Shale Network, 2020).[10] Knowing the composition of the HF fluids could increase regulatory and liability risks for HF activity to the extent it facilitates regulatory enforcement actions or private litigation (Olmstead and Richardson, 2014).[11]

Second, public debate about HF and opposition to unconventional O&G development from near or far could lead to stricter regulation, including bans (see Dokshin, 2021, for the public discourse in New York state). The threat of such regulation could motivate operators to adjust their behaviors. Third, investors in O&G companies could use the disclosures to pressure

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[10] The HF disclosures and the composition of HF fluids also received considerable attention from the scientific community (e.g., Tollefson, 2013), which in turn can further increase public pressure.

[11] However, identifying the responsible operator for contamination is very difficult, even when the HF fluids are known. Wells are typically located close to each other, and their produced water composition is not publicly available. Moreover, the burden of proof in litigation is high, which often leads to the dismissal of tort cases (Tsekerides and Lowney, 2015). For example, a tort case in Colorado was the first to be dismissed for non-compliance with the "*Lone Pine* order" (which is a court order that requires the plaintiffs among other things to demonstrate some evidentiary support for their key claims at the outset, usually strict *causality evidence* of damages). An appellate court later reversed this decision, holding that *Lone Pine* orders are prohibited under Colorado law. The *Lone Pine* order has also been used in Texas and Louisiana; in Ohio and Pennsylvania it has been denied (Watson, 2022).

firms to change their practices, especially if the practices entail regulatory or litigation risks that are ultimately borne by investors (e.g., Yang *et al.*, 2021, Bellon, 2022). For the same reason, investors could demand higher returns when financing HF operators. In addition, investors could have non-financial preferences (e.g., Fama and French, 2007), including preferences to use fewer hazardous chemicals in the HF process.

In the Online Appendix OA1, we provide anecdotal evidence illustrating the demand for information on the HF fluids by local communities, environmental groups, policymakers and regulators, investors, the media as well as plaintiffs in HF-related lawsuits. In addition, Online Appendix OA2 provides anecdotes from the regulatory and public debate on HF disclosure regulation illustrating public pressure.

In addition to the public pressure channel, it also possible that disclosure facilitates benchmark learning, i.e., HF operators learn from the other operators' disclosures and imitate high-productivity practices and fluid mixes (e.g., Fetter *et al.*, 2018, Tomar, 2022). However, it is not clear that higher productivity practices have less environmental impact. Moreover, the competitive costs from the disclosures (e.g., the imitation of practices) can reduce HF operators' incentives to innovate (e.g., Fetter *et al.*, 2018, Breuer *et al.*, 2022). Thus, at least in the long-run, the direction of the learning effect on pollution is unclear.

3. Data

We analyze patterns in surface water quality using the concentrations of four ions: Br^{-}, Cl^{-}, Ba, and Sr. These ions are regarded as specific signatures of flowback and produced waters (Entrekin *et al.*, 2011, Vidic *et al.*, 2013, Rosenblum *et al.*, 2017) because deep formation brines mobilized by HF contain high concentrations of all these four ions (Vengosh *et al.*, 2014, Brantley *et al.*, 2014, Blondes *et al.*, 2018). Thus, elevated concentrations of these ions could indicate contamination related to HF wells, if and when it exists.[12] Furthermore, these ions

[12] The four ions (salts) are tied to several environmental and health concerns (Vidic *et al.*, 2013). Cl^{-} increases the corrosivity of water and the leaching of lead from pipes (Stets *et al.*, 2018). High concentrations of Br^{-} can lead to the formation of bromine, which can subsequently react with organic matter to form brominated

have been measured and tracked with reasonable frequency over a long period in publicly available data, allowing us to estimate reliable baseline concentrations.

Water quality data come from the EPA (STORET), USGS (NWIS), the Shale Network (Shale Network, 2020), Susquehanna River Basin Commission, and from the PA DEP (SAC046). STORET and NWIS data contribute by far the most observations to our sample. Surface-water observations include rivers, lakes, streams, and ponds. The data sets provide information on the latitude and longitude of each water monitoring station, the ion, the type of surface water (e.g., rivers, lakes), the sampling method, and the agency in charge of the monitoring station.[13] We downloaded the data in September 2021.

We obtain data on the location and spud date of HF wells from three sources: (1) the WellDatabase; (2) Enverus (formerly Drillinginfo); and (3) the Pennsylvania Department of Environmental Protection (PADEP) and the Pennsylvania Department of Conservation of Natural Resources (PADCNR). WellDatabase and Enverus are data sources that are widely used in many empirical studies on the O&G industry. They collect O&G production information from various state agencies for each well. For Pennsylvania, PADEP and PADCNR provide comprehensive information, which we use to complement WellDatabase and Enverus information. The three databases provide information on the latitude and longitude of each well, the type of each well (horizontal vs. vertical), the production type of each well, and the spud date. By combining the three databases we make our sample of wells as comprehensive as possible. If a well appears in only one of the three databases, we use the spud date from the respective database. If a well appears in more than one database but is recorded with different spud dates in the databases, we first rely on the spud date in PADEP and

trihalomethanes (THMs), known to be associated with increased cancer risk (Brantley *et al.*, 2014). High concentrations of Ba can have health effects such as increased blood pressure (WHO, 2016). Although Sr is not currently regulated under the SDWA and hence there are no EPA limits, high concentrations may cause harm for skeletal health, especially in children and adolescents (Health Canada, 2018).

[13] Following Keiser and Shapiro (2019a), we identify each monitoring site by latitude and longitude because monitoring sites are often assigned different codes and names in different repositories.

PADCNR, then use the date recorded in the WellDatabase, and finally use the Enverus spud date if the well exists only in the latter.[14]

We obtain the adoption dates of the state disclosure mandates from state websites. We carefully review the text of the laws introducing the disclosure requirements and cross-validate these dates with those reported in the FracFocus repository. We also search for adoption dates for other (potentially concurrent) regulations related to HF drilling and wastewater disposal. Specifically, we consider regulations regarding wastewater discharge, injection wells for wastewater, design of wastewater pits as well as standards for well casing, blowout control and mechanical integrity testing. These rules and their adoption dates are reported in the Online Appendix (OA3). We use these dates to construct controls for these regulations.

To assemble the estimation sample, we assign each monitoring station and HF well to a watershed (HUC10)[15] through a QGIS geographical software. Watersheds are homogenous geologic areas defined by the US Geological Survey (USGS) that channel surface water to creeks, streams, and rivers, and eventually to a common outflow point. The literature shows that water impacts of HF wells are detectable within watersheds (Agarwal *et al.*, 2020, Bonetti *et al.*, 2021). For this reason, we analyze cross-sectional and time-series variation in ion concentrations across watersheds with and without HF activity.

We retain water readings from monitoring stations that are located in states that have adopted HF fluids disclosure mandates and belong to HUC4s (sub-regions) that have at least one HF well spudding during the sample period. With these restrictions, we focus on sub-regions for which unconventional O&G development is relevant, but we do not impose the

[14] We use this order after carefully reviewing the three databases. PADEP and PADCNR appear to be the most reliable source followed by WellDatabase and Enverus.

[15] Data on the watershed boundaries come in *shapefile* formats from the Watershed Boundary Dataset (WBD) provided by the Natural Resources Conservation Service (NRCS) at the Geospatial Data Gateway (GDG). A watershed is uniquely identified by a 10-digit hydrologic unit code (HUC). The United States is divided and sub-divided into successively smaller hydrologic units. There are six levels in the hierarchy, represented by codes (HUC) that are 2 to 12 digits long, called regions (HUC2), sub-regions (HUC4), basins (HUC6), sub-basins (HUC8), watersheds (HUC10), and sub-watersheds (HUC12).

presence of HF activity in all watersheds within these sub-regions. We require non-missing information on the latitude/longitude of each monitoring station, the measurement date, the unit of measurement, the type of surface water (rivers, lakes), the ion sampled, and the amount of the ion measured. Furthermore, we require at least two water measurements per ion×sub-basin×month×year to estimate the ion concentration baselines in our models and remove HUC10s that have water measurements in the post-disclosure period only. These requirements yield a sample of 325,351 surface water quality measurements from January 2006 to September 2019, over 2,209 watersheds and 16 states with HF disclosure mandates. To our knowledge, this is the longest panel for which the impact of HF on water quality has been analyzed.

Table 1 reports the distribution of water quality observations and HF activity across these states with HF disclosure mandates. Figure 1 plots the time trend in HF activity in our sample, along with the staggered adoption timing of the disclosure regulation across states. Figure 2 shows HUC10s with and without HF activity and the locations of water monitoring stations.

Daily precipitation and temperature data come from Schlenker (2020) for Contiguous United States.[16] For the 2.5×2.5 mile grid, in which a particular monitoring station is located, we compute the average temperature on the day of the water measurement and the cumulative precipitation over the last three days including the day of water measurement.

Our final estimation sample consists of two sub-samples: (i) treatment HUC10s with at least one active HF well in the pre-disclosure period; (ii) control HUC10s without HF activity in the pre-disclosure period but located in treated states and within HUC4s that have HF activity in some HUC10s.[17] We provide descriptive statistics for the ion concentrations in the two sub-

[16] The raw data files give daily minimum and maximum temperature as well as total precipitation on a 2.5x2.5 mile grid for the contiguous United States from 1900-2019. The data are based on the PRISM weather dataset. The use of Schlenker (2020)'s Daily Weather Data allows us to measure the local weather conditions at the time and location of water measurement with greater precision than we could with other databases (e.g., National Oceanic and Atmospheric Administration National Climatic Data).

[17] The assignment of watersheds is based on the existence of HF activities in the pre-disclosure period. Thus, it is possible that, in some control watersheds, HF activities start during the post-disclosure period. In fact, we have 85 watersheds (with 12,758 water measurements) without HF activity in the pre-disclosure period but some HF activity in the post-disclosure period. Keeping these watersheds in the control group could overstate our estimates. Thus, we exclude them from the main analyses. As a robustness, we re-run our analyses

samples in Table 2, Panels A and B. All ion concentrations are reported in microgram per liter (μg/L). To limit the influence of outliers due to measurement or recording errors, we truncate the sample at the 99th percentile, computed per ion at the HUC4 level to allow for some regional variation in ion concentrations. Most of our surface water observations come from rivers and streams: 96.32% for Br^-, 93.34% for Cl^-, 93.87% for Ba and 96.42% for Sr. We take the natural logarithm of the ion concentrations to account for their highly skewed distributions.[18] We provide descriptive statistics for the distribution of monitoring stations and water measurements per ion and HUC10 in Table 2, Panel C. Ion concentration measurements can be sparsely distributed, except for Cl^-. On average, there are 15 monitoring stations per HUC10, ranging from 8 for Br^- to 17 for Sr. The average number of measurements per ion in a HUC10 ranges from 37 for Br^- to 85 for Cl^-.

4. Research Design

In our primary analysis, we test whether the adoption of the HF disclosure mandates are associated with reduced surface water impact of HF, as indicated by changes in the concentrations of Br^-, Cl^-, Ba, and Sr. We test this prediction using the panel data set of ion concentrations described in Section III. We exploit variation in the entry-into-force dates of the disclosure mandates across U.S. states as well as variation in HF activity across time and watersheds. We estimate the following model:

$$C_{ikd} = station_i + \boldsymbol{\alpha HUC10\_HF_k} \times \boldsymbol{POST_{sd}} + state_s[or\ HUC8_h] \times month_m \times year_t + HUC8_h \times month_m + \beta p_{ikd} + t_{ikd} + \varepsilon_{ikd} \quad (1)$$

where C_{ikd} is the natural logarithm of ion concentration, measured at monitoring i on day d located in HUC10 k, $station_i$ is the monitoring station fixed effect, $State_s(HUC8_h)$×month$_m$×

including these 85 watersheds and obtain results that are indistinguishable from those reported in the paper.

[18] There is no consensus in the literature on how to model concentrations in regressions. Keiser and Shapiro (2019a) model concentrations in raw levels and provide robustness in logs. Hill and Ma (2017) model concentrations in logs. Olmstead *et al*. (2013) model concentration in raw levels. We explore the sensitivity of our inferences to alternative specification and truncation choices in Online Appendix (OB3).

$year_t$ is (alternatively) state (or sub-basin)×month×year fixed effect, $HUC8_h$×month$_m$ is a sub-basin×calendar month fixed effect, p_{ikd} the 3-day cumulative precipitation registered on the day a water quality observation is drawn, t_{ikd} is the average temperature (in Celsius) on the day a water quality measurement is drawn,[19] and ε_{ikd} is the error term. *HUC10_HF* is a binary and time-invariant indicator variable marking watersheds with at least one HF well in the pre-disclosure period (treated HUC10s). *POST* is a binary indicator variable marking water measurements taken after the disclosure regulation has come into force. The key variable of interest is the interaction term, *HUC10_HF×POST*. It estimates the impact of the state disclosure mandates on ion concentrations in HUC10s with HF activity relative to changes in ion concentrations in HUC10s without HF activity. If HF disclosure regulation leads to less surface water impact of HF activity, be it via adjustments along the intensive or the extensive margin, we expect a negative coefficient on *HUC10_HF×POST*. Our inferences are based on standard errors that are clustered at the HUC10 level.

The described fixed effect structure controls flexibly for arbitrary monthly changes in the average concentration in a state (or HUC8) and the average concentration at the monitoring station. Thus, the model in Eq. (1) controls for: (i) cross-sectional and time-series heterogeneity in background ion concentrations in a state (or sub-basins) due to seasonal changes, including the effects of road de-icing or agriculture, as well as the effects of economic development associated with the rise of HF, including changes in the O&G prices, (ii) time-invariant heterogeneity of the water monitoring stations, including local ion concentrations, the way they are measured, the type of monitor, the type of water body, the location of the monitor, natural brine migration at the monitoring station location, and (iii) local weather (precipitation and temperature) at the time of the water measurement.[20]

19 We model daily temperature in a categorical form to allow for non-monotonic relations between ion concentration and temperature. Specifically, we code up five binary variables marking the following temperature brackets, in Celsius: $[< -10]$, $[-10; 3]$, $[3; 15]$, $[15; 25]$, $[> 25]$.

20 In the Online Appendix OB1, we provide a visualization of the identification strategy for Oklahoma.

The model essentially estimates the impact of the individual state disclosure mandates comparing the pre-and post-disclosure evolution in ion concentrations of treated HUC10s and control HUC10s within the same state (or same HUC8) and month. The estimated coefficient for *HUC10_HF×POST* is the average over all state mandates. This identification strategy assumes that the watersheds within a state or within a sub-basin (HUC8) are good controls for each other and exhibit similar trends in water quality but for the disclosure mandates. Thus, it is important that the state adoption dates are not selected in response to trends in water quality, changes in operator practices, or public pressure that would have changed HF practices regardless. In essence, the staggering of the dates needs to be plausibly exogenous. We later gauge this assumption as well as the assumption of parallel trends. We also explore recent econometric concerns about staggered difference-in-differences analyses (Goodman-Bacon, 2021, de Chaisemartin and D'Haultfoeuille, 2022).

5. Results

5.1 Water Quality Changes after the Introduction of Disclosure Regulation

We present results estimating Eq. (1) in Table 3. The explanatory power of the regressions is very high, suggesting that our models capture most of the background variation in ion concentrations across watersheds and within watersheds through time. We first estimate the effect of the disclosure mandates, *HUC10_HF×POST*, for each ion separately. We find significant reductions in the concentrations of Cl^{-}, Ba, Sr in the within-state model (Columns (3), (5) and (7)) and of Cl^{-} and Ba in the within-HUC8 model (Column (4) and (6)). For Br^{-}, the coefficients are not statistically significant at conventional levels.

The results indicate that in some models, statistical power can be low, likely due to the sparsity of water measurements for some ions. We therefore pool the water measurements for all ions in one regression to harness power.[21] In these pooled models, the coefficients on

[21] See also Hill and Ma (2017). When we pool all the ions, we estimate one regression for all ions and include a fixed effect for each ion as well as interactions of this ion indicator with the controls and fixed effects, so that the coefficients are specific to each ion. This model is akin to running a seemingly unrelated regression model.

HUC10_HF×POST are negative and statistically significant, irrespective of the fixed effects structure (Columns (9) and (10)). We also estimate models restricting the control watersheds to those located over shales in order to further reduce potential differences between treated and control watersheds. The findings in Columns (11) and (12) are essentially the same as those in Columns (9) and (10). Taken together, the results in Table 3 suggest that the introduction of the HF disclosure mandates is followed by improvements in water quality.

The magnitudes of the estimated reductions in ion concentrations are meaningful in terms of water quality. Using the within-state models, the reductions range between 4.4 percent for Sr and 17.8 percent of Cl^{-}. We also translate the percentage changes into ion concentration changes measured in µg/l. The estimated coefficients imply ion concentration declines in treated HUC10s of 8,469.83 µg/l for Cl^{-}, 5.73 µg/l for Ba, and 20.59 µg/l for Sr. Even relatively small ion concentration changes can be economically relevant because surface waters serve as intake for community water systems. For instance, higher Cl^{-} concentrations in source water raise lead leaching from pipes (Stets *et al.*, 2018). Small increases in Br^{-} in source water of treatment plants raise disinfectant by-product formation in drinking water, which in turn has been linked to increased bladder cancer rates (Regli *et al.*, 2015).

Next, we map out the estimated impact of disclosure regulation on ion concentrations over time. This allows us to gauge the existence of differential trends between treated and control HUC10s prior to the mandates, which would question the parallel trends assumption. We estimate Eq. (1) replacing *POST* with separate indicator variables, D_t, for each year, coded relative to the entry-into-force date of the disclosure regulation in the respective state. That is, D_1 is equal to one for any water measurement taken within 365 days of the date the state disclosure rule becomes effective (and zero otherwise), D_2 marks water measurements taken in the second year, and so on. We omit D_{-1} (i.e., the indicator for measurements taken in the

The model produces an estimate for the average concentration change over all ions.

365 days before the effective date), which serves as a benchmark. We use the within-HUC8 model shown in Column (12) of Table 3.

Figure 3 plots the coefficients from this temporal analysis for the model that pools all ions, together with their 90% confidence intervals. The coefficient on D_{-1} is zero and has no confidence interval; all other coefficients are estimated relative to it. Importantly, Figure 3 does not indicate any differences in the pre-trends for treated and control HUC10s. The figure shows that the decrease in ion concentrations starts after the disclosure regulation comes into force and continues to increase the following year; thereafter it stays fairly constant. Well operators typically have between 30 and 120 days from the spud date or well completion to provide the HF disclosures. Moreover, prior evidence suggests that the water impact of new HF wells does not occur until 90 days after well spudding (Bonetti *et al.*, 2021). Thus, we would not expect to see the full effect until a year after the mandate becomes effective.[22]

We gauge the robustness of the results with respect to: (i) sample composition and selection; (ii) clustering of the standard errors; (iii) truncation of the ion concentrations; (iv) alternative ways of dealing with ion measurements that are reported as below detection levels; and (v) estimating WLS models that give more weight to areas with more data and hence better baselines. These sensitivity analyses are presented in the Online Appendix (Sections OB2, OB3 and OB7) and show that our findings and estimated magnitudes are robust to a wide range of alternative design choices. Given recent studies in econometrics showing that staggered difference-in-differences analyses and two-way fixed effect structures can produce biased estimates in the presence of heterogeneous treatment (Goodman-Bacon, 2021, de Chaisemartin and D'Haultfoeuille, 2022), we also use a "stacked" regression approach and ascertain that our inferences are the same (Cengiz *et al.*, 2019, see Section OB9 for details).

[22] In Table 3 and Figure 3, the post-rule indicators mark water measurements after the state-specific effective dates. However, to better take into account when the information becomes public and contamination could show up, we could instead mark post-rule water measurements considering whether the rule applies to the spud or the completion date, how long it takes to complete a well, and how many days operators have to file the disclosure form. When we account for this timeline, we find a slightly sharper impact in year 1.

5.2 Assessing Alternative Explanations for the Effects on Water Quality

We conduct several analyses to assess alternative explanations for our results in Table 3. An important concern is the adoption dates of the mandates are endogenous, for instance, because states choose to adopt the disclosure requirements in response to local shocks to water quality (e.g., related to spills or accidents). Similarly, lawmakers might pass the disclosure rules in response to local public pressure. It is conceivable that these local shocks or pressures by themselves would have led to changes in operator practices that reduced HF water impact, rather than the disclosure rules. We perform a series of tests to gauge this alternative explanation but do not find evidence supporting it.[23]

Next, we conduct two "placebo" tests. First, we examine changes in the concentration of analytes that are not specific to HF water impact and unlikely to be directly affected by HF activity. Concentrations in these analytes, however, can reflect other economic activities, e.g., agriculture, as well as economic or housing growth due to HF activity in the local area. Thus, in using these analytes, we gauge how well our models control for these other potentially confounding effects on water quality.[24] Specifically, we use: (i) Dissolved oxygen (DO), (ii) Fecal Coliforms, (iii) Phosphorus. We do not find consistent patterns in the concentrations of these three analytes around the introduction of the disclosure mandates and all the estimated coefficients (except for one) are statistically insignificant (Table 4, Panel A).

Second, we examine changes in the four HF-specific ion concentrations around the disclosure mandates, but in watersheds with conventional drilling. Given that the disclosure mandates apply only to HF wells, watersheds with conventional wells should not exhibit the

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[23] First, we add lagged changes in the respective ion concentration to the model. This control mitigates concerns about mean reversion in water quality if states introduce the disclosure requirements in response to shocks to local water quality (Table B10). Second, we show that public pressure, economic or political differences and HF drilling intensity does not predict the relative timing of state disclosure rules (Table B11). We also find that, in most states (13 out of 16), Google searches peak after the start of the legislative process (not before). Third, we run tests based on Altonji *et al*. (2005) and Oster (2019) using proxies for local factors that could prompt lawmakers to pass the disclosure rules (Table B12). See Online Appendix for details.

[24] In Section OB4, we also report an additional test that explicitly considers whether our results reflect trends in water pollution due to agricultural activity.

same patterns. To check this, we re-estimate the analyses in Table 3, but define the treatment HUC10s as those with conventional (i.e., vertically drilled) wells in the pre-disclosure period but no HF activity. The control sample comprises HUC10s without conventional or HF wells in the pre-disclosure period. Consistent with our expectation, we do not find significant effects for the disclosure mandates in HUC10s with conventional drilling (Table 4, Panel B).

A common concern in regulatory studies such as ours is that there are other concurrent events that could also affect the outcome variables or the relevant corporate behavior. The staggering of the HF disclosure mandates in our setting alleviates this concern with respect to general changes in water quality that are unrelated to HF (e.g., federal regulation) as well as common trends in HF or drilling practices (e.g., technological change). However, almost all states in our sample have other regulations for HF activity that were introduced before or over the sample period. The ones that are particularly relevant for our analysis are rules on wastewater management and HF drilling standards. To the extent that the states introduced such HF regulations around the same time as their disclosure mandates, these other regulations could contribute to the water quality effects documented in Table 3.[25]

To explore this possibility, we create three interaction variables for these other regulations: (i) *HUC10_HF×CUM_WASTEWATER* represents the number of regulations related to wastewater handling at a given point of time in watersheds with HF wells (i.e., the variable increases by one when a new regulation for wastewater handling is introduced in a state); (ii) *HUC10_HF×CUM_HF_STANDARDS* represents the number of HF drilling standards at a point in time in watersheds with HF wells (i.e., the variable increases by one when a new

[25] To identify relevant regulatory changes for the O&G industry, we read the respective administrative codes and laws adopted by the states in our sample. Relevant regulations include provisions prohibiting the discharge of wastewater, regulating injection wells, imposing pit siting, liners, freeboard and overflow requirements, leak detection and blowout prevention systems, as well as well casing requirements. Some of these provisions have been adopted well before the start of our sample period and others were introduced only very recently. These cases pose little threat to our analysis. However, some have been adopted around the time of the disclosure mandates and five states (Ohio, Pennsylvania, Montana, North Dakota, and Utah) have introduced their HF disclosure requirements along with other regulatory amendments. Online Appendix OA3 describes these regulatory changes in more detail and provides their respective implementation dates.

drilling standard is introduced in a state); (iii) *HUC10_HF×CUM_HF_REG* represents the joint number of wastewater handling rules and drilling standards at a given point in time (i.e., the variable is the sum of the previous to two variables). If the documented changes in water quality primarily reflect these other regulatory changes, rather than the disclosure mandates, then the estimated coefficient for the disclosure mandates, *HUC10_HF×POST*, should be attenuated when we also include the control variables for the other regulations.

In Table 5, Columns (1)–(3) as well as (7)–(9), we report results for each of the new variables separately.[26] We find that changes in the other HF regulations are also associated with improvements in water quality. However, these results do not account for the disclosure mandates.[27] We therefore estimate models jointly introducing variables marking the disclosure mandates and the other regulatory changes. In these models, Columns (4)–(6) as well as (10)–(12), we find that the coefficients on *HUC10_HF×POST* are still negative and significant in all specifications. More importantly, we see little attenuation in the coefficient magnitudes relative to the estimates for the disclosure mandates reported in Table 3. This evidence makes it unlikely that the improvements in water quality are mainly driven by other regulatory changes that are concurrent or close in time to the disclosure mandates. The coefficients on the other HF regulations are now insignificant and close to zero. These results could reflect that some of the other HF rule changes during our analysis period are fairly minor, e.g., amendments to existing and initially more major rules that were put in place earlier.[28]

[26] For the sake of brevity, we report only the results for the "all ions pooled" specification.

[27] As noted in Fn. 25, a few states introduce other regulatory changes around the time of HF disclosure mandate. This overlap could boost the coefficients for other HF regulations if the indicator for the disclosure mandates is missing from the model. Generally speaking, however, the disclosure mandates and the other HF regulations are fairly "distant." The mean (median) absolute difference between the dates for the disclosure mandate and the other HF regulations is 52 months (27 months). For details, see Online Appendix OA3.

[28] The insignificant results for the other regulatory changes should thus be interpreted cautiously. Our tests intend to gauge the potentially confounding role of these other regulations, rather than to provide an estimate for their impact. For the latter, we would have to choose a sample period that includes the initial introduction of wastewater rules or HF drilling standards (as opposed to using a period centered on the disclosure mandates).

5.3 Changes in Operator Behavior: HF Drilling Activity and Per-Well Pollution

The evidence provided so far shows improvements in water quality after the introduction of the disclosure mandates. We now examine which margins HF operators adjust. The increase in water quality in the post-disclosure period could come from less HF activity (extensive margin) or from less water impact of each HF well (intensive margin).

We expect drilling activity to be driven primarily by market factors, e.g., energy prices and demand, as well as existing supply and new drilling opportunities in an area. It is important to control for these first-order forces when teasing out the impact of disclosure regulation on the extensive margin (i.e., on new HF wells). Thus, we restrict the analysis to HUC10s over shales, i.e., areas where HF is feasible. We further restrict the analysis to watersheds in sub-basins that are partially located in contiguous states (i.e., HUC8s that cross state borders), so that we compare the rate of well entry in watersheds of a state that introduced disclosure with the rate of entry in watersheds of the neighboring state without disclosure. We measure entry by taking the natural logarithm of the number of new HF wells spudded in a HUC10-month-year. We include HUC10 fixed effects to account for location-specific factors to well entry, and either region×month×year FE or shale×month×year FE to account for regional or shale-specific trends in unconventional O&G development as well as local price variation.[29]

Table 6, Columns (1)–(4), documents a decrease in well entry, irrespective of the fixed effects or the estimation sample. To further tighten the analysis, we also estimate the change in HF wells entry around the disclosure mandate relative to well entry for conventional wells (Table 6, Columns (5)–(6)). Since the latter wells are not subject to the disclosure rules, they represent a useful control to account for changes in the O&G industry broadly and local trends. We recode the dependent variable as the difference between the number of new HF wells and the number of new conventional wells spudded in a HUC10-month-year. We again include

[29] There are 30 shales in our sample. These shales can be further classified into five regions: North-East, South-Mid-West, South-West, Mountain, North-West. The extensive margin analysis focuses on watersheds with HF, which is why we change the fixed effects structure and conduct analyses within region or within shale.

controls for other HF regulations, *CUM_HF_REG*. Even in this specification, we still observe a significant decrease in HF wells entry. Figure 4 plots coefficients from the model in Column (6) of Table 6, mapping out the effect by quarter relative to the disclosure mandate. Figure 4 indicates parallel trends in the pre-disclosure period and a decline afterwards. The estimated coefficient in Column (4), which is the tightest model before differencing vertical wells, implies 0.04 fewer new HF wells per HUC10-month-year, relative to an average well entry of 0.74 per HUC10-month-year. Thus, on a percentage basis, the response on the extensive margin is smaller than the overall reduction in ion concentrations, which suggests additional improvements along the intensive margin.[30]

To quantify the impact of HF disclosure regulation along the intensive margin, we estimate the per-well effect on ion concentrations for the pre- and post-disclosure periods, separately. We restrict the estimation sample to HUC10s with HF in both the pre-and post-disclosure periods and modify Eq. (1), replacing *HUC10_HF*×*POST* with two cumulative well count variables, one that counts the total number of HF wells that were spudded within a HUC10 up to 120 days before a given water reading for the pre-disclosure period and one for the post-disclosure period. Over time, these well counts increase by one as new wells are spudded.

Table 7 reports the results. We find positive and significant per-well effects on ion concentrations before the disclosure mandates for Br^-, Cl^-, Sr and for all ions pooled together. For HF wells spudded in the post-period, the coefficients are smaller and at times no longer significant. Thus, relative to the pre-period, there are sizeable declines in the per-well effects. The estimated coefficients imply an average per-well decrease of 1.53 μg/l for Br^-, 9.55 μg/l for Cl^-, 0.24 μg/l for Sr. Overall, the results suggest significant improvements in water quality along the intensive margin as a result of the disclosure mandates.

[30] For robustness, we study well entry at different aggregation levels. The results are weaker and not statistically significant if we instead aggregate the dependent variable at the county-level. However, if we aggregate the dependent variable at the 5-digit zip code-level, we obtain similar patterns to those reported in Table 6.

Prior research suggests that mishandling of flowback and produced waters is likely a key mechanism by which HF could pollute surface water (Vidic *et al.,* 2013, Vengosh *et al.,* 2014). Consistent with this mechanism, Bonetti *et al*. (2021) find significant spikes in the four ion concentrations between 90 and 180 days after well spudding, which is when HF wells generate large amounts of flowback and produced water that need to be collected. Thus, the ion increases are directly tied to critical phases of HF. We explore changes in these patterns after the introduction of disclosure regulation by plotting the coefficients for HF well counts calculated over fixed time intervals around the well spud dates, both for the pre- and the post-period, respectively (Figure 5). Consistent with Bonetti *et al*. (2021), we find concentration spikes for the [91, 180]-day window. Importantly, this spike becomes less pronounced after mandatory disclosure. This (graphical) result is consistent with the documented improvements along the intensive margin, and closely ties the improvements to the HF process.

To assess the relative role of the intensive and the extensive margin adjustments for the decrease in ion concentrations, we perform a magnitude decomposition exercise. For Cl^-, we first multiply the average per-well decrease in pollution after the disclosure mandate (9.55 μg/l) with the average number of wells per HUC10 in the pre-disclosure period (41.40) to obtain an estimate for the total decrease in Cl^- concentration due to adjustments on the intensive margin (395.21 μg/l). We then compare this estimate with the estimated decrease in Cl^- concentrations due to adjustments on the extensive margin. We obtain this estimate by multiplying the per-well Cl^- concentration effect in the pre-disclosure period (38.17 μg/l) with the decrease in the number of wells in the post-disclosure period relative to the pre-period HUC10 average number of wells (1.65). Our estimate for the extensive margin is 63.04 μg/l. Comparing the two estimates, we conclude that around 86 percent of the decline in Cl^- concentrations comes from the intensive margin.

5.4 Specific Changes in HF Operators' Practices

In this section, we study specific changes in HF operator practices that could explain or contribute to the increase in water quality after mandatory disclosure. First, we examine changes in the environmental performance of HF wells, which could indicate investments in better HF well technology. We cannot directly observe the technological changes of HF operators, but we can compute the ratio between the O&G production volume, in barrels, and the local ion concentrations, in μg/l, all at the HUC10-month-year level. This ratio is a reasonable proxy for the environmental performance of HF wells (Wang and Shen, 2016). Table 8 reports OLS estimates of the impact of disclosure regulation on environmental performance. We provide results for a treatment sample that includes HUC10s with HF in the pre-disclosure period (Columns (1)-(2)) and for a treatment sample that includes HUC10s with HF in the pre- and post-disclosure periods (Columns (3)-(4)). For brevity, we report the results for the model pooling all ions. We find that, after mandatory disclosure, HF wells have higher environmental performance, i.e., the same production is associated with lower ion concentrations. This evidence is consistent with our earlier intensive margin results.

Second, we examine whether HF operators reduce the use of hazardous chemicals after the HF fluid disclosures become mandatory. We use data on the chemicals used in HF from Konschnik and Dayalu (2016) and create a variable that captures the combined percentage share of all hazardous chemicals used in the HF fluids. We first compute for each well the ratio of the total amount of hazardous chemicals to total fluids injected, and then average over all wells at the HUC10-month-year level. Hazardous chemicals are those (i) regulated as primary contaminants by the SDWA; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on fracturing operations (EPA, 2014). For the pre-disclosure period, we have to use voluntarily disclosed information about the share of hazardous chemicals to calculate the HUC10-month-year averages.[31] Assuming that operators using a larger fraction of hazardous chemicals were more reluctant to provide information prior to the mandates, the use of voluntary disclosures in the pre-period is likely to bias against us finding a reduction in the share of hazardous chemicals. In addition, we compute the fraction of hazardous chemicals using only those related to chloride to better link the HF fluid analysis here with our earlier water quality analyses using chloride concentrations in surface waters. Table C1 lists the most common hazardous chemicals in HF fluids and Table C2 provides descriptive statistics for the two hazardous chemical variables. We estimate changes in the use of hazardous chemicals after the HF disclosure mandates using watershed and month×year fixed effects to flexibly control for broader changes in the composition of HF fluids. Table 9 reports the results. We find that operators disclose using fewer hazardous chemicals, both overall and chloride-related, after disclosure regulation. These results are consistent with the documented decline in chloride and, more generally, ion concentrations in surface waters.

Third, spills, leaks and accidents related to HF wastewater are likely a key pathway for surface water contamination. Transparency and public pressure should provide operators with incentives to improve the safety of the drilling process and the management of HF wastewater. Thus, we examine the effect of the disclosure regulation on the occurrence of such HF-related incidents. We use data on recorded major HF-related spills from Brantley *et al*. (2014) and Patterson *et al.* (2017). As these data extend only to 2015 and are confined to Pennsylvania as well as Colorado, New Mexico, and North Dakota, respectively, we restrict the analysis accordingly. We count the number of HF-related incidents for each HUC10-month-year using either all HF-related incidents or all HF incidents related to wastewater management. Table C3 reports descriptive statistics for these incidents. We estimate changes in these incidents after the introduction of disclosure regulation for all HUC10s over shales using watershed and

31 Not all watersheds have HF wells, for which voluntary disclosures are available in the pre-period. Thus, we first compute pre-disclosure averages at the HUC8 level using voluntary disclosures and then use these averages for watersheds (HUC10s) without voluntary disclosures in the pre-period.

month×year fixed effects. Table 10 reports the results. Consistent with our water quality results in Table 3, we find statistically and economically significant declines in the number of HF-related incidents in general and in those related to wastewater management.

5.5 The Role of Public Pressure for the Observed Improvements in Water Quality

As discussed in Section II.C, disclosure regulation can enable social movements, environmental groups, local communities, and the media to exert pressure on HF operators (see Online Appendix OA1 and OA2 for anecdotal evidence from various sources). In this section, we provide more formal evidence that targeted transparency indeed operates through public pressure.[32] We measure public pressure using several proxies and present a series of tests.

First, we create a variable indicating the presence of local environmental NGOs. We obtain a list of local anti-fracking NGOs from *America Against Fracking*, *Pennsylvania Against Fracking Coalition*, and *Frack Action*. We augment this list with data from GuideStar, which contains nonprofit organizations filing Form 990. To identify local environmental groups that focus on water quality issues, we retain nonprofits with the NTEE codes, C01, C02, C03, C011, C12, C20, C30, C32, C34, and institutional names that include the words: *watershed*, *river*, *water*, *creek*, *lake*, or *stream*. We remove from this list four NGOs with more than 100 employees, as they are unlikely to operate locally only. We then assign environmental groups to a local community based on their address to Census Core-Based Statistical Areas (and counties if the address is not within any CBSA). We ensure that the environmental NGOs are active in the year before the state disclosure mandate is adopted.

We analyze whether the results in Table 3 differ across locations with or without the

[32] We recognize that public pressure could also be a confounding factor if state legislators adopt the disclosure rules in response to public pressure. We perform several tests to gauge this possibility. First, we show that public pressure measured by Google searches does not predict the timing of the disclosure rules (Table B11). See also OB8 for additional tests examining the potential endogeneity of the adoption dates. Second, we examine the relative timing of the legislative process and Google searches. We find that, for most states in our sample (13 out of 16), Google searches peak after the legislative process has already started, consistent with disclosure regulation leading to more public pressure, rather than the other way around (see also Figure 6). Finally, we show that the results are not driven by (and if anything weaker in) the few states where Google searches peak before the state adopts the disclosure rule.

presence of an environmental group. Table 11, Column (1), shows that the effect of disclosure regulation on ion concentrations is larger in areas which have at least one active local anti-fracking or water protection NGO. We alternatively use the presence of a local newspaper to capture differences in public pressure. We code counties with at least one (no) local newspaper in the year leading up to the disclosure mandate (which assumes that media pressure is largely confined to the county in which the newspaper is published). Table 11, Column (2), shows that the effect of disclosure regulation on water quality is larger in counties with a local newspaper.

Second, we explore whether the impact of disclosure regulation is more pronounced in areas that experience larger increases in public pressure after the mandates are introduced. We measure increases in public pressure using changes in media coverage discussing HF as a source of water pollution and, alternatively, changes in Google search intensity.[33] We then use these proxies to split the treatment coefficients. In Table 11, Column (3), we report separate coefficients for counties with increases and decreases in HF-related media coverage in the year after the mandates (relative to the year before adoption). The results show that the disclosure effect is more pronounced in counties where newspaper coverage increases.

Similarly, in Table 11, Column (4), we report separate treatment coefficients for states with above and below median increases in the average number of Google searches for the term "fracking" in the post-disclosure period (relative to pre-period). The results show that the disclosure effect is larger in states with stronger increases in Google search intensity.

Third, we expect HF operators owned by publicly traded O&G firms to face greater public pressure and more scrutiny than HF operators owned by private firms (see also Table OA1 for anecdotal evidence). To explore this heterogeneity, we estimate separate treatment coefficients for watersheds, in which more (less) than 50 percent of the wells are owned by publicly traded

[33] In the Online Appendix, Section OB5, we verify that these two proxies for public pressure increase after the disclosure mandates come into force. We find significant post-disclosure increases in the number of newspaper articles pointing to HF as a source of water pollution and also in the number of Google searches for the term "fracking." These effects are also more pronounced in counties where the population is more educated.

operators. The results in Table 11, Column (5), indicate that the disclosure effect is greater when the fraction of publicly traded HF operators is higher.

In sum, we obtain consistent results for several proxies suggesting that the improvements in water quality after the introduction of mandatory disclosure are stronger when public pressure is higher and that the mandates increase such pressure. The three final tests in Table 11 explore features of the disclosure regime.

First, we exploit improvements of the FracFocus website, which is the primary repository for the HF disclosure forms. Since its launch in 2011, the FracFocus website was revamped several times to improve the accessibility and dissemination of the HF disclosure forms. We identify three major changes during our sample period (Online Appendix OB10). To exploit these shifts, we estimate an alternative version of Eq. (1) that interacts *HUC10_HF×POST* with a count variable, *CUM_FF_CHANGES,* indicating the cumulative number of website changes implemented by FracFocus up to the respective point in time (i.e., the variable goes from 0 to 4). The results in Table 11, Column (6), indicate further decreases in the ion concentrations in HF watersheds as the dissemination of HF disclosure forms improves. This evidence supports our interpretation that the HF disclosures are the force behind the increases in public pressure and the improvements in water quality.

Second, we consider the ease with which HF operators can obtain trade secret exemptions for the chemical disclosures, as they could make the disclosure forms less effective (McFeeley, 2012). Given that the composition of HF fluids is potentially proprietary, all states allow trade secret exemptions, but differ in how easy it is to obtain them. If granted, operators can withhold the identifying name of the respective chemical, but still have to report the amount and the percentage in the HF fluid. To measure how easy it is for an operator to obtain a trade secret exemption, we consider the following five conditions that states may require to claim a trade-secret exemption (McFeeley, 2012): (1) the submission of a formal request is required to claim for a trade secret exemption; (2) a factual justification to claim for a trade secret exemption is required in the submission; (3) operators have to provide supporting information; (4) there is a process for evaluating the trade secret claim; (5) operators have to follow specific standards to prove that the trade secret exemption is justified. The more conditions are required, the more difficult it is for operators to obtain the trade secret exemption. The Online Appendix (Table OA4) describes the trade secret framework for each state in our sample.[34] In Table 11, Column (7), we report separate coefficient estimates for two state groups, splitting on whether a state has two or more (fewer) conditions for obtaining trade secret exemptions, *High Group* (*Low Group*). The results suggest that the disclosure mandates have stronger effect in states where it is more difficult to obtain a trade secret exemption.

Finally, we consider differences in how much time HF operators are given to file the disclosure forms as a proxy for the strictness of the disclosure regime. Since water impact from HF wells is best detected in the early phases of production (Bonetti *et al*., 2021), timelier disclosures should put local communities in a better informational position. The filing deadlines vary substantially across states and we split states into two groups depending on whether the number of days operators have to file the report are below (*High Group*) or above *(Low Group)* the sample median. In Table 11, Column (8), we find that larger water quality effects in states where the HF disclosure is timelier.

6. Conclusion

We study to what extent targeting corporate activities that have dispersed environmental externalities with disclosure regulation facilitates their internalization. We still have scant evidence as to whether mandated disclosure works for such activities and, if so, how it produces the intended effects. Towards this end, we study the effects of targeted transparency for HF operators in the U.S. The rise of unconventional O&G development has triggered a major and still ongoing public debate about HF. In response to significant concerns about its

[34] Not all the states require the five conditions to be met to apply for an exemption. The sample distribution goes from 0 to 4, and five states have no requirements for the exemption.

environmental and health risks, U.S. states with unconventional O&G development passed disclosure rules for HF wells in an effort to increase the transparency of HF practices.

We study the effects of this disclosure regulation with respect to the environmental impact of HF wells on surface waters as well as the practices of HF operators. We estimate changes in water quality using four ions that are considered specific signatures of HF impact and find significant declines of these ion concentrations in surface waters after the disclosure mandates are introduced. We examine the source of these improvements in water quality and find that, aside from a minor decline in drilling activity, most changes are attributable to adjustments along the intensive margin. Specifically, we document a smaller water impact per well and per unit of O&G production, a decline in the use of hazardous chemicals, and fewer spills and accidents related to wastewater handling. Thus, our study provides detailed evidence that, with mandatory disclosure, HF operators change their practices.

The core idea of targeted transparency for corporate activities with environmental externalities is to enlist public pressure. Illustrating that this mechanism is at play in our setting, we examine several proxies for public pressure and find that water quality improvements after the disclosure mandates are greater in areas where public pressure is higher. Specifically, we find larger decreases in HF-related ion concentrations in areas with a greater presence of local environmental NGOs and in counties with more local newspapers. We show that media coverage and internet searches intensify after disclosure regulation and that the improvements in water quality are more pronounced in states with more news articles discussing HF in relation to water pollution, with more Google searches for HF after the disclosure mandate, and for publicly listed operators that face greater scrutiny. All this evidence is consistent with the idea that disclosure regulation enhances the ability of stakeholders to exert public pressure.

Finally, our study provides novel longitudinal evidence on the environmental impact of HF on U.S. surface waters. Although our analysis based on HF-related ion concentrations suggests significant improvements in water impact, readers should interpret this evidence cautiously as we lack data to study potentially more harmful chemicals.

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Figure 1 – Trends in HF Activity and the Evolution of Disclosure Mandates in the U.S.

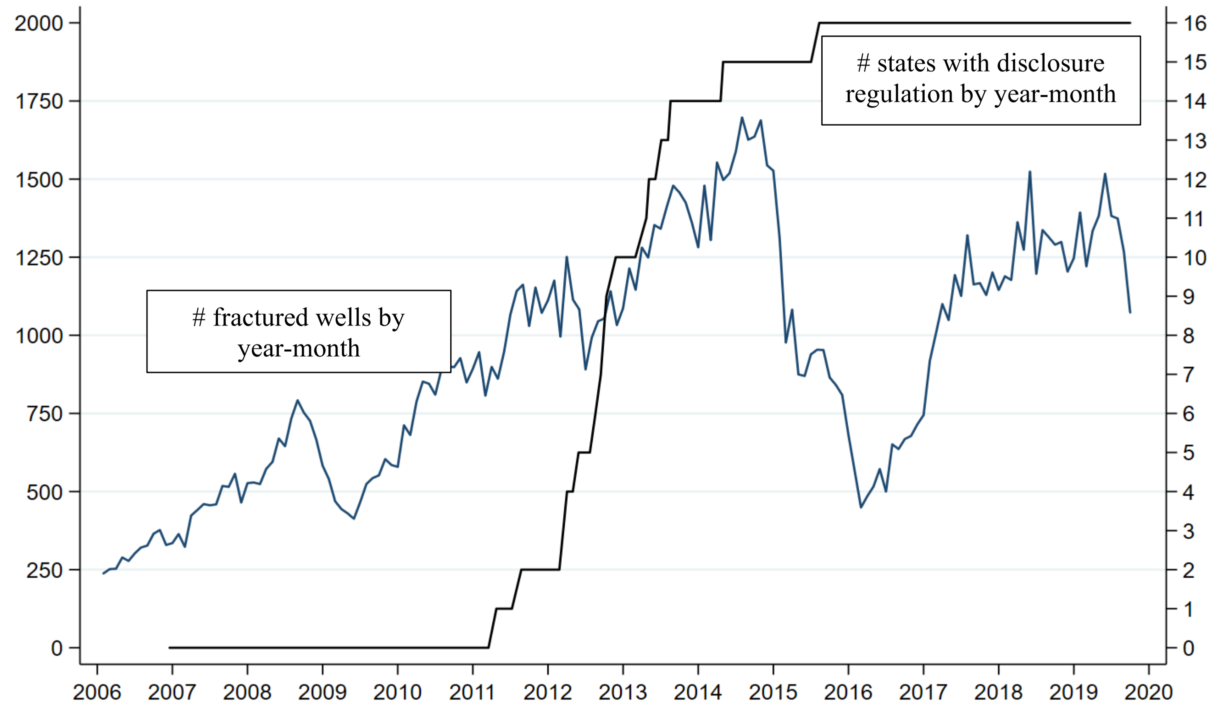
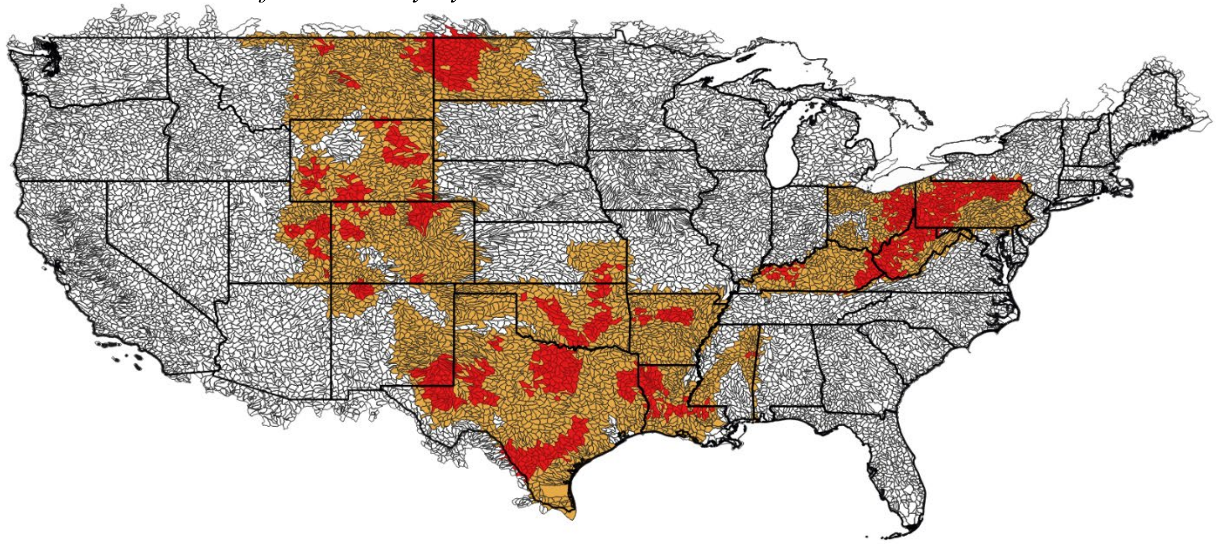


Figure 1 plots the time trend in HF activity in the U.S. along with the adoption timing of the HF disclosure regulation by the U.S. states with HF activity. The *x* axis shows the year. The *left-y* axis shows the number of new HF wells by spud year-month. The *right-y* axis shows the cumulative number of sample states adopting the disclosure regulation in a given year and month. Data on HF wells come from the WellDatabase, Enverus, the Pennsylvania Department of Environmental Protection and the Pennsylvania Department of Conservation of Natural Resources.

Figure 2 – Location of HF Wells and Water Monitoring Stations

Panel A – Location of HF Activity by Watershed



Panel B – Location of Water Monitoring Stations by Watershed

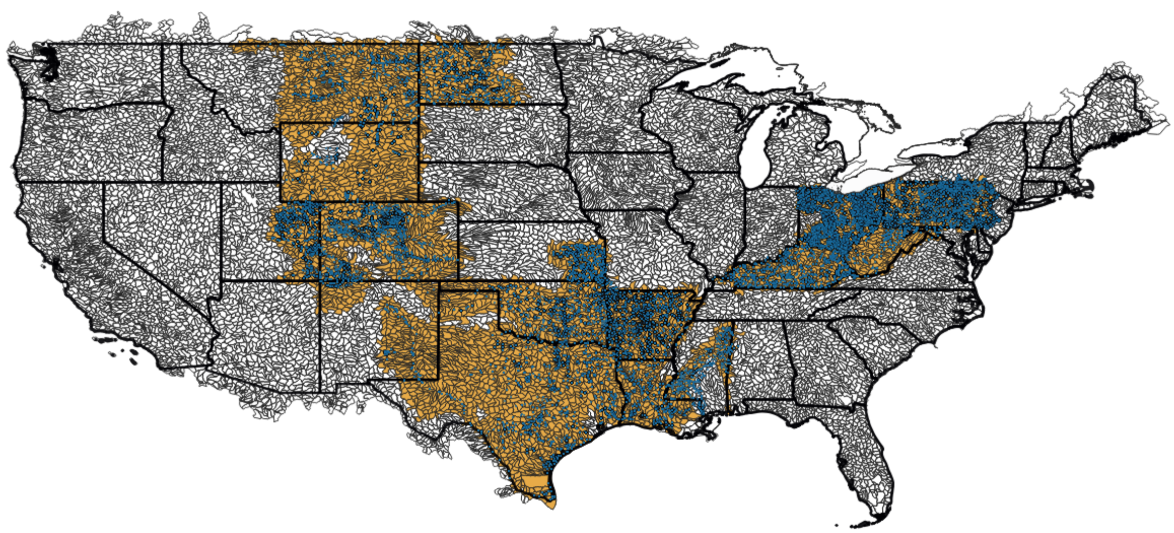


Figure 2 shows the location of HF activity (Panel A) and the location of water monitoring stations (Panel B) across watersheds (HUC10s). Watersheds in the treatment sample are colored in red. Watersheds in the control sample are colored in ocher. Blue dots mark the location of monitoring stations. Data on the location of wells come from the WellDatabase, Enverus, the Pennsylvania Department of Environmental Protection and the Pennsylvania Department of Conservation of Natural Resources. Data on the location of water monitoring stations come from the EPA (STORET data), USGS (NWIS data), Susquehanna River Basin Commission, Shale Network, and from the Pennsylvania DEP. Thin black lines outline HUC10 boundaries; thick black lines depict state boundaries.

Figure 3 – Mapping Out the Effect of HF Disclosure Regulation

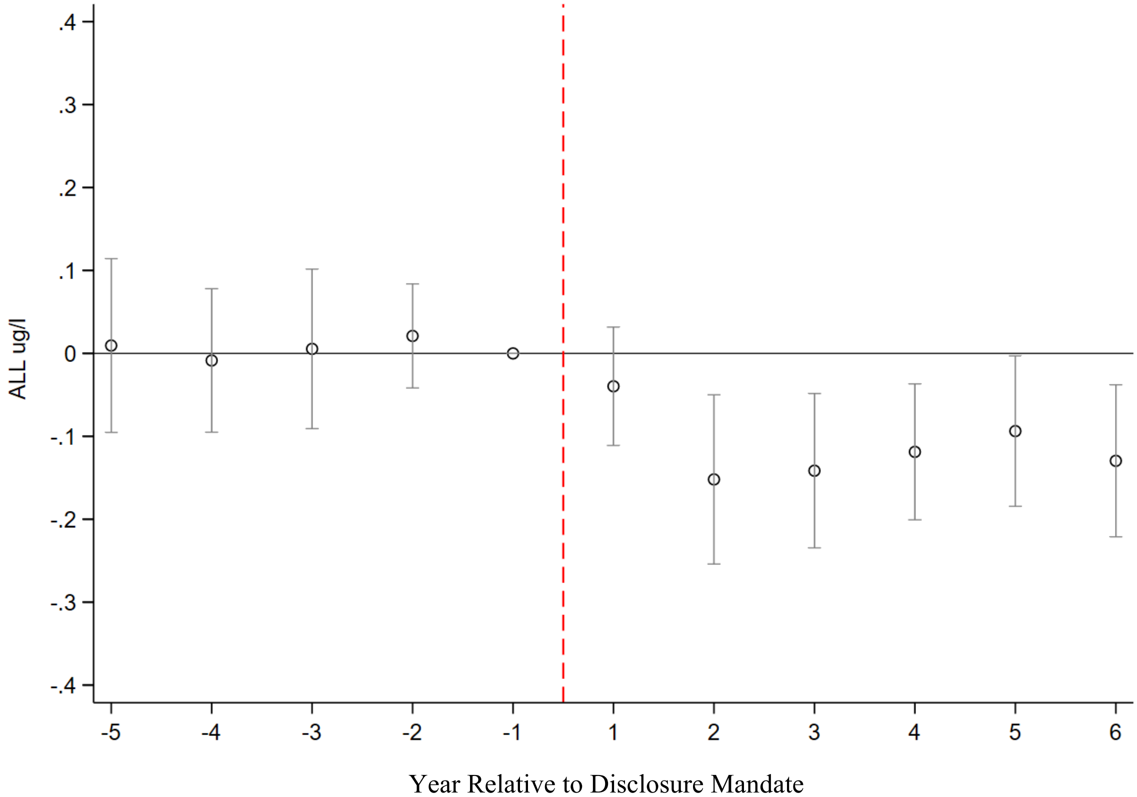


Figure 3 plots coefficients from the estimation of Eq. (1), together with the respective 90% confidence intervals, adding indicators for the years relative to the introduction of the disclosure mandate. Year 1 comprises all water measurements that take place within the first 365 days from the state-specific entry-into-force date. Year -1 comprises measurements in the 365 days before the entry-into-force date. The coefficient for the year before the disclosure mandate (-1) is omitted from the regression and therefore serves as benchmark. We use the within-HUC8 model shown in Column (12) of Table 3.

Figure 4 – Extensive Margin: Changes in HF Activity after Disclosure Regulation

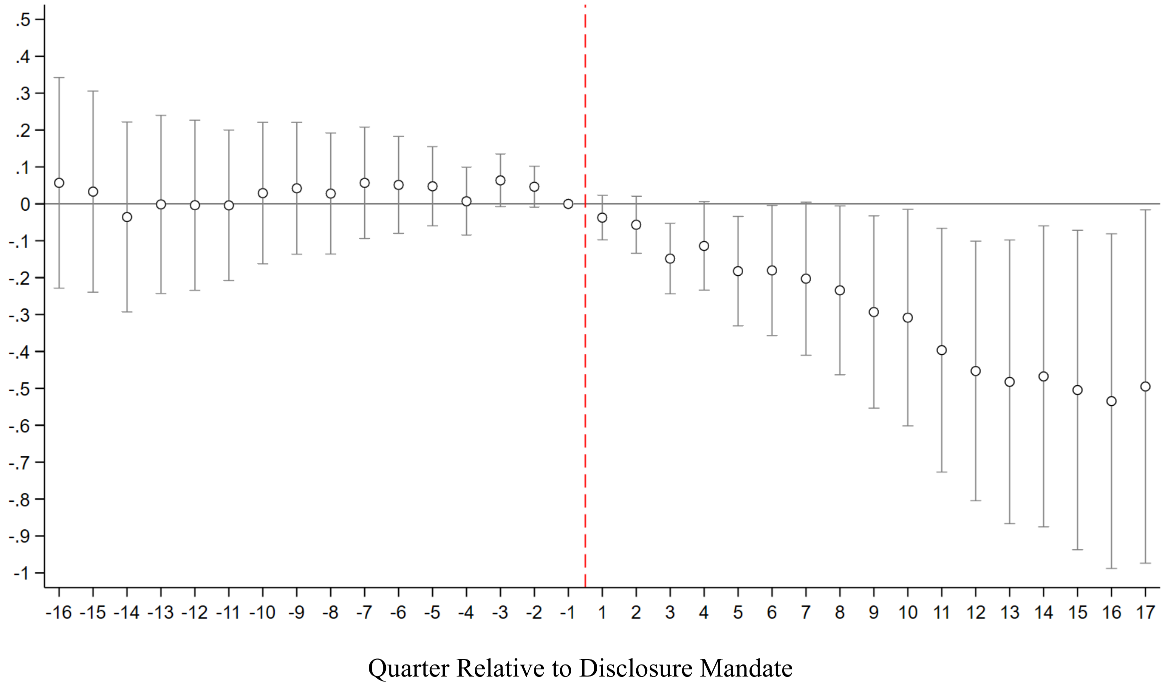


Figure 4 plots coefficients from estimating the model shown in Column (6) of Table 6, together with the respective 95% confidence intervals, adding indicators for the quarter relative to the introduction of the disclosure mandate. Quarter 1 comprises all new wells that are spudded within the first 90 days from the state-specific entry-into-force date. Quarter -1 comprises wells spudded in the 90 days before the entry-into-force date. The coefficient for the quarter before the disclosure mandate (-1) is omitted from the model and therefore serves as benchmark. The sample is restricted to observations from HUC8s that cross state lines (border design).

Figure 5 – Mapping Out the Per-Well Impact Before and After Disclosure Regulation

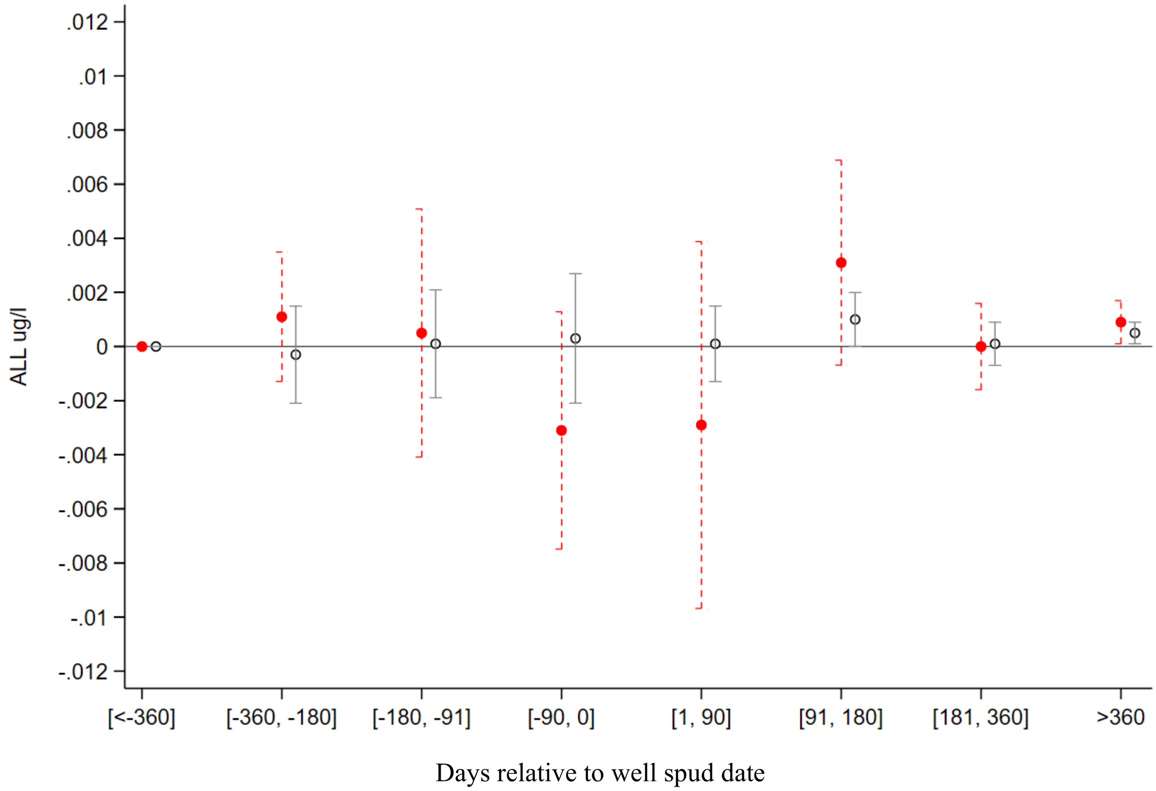
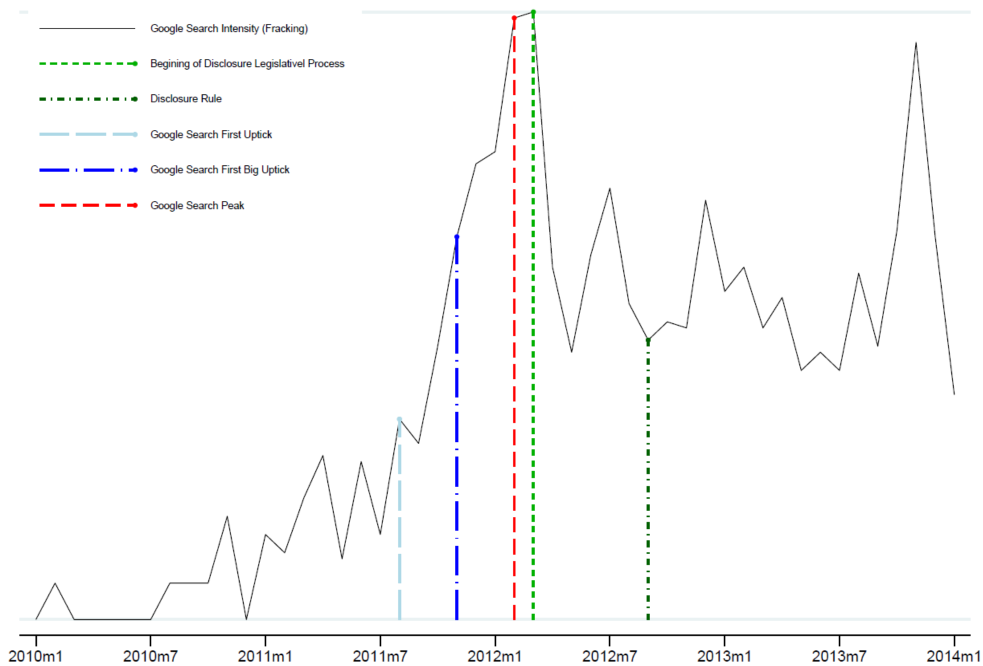
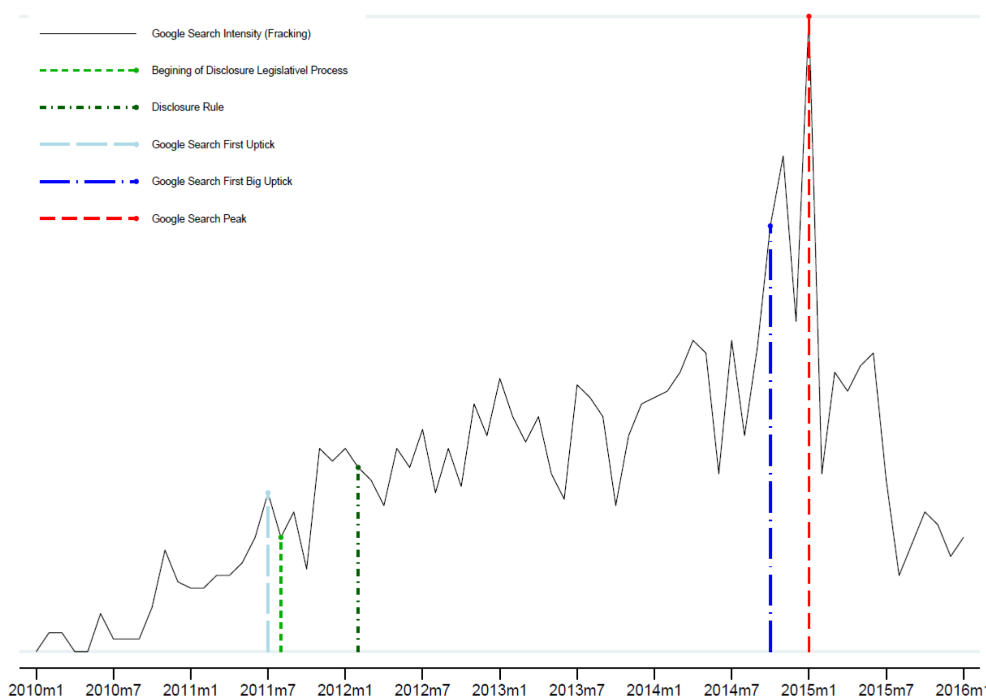


Figure 5 plots coefficients from estimating the model shown in Column (5) of Table 7, together with the respective 95% confidence intervals, using separate HF well counts calculated over fixed time intervals around the well spud dates. We estimate the coefficients for the pre- and post-disclosure period separately. The red (gray) dots are the coefficients for HF wells spudded in the pre-disclosure (post-disclosure) period.

Figure 6 – Google Search Trends around the Introduction of the Disclosure Rules



Ohio



Texas

Figure 6 plots the evolution of Google searches of the term "fracking" for Ohio and Texas, respectively. We superimpose the key legislative events for the disclosure rule (i.e., the beginning of the legislative process and the adoption date). We have performed the same exercise for the remaining states in the sample. In total, 13 out of the 16 sample states have a pattern like Texas (i.e., Google searches peak after adoption).

Table 1 – Sample Composition and Descriptive Statistics

Panel A: Sample composition and entry-into-force dates of the state disclosure mandates

State	Unique monitors	Unique wells	N	Entry-into-force
Arkansas	1,156	6,472	51,898	15-Jan-2011
Colorado	1,298	10,343	23,438	01-Apr-2012
Kansas	379	132	10,341	02-Dec-2013
Kentucky	601	695	8,079	19-Mar-2015
Louisiana	303	4,467	5,764	20-Oct-2011
Mississippi	128	163	2,252	04-Mar-2013
Montana	499	1,381	6,799	26-Aug-2011
New Mexico	119	11,470	1,368	15-Feb-2012
North Dakota	519	17,243	13,904	01-Apr-2012
Ohio	3,768	3,036	68,148	10-Sep-2012
Oklahoma	473	8,254	12,732	01-Jan-2013
Pennsylvania	2,066	12,319	88,122	16-Apr-2012
Texas	723	65,468	10,411	01-Feb-2012
Utah	650	1,421	12,982	01-Nov-2012
West Virginia	92	4,053	1,080	29-Aug-2011
Wyoming	176	7,407	8,033	17-Aug-2010

Panel B: Number of watersheds in the treatment and control samples

	Bromide	**Chloride**	**Barium**	**Strontium**
# HUC10s w/ HF in pre-period	163	573	358	216
# HUC10s w/o HF in pre-period	268	1,618	884	409

Table 1, Panel A, provides the number of water monitoring stations, HF wells and water quality measurements per state as well as the date when the disclosure of the HF fluid composition became mandatory. Panel B shows the number of watersheds in the treatment and control samples for the respective ion. HUC10s are assigned to treatment and control depending on the existence of HF activity in the pre-disclosure period.

Table 2 – Descriptive Statistics for Surface Water Measurements (μ/l)

Panel A – Treated HUC10s with HF in the pre-disclosure period

Bromide	N	Mean	p25	p50	p75	SD
Concentration	6,216	121.303	31.480	60.000	100.000	333.849
Ln(Concentration)	6,216	4.139	3.481	4.111	4.615	1.090
Chloride						
Concentration	46,269	49,130.850	5,620.000	15,000.000	39,680.000	177,371.300
Ln(Concentration)	46,269	9.588	8.634	9.616	10.589	1.691
Barium						
Concentration	26,001	53.147	31.000	43.800	63.000	75.472
Ln(Concentration)	26,001	3.696	3.466	3.802	4.159	0.895
Strontium						
Concentration	21,484	296.759	49.000	146.000	290.000	523.933
Ln(Concentration)	21,484	4.895	3.912	4.990	5.673	1.250

Panel B – HUC10s without HF in the pre-disclosure period

Bromide						
Concentration	9,567	221.260	20.300	43.682	101.250	1,798.698
Ln(Concentration)	9,567	3.962	3.060	3.800	4.629	1.165
Chloride						
Concentration	142,060	103,213.10	4,680.00	14,165.63	35,800.00	980,708.70
Ln(Concentration)	142,060	9.298	8.451	9.559	10.486	2.114
Barium						
Concentration	46,702	64.121	30.000	47.000	71.000	524.401
Ln(Concentration)	46,702	3.700	3.434	3.871	4.277	1.059
Strontium						
Concentration	27,052	705.277	81.000	251.000	654.000	1,360.458
Ln(Concentration)	27,052	5.366	4.407	5.529	6.485	1.734

Table 2 presents descriptive statistics for surface water ion concentrations. Panel A reports statistics for the ion concentrations in treatment watersheds (HUC10s) with HF activity in the pre-disclosure period. Panel B reports statistics for the ion concentrations in control watersheds (HUC10s) without HF activity in the pre-disclosure period, that are located in treatment states and within sub-regions (HUC4s) that had HF activity in some HUC10s. The panels report statistics for the raw ion concentrations and after applying the natural logarithm (ln).

Panel C – Distribution of surface water measurements

Unique # of HUC10s by state	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
	2,209	182	136	192	242	67

Unique # of HUC10s by state/ion	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
Bromide	431	77	36	70	149	55
Chloride	2,209	179	135	171	242	71
Barium	1,247	141	101	134	199	64
Strontium	628	147	29	183	230	88

Unique # of monitoring stations by HUC10	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
	12,950	15	5	12	22	13

Unique # of monitoring stations by HUC10/ion	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
Bromide	1,453	8	3	5	8	8
Chloride	12,577	15	6	11	21	13
Barium	6,995	14	5	11	20	12
Strontium	4,829	17	7	14	22	13

Water quality observations by HUC10/ion	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
Bromide	15,783	37	4	12	37	62
Chloride	188,329	85	12	34	107	152
Barium	72,703	58	11	34	81	72
Strontium	48,536	77	15	49	107	91

Panel C presents distributional information on the number of HUC10s by state and by state and ion, the number of water quality monitoring stations by HUC10 and by HUC10 and ion as well as the number of surface water measurements quality by HUC10 and ion.

Table 3 – Disclosure Mandates and Water Quality

	Bromide (µg/l)		Chloride (µg/l)		Barium (µg/l)		Strontium (µg/l)		All Ions pooled (µg/l)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HUC10_HF×POST	-0.1108	0.0449	**-0.1955*****	**-0.1183****	**-0.0969*****	**-0.0589****	**-0.0448****	-0.0382	**-0.1509*****	**-0.0928****	**-0.1476*****	**-0.0925****
	[0.0714]	[0.1232]	**[0.0557]**	**[0.0520]**	**[0.0352]**	**[0.0346]**	**[0.0223]**	[0.0290]	**[0.0386]**	**[0.0363]**	**[0.0418]**	**[0.0365]**
Observations	15,783	14,538	188,329	176,729	72,703	65,812	48,536	46,308	325,351	303,387	220,208	206,389
R-squared	0.860	0.915	0.865	0.903	0.834	0.867	0.968	0.976	0.961	0.971	0.961	0.971
Treatment Sample	HUC10s with HF activity in the pre-disclosure period											
Full Sample	All HUC10s in sub-regions (HUC4s) in treated states with some HF activity										HUC10s over shales in treated states	
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Table 3 reports OLS coefficients estimating Eq. (1) to assess the impact of the state disclosure mandates on the respective ion concentrations. The models in Columns (9)-(12) pool all four ion concentrations in one model, as described in Section IV. In Columns (1)-(10), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre-and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. In Columns (11)-(12), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period, but the control HUC10s without HF activity in the pre- and post-disclosure period are restricted to those located over shales in treated states. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 4 – Disclosure Mandates and Water Quality: Non-HF Specific Analytes and Vertical Wells

Panel A – Analytes that are not specific to HF impact

	Dissolved oxygen		Fecal Coliform (μg/l)		Phosphorus (μg/l)		All Analytes pooled	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HUC10_HF×POST	0.0141	-0.0402	-0.1567	0.1475	**-0.0309****	0.0189	-0.0190	-0.0046
	[0.0475]	[0.0533]	[0.1809]	[0.5896]	**[0.0150]**	[0.0141]	[0.0273]	[0.0319]
Observations	110,339	103,769	26,729	25,472	111,956	106,069	249,024	235,310
R-squared	0.760	0.818	0.555	0.620	0.524	0.650	0.911	0.933
Treatment Sample	HUC10s with HF activity in the pre-disclosure period							
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes

Table 4, Panel A, reports OLS coefficients estimating Eq. (1) for three water quality proxies that are not specific to HF impact. The models in Columns (7) and (8) pool all analytes in one model, as described in Section IV. The sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Panel B – Conventional drilling

	Bromide (μg/l)		Chloride (μg/l)		Barium (μg/l)		Strontium (μg/l)		All Ions pooled (μg/l)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HUC10_Conv×POST	0.0110	0.0107	-0.0499	-0.0593	-0.0260	-0.0504	-0.0157	-0.0587	-0.0409	-0.0567
	[0.1461]	[0.0170]	[0.0379]	[0.0570]	[0.0170]	[0.0275]	[0.0401]	[0.0528]	[0.0289]	[0.0394]
Observations	9,637	8,686	141,131	130,536	45,915	40,027	26,631	24,627	223,314	203,876
R-squared	0.879	0.929	0.870	0.905	0.838	0.864	0.968	0.975	0.956	0.967
Treatment Sample	HUC10s with conventional drilling activity in the pre-disclosure period									
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Table 4, Panel B, reports OLS coefficients estimating Eq. (1) for HUC10s with conventional, i.e., vertically drilled, wells around the introduction of the disclosure mandates. The sample consists of treatment HUC10s with conventional drilling in the pre-disclosure period (and not HF) and control HUC10s without conventional drilling (and not HF activity) in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some conventional drilling activity. *HUC10_Conv* is a binary indicator marking watersheds with conventional drilling activity (treated HUC10s). *POST* is a binary variable marking water quality observations in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 5 – Disclosure Mandates and Water Quality: Controlling for other HF Regulations

	All Ions pooled (µg/l)											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HUC10_HF×POST				**-0.1364***** **[0.0481]**	**-0.1907***** **[0.0672]**	**-0.1600**** **[0.0626]**				**-0.0874**** **[0.0415]**	**-0.0919*** **[0.0491]**	**-0.0871*** **[0.0491]**
HUC10_HF×CUM_WASTEWATER	**-0.0331***** **[0.0076]**			-0.0072 [0.0092]			**-0.0181**** **[0.0075]**			-0.0027 [0.0077]		
HUC10_HF×CUM_HF_STANDARDS		**-0.0265***** **[0.0058]**			0.0159 [0.0133]			**-0.0197**** **[0.0079]**			-0.0005 [0.0109]	
HUC10_HF×CUM_HF_REG			**-0.0179***** **[0.0036]**			0.0020 [0.0067]			**-0.0121***** **[0.0046]**			-0.0014 [0.0057]
Observations	325,351	325,351	325,351	325,351	325,351	325,351	303,387	303,387	303,387	303,387	303,387	303,387
R-squared	0.961	0.961	0.961	0.961	0.961	0.961	0.971	0.971	0.971	0.971	0.971	0.971
Coef. *HUC10_HF×POST* (Table 3)				**-0.1509**	**-0.1509**	**-0.1509**				**-0.0928**	**-0.0928**	**-0.0928**
Treatment Sample	HUC10s with HF activity in the pre-disclosure period											
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
HUC8×Month	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
HUC8×Month×Year FE	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes

Table 5 reports OLS coefficients estimating Eq. (1), but adding controls for other HF regulations using three alternative variables: (i) *HUC10_HF×CUM_WASTEWATER,* which represents the cumulative number of regulations related to wastewater handling at a given point of time (i.e., the variable increases by one when a new regulation for wastewater handling is introduced in a state) in watersheds with HF wells in the pre-disclosure period; (ii) *HUC10_HF×CUM_HF_STANDARDS*, which represents the number of HF drilling standards at a point in time (i.e., the variable increases by one when a new drilling standard is introduced) in watersheds with HF wells in the pre-disclosure period; (iii) *HUC10_HF×CUM_HF_REG,* which represents the joint number of wastewater handling rules and drilling standards at a given point in time (i.e., the variable is the sum of the previous to two variables) in watersheds with HF wells in the pre-disclosure period The sample consists of treatment HUC10s with HF activity in the pre- and post-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. We report the respective coefficient of interest from Table 3 for comparison. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 6 – Disclosure Mandates and Well Entry: Extensive Margin Analysis

	#HF wells (1)	#HF wells (2)	#HF wells (3)	#HF wells (4)	#[HF – V] wells (5)	#[HF – V] wells (6)
POST	**-0.0554***** **[0.0162]**	**-0.0629***** **[0.0213]**	**-0.0559***** **[0.0196]**	**-0.0506*** **[0.0285]**	**-0.0505**** **[0.0257]**	**-0.0692*** **[0.03721]**
CUM_HF_REG					**0.0575***** **[0.0107]**	**0.0687***** **[0.0160]**
Observations	199,962	112,644	199,773	112,455	199,773	112,455
R-squared	0.383	0.408	0.468	0.461	0.480	0.492
Sample	ALL	HUC8s across two or more states	ALL	HUC8s across two or more states	ALL	HUC8s across two or more states
HUC10 FE	Yes	Yes	Yes	Yes	Yes	Yes
Region×Month×Year FE	Yes	Yes	No	No	No	No
Shale×Month×Year FE	No	No	Yes	Yes	Yes	Yes

Table 6 reports OLS coefficients estimating the impact of the state disclosure mandates on HF well entry. The sample comprises HUC10s in treatment states over shales. In Columns (1)-(4), the dependent variable is the natural logarithm of one plus the number of new HF wells spudded in a given HUC10-month-year. In Columns (5)–(6), the dependent variable is the natural logarithm of one plus the number of new HF wells minus the number of new conventional (or vertical) wells. In these models, we also control for changes in other HF regulations. In Columns (2), (4) and (6), the sample is restricted to HUC10s within HUC8s that are partially located in at least two states (i.e., are crossing state lines). *POST* is a binary variable equal to one in the post-disclosure period. In Columns (1)–(2), we include region×month×year fixed effects in the model. In Columns (3)–(6), we include shale×month×year fixed effects. There are 30 shales in our sample that can be classified into five regions: North-East, South-Mid-West, South-West, Mountain, North-West. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 7 – Disclosure Mandates and Water Quality: Intensive Margin (Per-Well) Analysis

	Bromide (μg/l) (1)	Chloride (μg/l) (2)	Barium (μg/l) (3)	Strontium (μg/l) (4)	All Ions Pooled (μg/l) (5)
#WELL_HUC10_HF_POST	0.0005	**0.0006****	-0.0001	0.0004	**0.0005***
	[0.0020]	**[0.0003]**	[0.0001]	[0.0003]	**[0.0003]**
#WELL_HUC10_HF_PRE	**0.0075*****	**0.0008****	-0.0003	**0.0009****	**0.0007****
	[0.0020]	**[0.0003]**	[0.0002]	**[0.0004]**	**[0.0003]**
Observations	4,797	32,917	16,989	15,886	70,589
R-squared	0.894	0.922	0.893	0.973	0.986
F-Test	0.077	0.784	0.651	0.386	0.664
Treatment Sample	HUC10s with HF in the pre & post disclosure period				
Monitoring station FE	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes
HUC8×Month×Year FE	Yes	Yes	Yes	Yes	Yes

Table 7 reports OLS coefficients estimating the per-well effects of new HF wells on ion concentrations, separately for the pre- and the post-disclosure periods. The sample consists of HUC10s with HF activity in the pre-disclosure and the post-disclosure periods. *#WELL_HUC10_HF_POST* (*PRE*) is a cumulative well count variable, which increases by one when a new HF well in the respective HUC10 is spudded. Given the findings in Bonetti et al. (2021), we align water measurements on a given day with well counts that are lagged by 120 days. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 8 – Environmental Performance (Production per Unit of Pollution)

	O&G Production / All Ions (μg/l) (1)	O&G Production / All Ions (μg/l) (2)	O&G Production / All Ions (μg/l) (3)	O&G Production / All Ions Pooled (μg/l) (4)
HUC10_HF×POST	**40.4681****	**23.2152***	**49.0126*****	**31.7463***
	[16.4891]	**[14.1630]**	**[18.4847]**	**[18.5015]**
Observations	269,473	251,912	249,685	231,869
R-squared	0.946	0.962	0.946	0.962
Treatment Sample	HUC10s with HF activity in the pre	HUC10s with HF activity in the pre	HUC10s with HF activity in pre & post	HUC10s with HF in activity in pre & post
Monitoring station FE	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes

Table 8 reports OLS coefficients estimating Eq. (1) for an alternative dependent variable: the ratio of the average O&G production (bbl) in a given HUC10-month-year and the sum of the four ion concentrations (μg/l). In Columns (1)-(2), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period (and non-missing O&G production data) and control HUC10s without HF in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. In Columns (3)-(4), the sample consists of treatment HUC10s with HF activity in the pre- *and* post-disclosure period (and non-missing O&G production data) and control HUC10s without HF in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking treated watersheds (HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 9 – Chemicals used in the HF Fluids

	All Hazardous Chemicals (1)	Chloride-related Chemicals (2)
POST	**-0.0097*** **	**-0.0034*** **
	[0.0024]	**[0.0013]**
Observations	15,607	15,607
R-squared	0.335	0.157
Sample	HUC10s over shales	
HUC10 FE	Yes	Yes
Month×Year FE	Yes	Yes

Table 9 reports OLS coefficients estimating the impact of the disclosure mandates on the chemicals used in HF fluids. Data on the chemicals disclosed by well operators are from Konschnik and Dayalu (2016). The dependent variable is constructed at the HUC10 level, averaging over all HF well disclosures for each HUC10-month-year. We compute averages for the amount of all hazardous chemicals, chloride-related chemicals, respectively. For each HF well, we scale the respective amount by the total amount of fluids injected. Hazardous chemicals are those (i) regulated as primary contaminants by the Safe Drinking Water Act; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on HF operations (USEPA, 2012a, 2014). For the pre-period, we use voluntary disclosures to calculate HUC10-month-year averages, following Fetter (2017). *POST* is a binary variable equal to one in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 10 – HF-Related Incidents

	All Incidents		Wastewater Incidents	
	(1)	(2)	(3)	(4)
POST	**-0.1623****	-0.0758	**-0.1443*****	**-0.0894****
	[0.0754]	[0.0781]	**[0.0308]**	**[0.0371]**
Observations	7,562	5,001	6,440	4,280
R-squared	0.319	0.351	0.190	0.209
Sample	HUC10s over shales			
	ALL	HUC8s across two or more states	ALL	HUC8s across two or more states
HUC10 FE	Yes	Yes	Yes	Yes
Month×Year FE	Yes	Yes	Yes	Yes

Table 10 reports OLS coefficients estimating the impact of the state disclosure mandates on HF-related incidents such as spills, leaks and accidents (sample up to Dec 2015). The sample comprises HUC10s over shales in states covered in Brantley *et al*. (2014) and Patterson *et al.* (2017). The dependent variable is the logarithm of one plus the number of HF-related incidents in a given HUC10-month-year. Columns (1)-(2) report results for all HF-related incidents. Columns (3)-(4) report results using only spills related to the disposal of wastewater. In Columns (2) and (4), the sample is restricted to HUC10s within HUC8s that are located in at least two neighboring states, i.e., are crossing state lines. *POST* is a binary variable equal to one in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 11 – HF Activity and Water Quality: Role of Public Pressure

	All Ions Pooled (μg/l)							
	Role of public pressure – partitioning on:						*Features of the disclosure regime – partitioning on:*	
	NGOs	*Media Scrutiny*	*Increase in media coverage*	*Increase in Google searches*	*Publicly Owned Operators*	*FracFocus Dissemination*	*Trade Secret Exemptions*	*Disclosure Timeliness*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
POST×HUC10_HF×High Group	**-0.1992****	**-0.1908*****	**-0.2734*****	**-0.1195****	**-0.1633*****		**-0.1275****	**-0.1536*****
	[0.0893]	**[0.0686]**	**[0.0601]**	**[0.0563]**	**[0.0587]**		**[0.0508]**	**[0.0586]**
POST×HUC10_HF×Low Group	**-0.0893****	**-0.0906****	**-0.0656****	**-0.0580****	**-0.0844****		-0.0582	-0.0161
	[0.0367]	**[0.0365]**	**[0.0325]**	**[0.0260]**	**[0.0362]**		[0.0446]	[0.0269]
POST×HUC10_HF						**-0.0774****		
						[0.0378]		
POST×HUC10_HF× CUM_FF_CHANGES						**-0.0255***		
						[0.0152]		
Observations	303,387	303,387	303,387	303,387	303,387	303,387	303,387	303,387
R-squared	0.971	0.971	0.971	0.971	0.971	0.971	0.971	0.971
Treatment Sample	HUC10s with HF activity in the pre-disclosure period							
F-Test	0.1967	**0.0998**	**0.0001**	0.2995	**0.0870**	NA	**0.2881**	**0.0364**
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HUC8×Month×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 11, Panel A, Columns (1)-(5) reports coefficients from an alternative version of Eq. (1), for which we split *POST×HUC10_HF* by two non-overlapping variables marking observations in the post-disclosure period that fall into a *High Group* and into a *Low Group*, respectively. The high/low partitions are as follows: (1) core-based statistical areas/counties with *at least one* (*no*) local anti-fracking NGO active in the year before the adoption of the disclosure mandate; (2) counties with an *at least one* (*no*) local newspapers active in the 360 days leading up to the adoption of the disclosure mandate; (3) counties with an *increase* (*decrease*) in the number of newspapers articles pointing to HF as a source of water pollution between the pre- and post-disclosure period; (4) states with an *above* (*below*) sample median of the change in the state-specific average Google search trend for the term "fracking" between the pre- and post-disclosure periods; (5) HUC10s with an *above* (*below*) 50 percent of wells owned by publicly traded operators. *HUC10_HF* is an indicator variable marking treated watersheds (HUC10s). In Column (6), we estimate an alternative version of Eq. (1), in which we include the cumulative number of website changes implemented by FracFocus to implement accessibility and dissemination, *CUM_FF_CHANGES* interacted with *HUC10_HF×POST.* Columns (7)-(8) reports coefficients from an alternative version of Eq. (1), for which we split *POST×HUC10_HF* by two non-overlapping variables marking observations in the post-disclosure period that fall into a *High Group* and into a *Low Group*, respectively. The high/low partitions are as follows: (7) states in which it is *more difficult* (*easier*) to obtain trade secret exemptions for the disclosure of HF fluids. The former (latter) group includes states with two or more (none or one) conditions for trade secret exemptions; (8) states, for which the required disclosures need to be timelier, based on a *below* (*above*) the sample median split on the #days between the spud date and the required regulatory filing date. The sample includes treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. We report results with HUC8 ×Month ×Year FE. The results with HUC8 ×Month ×Year FE are very similar. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Appendix

Example of HF Fluid Disclosures

Hydraulic Fracturing Fluid Product Component Information Disclosure

Job Start Date:	6/26/2014
Job End Date:	6/26/2014
State:	Texas
County:	Jack
API Number:	42-237-39497-00-00
Operator Name:	Atlas Energy, L.P.
Well Name and Number:	Worthington 2
Longitude:	-98.14464000
Latitude:	33.27892000
Datum:	NAD27
Federal/Tribal Well:	NO
True Vertical Depth:	5,414
Total Base Water Volume (gal):	270,144
Total Base Non Water Volume:	0

Hydraulic Fracturing Fluid Composition:

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by mass)**	Maximum Ingredient Concentration in HF Fluid (% by mass)**	Comments
Water	Operator	Carrier					
			Water	7732-18-5	100.00000	93.00553	
Sand, White, 20/40	Baker Hughes	Proppant					
			Crystalline Silica (Quartz)	14808-60-7	100.00000	3.01346	
HCl, 10.1 - 15%	Baker Hughes	Acidizing					
			Water	7732-18-5	85.00000	2.35918	SmartCare Product
			Hydrochloric Acid	7647-01-0	15.00000	0.41633	SmartCare Product
Sand, White, 16/30	Baker Hughes	Proppant					
			Crystalline Silica (Quartz)	14808-60-7	100.00000	0.46337	
Preferred Garnet RC 16/30	Baker Hughes	Proppant					
			Crystalline Slica (Quartz)	14808-60-7	98.00000	0.21888	
			Castor Oil	8001-79-4	5.00000	0.01117	
			Iron Oxide (colorant)	1309-37-1	1.00000	0.00223	
FRW-15A, tote	Baker Hughes	Friction Reducer					
			Contains non-hazardous ingredients that are shown in the non-MSDS section of this report.	NA	100.00000	0.11206	SmartCare Product
ClayCare, ClayTreat-2C, 330 gl tote	Baker Hughes	Clay Control					
			Choline Chloride	67-48-1	75.00000	0.03465	SmartCare Product

The figure displays an example for HF fluid disclosures. It is taken from a well spudded in Texas after the state adopted the disclosure mandate. The figure shows the information provided by the disclosure, including the start date of the on-site operations, well ID, operator name, the coordinates of the well and information on the water consumed along with the chemicals used by the operator drilling the well. Some of the ingredients and chemicals CAS numbers are not disclosed because of trade secret exemptions. In this example, the operator still has to report the trade name, the purpose of the chemical and the quantity used.

Online Appendix

This Online Appendix provides additional descriptive evidence, background information as well as supplemental analyses and additional descriptive statistics.

Section OA – Descriptive or anecdotal evidence and background information

Section OB – Supplemental analysis

Section OC – Additional descriptive statistics for data used in the paper

OA1 – Examples for the Demand for HF Fluid Disclosures

Calls for more transparency

Outlet	Date	*Title* / Quotes
Pennlive	September 5, 2010	*'Gasland,' a documentary about the natural gas industry in Pennsylvania, is a national hit* The movie "Gasland" — about the environmental hazards of drilling and fracking shale for natural gas — has become a national sensation. The documentary has aired repeatedly on HBO in recent months. Critics, including some Pennsylvania government officials, say it's a shameless piece of propaganda riddled with inaccuracies. Fans say it opened their eyes to what really happens when drillers come to town. Either way, it has become a force to be reckoned with in the ongoing political debate over Marcellus Shale in Pennsylvania. (…) Q: The film focuses <u>on the secrecy surrounding the chemicals used in fracking</u>. Range Resources and several other companies have since begun publicly posting the fracking recipe for each of their wells in Pennsylvania. Your thoughts on that? A: <u>They're clearly afraid of federal regulation</u>. They're trying to get out ahead of the curve. The governor of Wyoming publicly stated (his state) passed this (fracking disclosure) law to keep the EPA out. <u>That Wyoming law requires the industry to disclose the chemicals to the state, but not to the people</u>. There has to be a federal standard in America. ... Right now, the gas industry is exempt from the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act. ... We shouldn't be having any discussion of drilling until those exemptions are reversed.
Huffington Post	November 21, 2012	*Fracking's Toxic Secret: Lack of Transparency Over Natural Gas Drilling Endangers Public Health, Advocates Say* (…) <u>The disclosing of chemicals used by the industry remains seriously incomplete</u>. Couple that with the incomplete reports on water tests and it aggravates a situation where landowners don't have a full picture of what is going on," said Kate Sinding, a senior attorney with the Natural Resources Defence Council. <u>David Headley, of Smithfield, Penn, is one of those that's been getting incomplete information about contaminates in his water</u>. In April 2010, four years after the first natural gas well was drilled near his home, the DEP tested Headley's drinking water and reported low levels of barium, strontium and manganese. "We were told the water was safe to drink," David Headley said. "But we had an infant in the house, and a pre-teen. We weren't about to let them drink it." (…)
National Geographic	March, 2013	*The New Oil Landscape* (…) <u>Of special concern are the hundreds of fracking components, some of which contain chemicals known to be or suspected of being carcinogenic or otherwise toxic</u>. Increasing the likelihood of unwanted environmental effects is the so-called Halliburton loophole, named after the company that patented an early version of hydraulic fracturing. Passed during the Bush-Cheney Administration, <u>the loophole exempts the oil and gas industry from the requirements of the Safe Drinking Water Act</u>. What's more, manufacturers and operators are not required to disclose all their ingredients, on the principle that trade secrets might be revealed. Even <u>George P. Mitchell, the Texas wildcatter who pioneered the use of fracking, has called for more transparency and tighter regulation</u>. In the absence of well-defined federal oversight, states are starting to assert control. In 2011 the North Dakota legislature passed a bill that said, in effect, fracking is safe, end of discussion. (…)

Demand from local communities, NGOs, and environmental activists

Outlet	**Date**	***Title* / Quotes**
The Bismarck Tribune	April 1, 2012	*Environmentalists sue over fracking fluids* CHEYENNE, Wyo. (AP) – Environmentalists are suing the Wyoming Oil and Gas Conservation Commission, saying the regulatory agency hasn't done enough to justify honoring requests by companies to keep the public from reviewing ingredients in hydraulic fracturing fluids. The groups Powder River Basin Resource Council, Wyoming Outdoor Council, Earthworks and OMB Watch sued in Natrona County District Court on Monday. They allege the commission denied their state open records requests to review fracking fluid ingredients. Hydraulic fracturing involves pumping water, sand and chemicals into oil and gas wells to crack open fissures. Wyoming has required oilfield service companies to disclose to state officials the ingredients in their fracking fluids since 2010. Environmentalists have raised alarm for years that fracking could contaminate groundwater. Few if any such cases are confirmed although last year the U.S. Environmental Protection Agency theorized that fracking may have contaminated the groundwater near Pavillion, a small community in central Fremont County. Testing groundwater for fracking-related pollution gets complicated because what goes into fracking fluids isn't generally known outside the companies that make it. Wyoming's open records law provides an exception for public disclosure of trade secrets. The groups say the commission has repeatedly allowed companies to invoke the exception - on flimsy grounds - to keep fracking fluid ingredients out of the public realm. He pointed out that companies must also track fracking fluids after they've been used and account for their reuse, storage or disposal. Wyoming led the nation in its fracking disclosure regulations and other states are following suit, Gov. Matt Mead said in a statement. "Wyoming and the additional states requiring disclosure believe it is the states rather than the federal government that should regulate hydraulic fracturing," said Mead, who as governor is chairman of the commission. "We will watch this case closely to determine if either the rules or the administration of the rules need work. If improvements need to be made we will make them."

Demand from policy makers and regulators

The Obama Administration attempted to introduce federal legislation on HF fluid disclosures, but the effort eventually failed.

Outlet	Date	***Title*** / Quotes
Gas Daily	May 4, 2011	*Maryland to sue Chesapeake over Pa. fluid spill* The state of Maryland intends to sue Chesapeake Energy for allegedly violating federal environmental laws when hydraulic fracturing fluids from one of its Marcellus Shale gas wells spilled into a north-eastern Pennsylvania creek. "Companies cannot expose citizens to dangerous chemicals that pose serious health risks to the environment and to public health," Maryland Attorney General Douglas Gansler said late Monday. "We are using all resources available to hold Chesapeake Energy accountable for its actions." Gansler said in a letter to Oklahoma City-based Chesapeake that he plans to sue the company and its affiliates for violating the federal Resource Conservation and Recovery Act and the Clean Water Act. Federal law mandates that Gansler give the company 90 days notice of his intent. On April 19, thousands of gallons of fracking fluid were released from the Bradford County well into Towanda Creek, a tributary of the Susquehanna River, which supplies drinking water to about 6.2 million people in Pennsylvania, Delaware and Maryland (GD 4/20). <u>"Exposure to toxic and carcinogenic chemicals in unknown quantities creates a risk of imminent and substantial endangerment to humans using Maryland waterways for recreation and to the environment," Gansler said. "Although the precise mixture of these fracking fluids is not known, a recent congressional study found that they contain 750 chemicals and other components, including several extremely toxic compounds. High levels of these contaminants remain in the fracking fluid that returns to the surface as wastewater after a well has been hydrofracked</u>." He said radioactivity levels in Pennsylvania's fracking wastewater "have sometimes been thousands of times above the maximum allowed by federal standards for drinking water."
Reuters	January 25, 2012	*Obama backs shale gas drilling* Improvements in drilling techniques have transformed the U.S. energy landscape in recent years by unlocking the country's immense shale oil and gas reserves. But the drilling boom has raised concerns about the safety of natural gas extraction techniques like hydraulic fracturing, or fracking, which environmentalists say could pollute water supplies. <u>Still, with fracking mostly exempt from federal oversight and most shale gas production occurring on private lands, the Obama administration is limited in its authority over the practice.</u> <u>Obama said the administration would move forward with rules that would require companies to disclose chemicals used during the fracking process on public lands.</u> In wide-ranging comments about the energy industry, Obama also said he would direct his administration to open 75 percent of the country's potential offshore oil and gas resources to drilling. This proposal would be carried out in the latest offshore drilling plan released by the Interior Department in November.
The Tampa Tribune	March 21, 2015	*Fracking chemicals must be disclosed; New rule requires drillers to be more transparent* <u>The Obama administration said Friday it is requiring companies that drill for oil and natural gas on federal lands to disclose chemicals used in hydraulic fracturing, the first major federal regulation of the controversial drilling technique that has sparked an ongoing boom in natural gas production but raised widespread concerns about possible groundwater contamination.</u> A rule to take effect in June also updates requirements for well construction and disposal of water and other fluids used in fracking, as the drilling method is more commonly known. The rule has been under consideration for more than three years, drawing criticism from the oil and gas industry and environmental groups alike. The industry fears federal regulation could duplicate efforts by states and hinder the drilling boom, while some environmental groups worry that lenient rules could allow unsafe drilling techniques to pollute groundwater.

	<u>Reaction to the rule was immediate. An industry group announced it was filing a lawsuit to block the regulation and the Republican chairman of the Senate Environment and Public Works Committee announced legislation to keep fracking regulations under state management</u>. The final rule hews closely to a draft that has lingered since the Obama administration proposed it in May 2013. <u>The rule relies on an online database used by at least 16 states to track the chemicals used in fracking operations. The website, FracFocus.org, was formed by industry and intergovernmental groups in 2011 and allows users to gather well-specific data on tens of thousands of drilling sites across the country. Companies will have to disclose the chemicals they use within 30 days of the fracking operation. Interior Secretary Sally Jewell said the rule will allow for continued responsible development of federal oil and gas resources on millions of acres of public lands while assuring the public that transparent and effective safety and environmental protections are in place.</u> Jewell, who worked on fracking operations in Oklahoma long before joining the government in 2013, said decades-old federal regulations have failed to keep pace with modern technological advances. The League of Conservation Voters called the bill an important step forward to regulate fracking.

Demand from shareholders

Shareholders request information on HF to assess the potential for reputational risks and vulnerability to litigation, as illustrated below:

Outlet	**Date**	***Title* / Quotes**
ExxonMobil - DEFINITIVE PROXY STATEMENT	April 13, 2010	*ExxonMobil - DEFINITIVE PROXY STATEMENT, filed 2010-04-13* ITEM 10 – REPORT ON NATURAL GAS PRODUCTION This proposal was submitted by The Park Foundation, 311 California St., Suite 510, San Francisco, CA 94104, as lead proponent of a filing group. Fracturing operations can have significant impacts on surrounding communities including the potential for increased incidents of toxic spills, impacts to local water quantity and quality, and degradation of air quality. Government officials in Ohio, Pennsylvania and Colorado have documented methane gas linked to fracturing operations in drinking water. In Wyoming, the US Environmental Protection Agency (EPA) recently found a chemical known to be used in fracturing in at least three wells adjacent to drilling operations. There is virtually no public disclosure of chemicals used at fracturing locations. The Energy Policy Act of 2005 stripped EPA of its authority to regulate fracturing under the Safe Drinking Water Act and state regulation is uneven and limited. But recently, some new federal and state regulations have been proposed. In June 2009, federal legislation to reinstate EPA authority to regulate fracturing was introduced. In September 2009, the New York State Department of Environmental Conservation released draft permit conditions that would require disclosure of chemicals used, specific well construction protocols, and baseline pre-testing of surrounding drinking water wells. New York sits above part of the Marcellus Shale, which some believe to be the largest onshore natural gas reserve. Media attention has increased exponentially. A search of the Nexis Mega-News library on November 11, 2009 found 1807 articles mentioning ‘hydraulic fracturing’ and environment in the last two years, a 265 percent increase over the prior three years. Because of public concern, in September 2009, some natural gas operators and drillers began advocating greater disclosure of the chemical constituents used in fracturing. In the proponents’ opinion, emerging technologies to track ‘chemical signatures’ from drilling activities increase the potential for reputational damage and vulnerability to litigation. Furthermore, we believe uneven regulatory controls and reported contamination incidents compel companies to protect their long-term financial interests by taking measures beyond regulatory requirements to reduce environmental hazards. Therefore, be it resolved, Shareholders request that the Board of Directors prepare a report by October 1, 2010, at reasonable cost and omitting proprietary information, summarizing 1. the environmental impact of fracturing operations of ExxonMobil; 2. potential policies for the company to adopt, above and beyond regulatory requirements, to reduce or eliminate hazards to air, water, and soil quality from fracturing. Supporting statement: Proponents believe the policies explored by the report should include, among other things, use of less toxic fracturing fluids, recycling or reuse of waste fluids, and other structural or procedural strategies to reduce fracturing hazards.” The Board recommends you vote AGAINST this proposal for the following reasons: ExxonMobil’s Environmental Policy states that we will comply with all applicable laws and regulations and apply responsible standards where laws do not exist, including precautions specific to hydraulic fracturing. The Board believes

		the minimal environmental impacts of hydraulic fracturing have been well-documented and regulatory protections are well-established; therefore, an additional report is not necessary. ExxonMobil supports the disclosure of the identity of the ingredients being used in fracturing fluids at each site. While we understand the intellectual property concerns of service companies when it comes to disclosing the proprietary formulations in their exact amounts, we believe the concerns of community members can be alleviated by the disclosure of all ingredients used in these fluids. We understand that some communities and homeowners new to drilling operations may have concerns. We are committed to working with them to demonstrate that we can address environmental concerns they may have, while providing good jobs and income associated with the safe and efficient production of natural gas.
Multiple Shareholder Proposals	Multiple dates	Several other companies are targeted by shareholder proposals related to HF disclosures

Company	**Year**	**Outcome**	**Votes %**
ANADARKO PETROLEUM CORP.	2012	Withdrawn	
CABOT OIL & GAS CORPORATION	2010	Voted	35.9
CABOT OIL & GAS CORPORATION	2013	Withdrawn	
CHESAPEAKE ENERGY CORP.	2012	Withdrawn	
CHEVRON CORPORATION	2012	Voted	27.9
CHEVRON CORPORATION	2013	Voted	30.2
CHEVRON CORPORATION	2014	Voted	26.6
EL PASO CORPORATION	2010	Withdrawn	
ENERGEN CORPORATION	2010	Withdrawn	
EOG RESOURCES, INC.	2010	Voted	30.9
EOG RESOURCES, INC.	2012	Withdrawn	
EOG RESOURCES, INC.	2013	Withdrawn	
EOG RESOURCES, INC.	2014	Voted	28
EQT CORPORATION	2010	Omitted	
EQT CORPORATION	2014	Withdrawn	
EXXON MOBIL CORPORATION	2010	Voted	26.3
EXXON MOBIL CORPORATION	2011	Voted	28.2
EXXON MOBIL CORPORATION	2012	Voted	29.6
EXXON MOBIL CORPORATION	2013	Voted	30.2
HESS CORPORATION	2010	Withdrawn	
NOBLE ENERGY, INC.	2012	Withdrawn	
OCCIDENTAL PETROLEUM CORP.	2014	Withdrawn	
PIONEER NATURAL RESOURCES COMPANY	2013	Voted	41.7
RANGE RESOURCES CORPORATION	2010	Withdrawn	

Withdrawn proposals are those for which the company has agreed to take action ahead of the vote at the annual general meeting. Omitted proposal are those for which the company has petitioned the SEC to be authorized to exclude the proposal from the proxy statement (see SEC rule 14a-8)

Demand from potential plaintiffs

HF fluid information can help plaintiffs to prove contamination and establish causation. In the following example, an article in a local newspaper explains how landowners (in the proximity of HF wells) can use HF disclosures.

Outlet	**Date**	***Title* / Quotes**
Great Falls Tribune	January 19, 2017	*Fracking chemicals focus of lawsuit seeking more disclosure* Landowners are being denied information needed in order to test for the presence of fracking chemicals in their water before fracking occurs, which is essential to establish baseline information should contamination problems occur later, O'Brien said. Fracking chemicals are toxic or carcinogenic to humans, who may be exposed to the chemicals through surface spills of fracking fluids, groundwater contamination and chemical releases into the air, the lawsuit says. The plaintiffs argue the trade information should be disclosed to a state regulator, who could then make a determination whether trade secrets are involved. "The constitutional right-to-know provision does not mandate disclosure of bona fide de trade secrets, but it creates an express presumption in favor of public access to information and places the burden of establishing trade secret status on the entity seeking to withhold information from public disclosure," the lawsuit says. The first recorded hydraulic fracturing operation in Montana was in the 1950s, Halvorson said. "We are aware of no chemicals related to the hydraulic fracturing process being detected in groundwater," he said. A well hasn't been fracked in more than a year as the state has seen a decline in oil and gas production due to lower oil prices. It doesn't make sense for the public to wait until activity picks up to seek changes, O'Brien said. "It's hard to ask regulators to make changes in a boom," she said. If chemicals are secret, O'Brien said, it's impossible to determine whether contamination, should it occur, is caused by hydraulic fracturing or something else. Board members examined the evidence submitted in the rulemaking petition to the board seeking more disclosure including technical papers and concluded no evidence was presented that the rules were inadequate, Halvorson said. An incident in North Dakota in which chemicals were detected in the groundwater was presented in the petition, Halvorson said. That incident occurred prior to the current hydraulic fracturing rule that the board adopted in 2011, he said. The incident that lead to that problem would have been addressed by the 2011 Montana rule, he said. The lawsuit calls the board's reasons for denying the rulemaking petition "factually erroneous, unsupported, and irrational." The board will discuss the MEIC filing and the request for rulemaking contained the filling at its Feb. 2 meeting, Halvorson said. The plaintiffs Montana Environmental Information Center, Natural Resources Defense Council, Dr. Mary Anne Mercer, David Katz, Anne Moses, Jack and Bonnie, Martinell, Dr. Willis Weight, and Dr. David Lehnherr.

OA2 – Examples for the Regulatory and Public Debate on HF Disclosures

Regulatory Pressures

Outlet	Date	*Title* / Quotes
Congressional research on HF and disclosure requirement (Murril and Vann, 2012)	May 2012	*Congressional research on HF and disclosure requirements* In his 2012 State of the Union Address, Obama said he would obligate "all companies that drill for gas on public lands to disclose the chemicals they use," citing health and safety concerns. In May 2012, the Bureau of Land Management (BLM) published a proposed rule that would require companies employing hydraulic fracturing on lands managed by BLM to disclose the content of the fracturing fluid. In addition, there have been legislative efforts in the 112th Congress. H.R. 1084 and S. 587, the Fracturing Responsibility and Awareness of Chemicals Act (FRAC Act), would create more broadly applicable disclosure requirements for parties engaged in hydraulic fracturing (…). We also note that regulatory risk arises from the pressure on states and local authority to implement stricter regulations on HF:
Environment	March 27, 2012	*Groups seek fuller disclosure of fracking in Wyoming* SALMON, Idaho (Reuters) - Environmental groups are asking a state court to force Wyoming to provide a more complete list of chemicals used in hydraulic fracturing, or fracking, a drilling technique vital to natural gas and oil production in the state. Wyoming in 2010 became the first state to require disclosure of chemicals that energy companies inject - along with sand and water - deep underground to free gas or oil from rock. But the state exempted products and chemicals that qualified as confidential commercial information, or trade secrets. The Wyoming Outdoor Council and others contend in a legal petition in state court that the Wyoming Oil and Gas Conservation Commission has illegally allowed energy drillers to claim exemptions where they were not warranted. The groups claim such secrecy is impeding efforts to protect public health and water quality. There are 150 chemicals in Wyoming that these companies have asked to be protected under trade secret status," said Steve Jones, watershed program protection attorney for the Wyoming Outdoor Council. Since these chemicals pose a potential threat to ground water and to people's heath, we need to know what they are." The court challenge in Wyoming may have broader implications as other states, including Pennsylvania and Texas, have adopted similar standards for disclosure. Fracking and other drilling advancements have unlocked vast supplies of domestic natural gas, but health and environmental groups worry fracking operations near homes and schools can pollute air and water. The effort to force disclosure comes after the U.S. Environmental Protection Agency agreed earlier this month to work with Wyoming to retest water supplies in Pavillion, the Wyoming town where a 2011 EPA draft study linked natural gas fracking to pollution of a nearby aquifer. Industry representatives said disclosure of so-called "recipes" will hamper market place driven efforts to develop more benign - or greener - fracking chemistry. If companies can't get the benefit of their intellectual capital, we don't get the benefit of their innovation," said energy company advisor Jason Hutt of Bracewell & Giuliani LLP, an international law firm headquartered in Texas. The outdoor council, Powder River Basin Resource Council and others are asking a Wyoming judge to find that the state Oil and Gas Conservation Commission's actions in granting trade secret exemptions in certain cases were "arbitrary, capricious, an abuse of discretion" or otherwise illegal.

Outlet	Date	*Title* / Quotes
The New York Post	December 18, 2014	*A pain in the gas! NY bans fracking, but don't blame me* 'Would I let my child play in a school field nearby, drink water from the tap or grow vegetables from the soil? My answer is no.' - Health Commissioner Dr. Howard Zucker. Get the frack outta here! After two years of studying the politically explosive issue, the Cuomo administration announced Wednesday that it won't allow hydraulic fracking in New York. Gov. Cuomo - who waited six weeks after his re-election to disclose the decision - insisted it was the environmental and health experts in his administration who made the call. "I had nothing to do with it," insisted the governor, who has a reputation as the decider-in-chief when it comes to other projects. The administration's experts cited safety concerns for dousing the controversial but potentially lucrative gas-extraction process. "Would I live in a community [with fracking] based on the facts I have now?" Dr. Howard Zucker, the state health commissioner, asked rhetorically at a Cabinet meeting in Albany. "Would I let my child play in a school field nearby, drink water from the tap or grow vegetables from the soil? . . . My answer is no." Zucker spoke at length about scientific studies he said found "significant public health risks" with fracking, even while conceding many of the studies were inconclusive. "Relying on limited data would be negligent on my part," Zucker added. "I cannot support high-volume hydraulic fracturing in the great state of New York." Cuomo praised Zucker's presentation as "highly effective," "powerful" and "poignant." The state has been evaluating fracking since before Cuomo took office in 2010. Agencies in his own administration have been studying the issue intensely for two years. But the governor said that he adopted a neutral, hands-off approach and that politics had nothing to do with the results. "My answer has been I don't know, and it's not what I do," he said. "Let's bring the emotion down. Let's ask the qualified experts what their opinion is. All things being equal, I will be bound by what the experts say. I am not in a position to second-guess them." Fracking advocates blasted the outcome as an economic disaster for upstate towns. "Our rural communities are dying a slow, painful, poverty-stricken death and hope is scarce," said state Sen. Cathy Young (R-Jamestown). "Gov. Cuomo's decision to ban exploration of our natural gas resources is a punch in the gut to the Southern Tier." Former Pennsylvania Gov. Ed Rendell, who legalized fracking in his state, said Cuomo was making a mistake. "If you put the right regulations in place, you can protect the environment," he said. "There's no form of energy produced today that doesn't have potential to cause environmental problems." Environmental advocates, meanwhile, were celebrating. "The governor promised he would make his decision on the science, and he kept his promise," said Riverkeeper head Paul Gallay.

Investor Pressures

Outlet	Date	***Title*** **/ Quotes**
Disclosing the facts	November 7, 2013	*A coalition of investors organized a campaign on "Disclosing the Facts" Campaign* [As you Sow (shareholder advocacy organization), Boston Common Asset Management, LLC (Investment management group), Green Century Capital Management (financial advisory firm), the Investor Environmental Health Network (collaborative partnership of investment managers and advisors)]. The campaign aims at scoring companies based on their disclosure practices (including chemical use and whether companies report quantitatively on reduction of toxic chemical use). Extracts from the "Disclosing the facts 2019" press release: "*The best companies are increasing their water efficiency, re-using water from operations, using non-potable waste streams, and even treating wastewater*" - "*Our report shows that smart use of water and chemicals continues to evolve, but more needs to be done*." "*This enables investors to assess and compare how well companies are reducing costs and risks*." (Investors have concerns and see risks) HYDRAULIC FRACTURING REPORT CARD: I INDUSTRY SCORES "F" ON RISK DISCLOSURES TO INVESTORS *Shareholder analysis of 24 companies finds energy producers – with BP, Exxon Mobil and Occidental at the bottom failing to adequately report efforts to reduce environmental and community impacts.* BOSTON, MA – November 7, 2013 - The oil & gas production industry is consistently failing to report measurable reductions of its impacts on communities and the environment from hydraulic fracturing operations, according to a scorecard report released today by As You Sow, Boston Common Asset Management, Green Century Capital Management (Green Century), and the Investor Environmental Health Network (IEHN). Available online at disclosingthefacts.org, the report, *Disclosing the Facts: Transparency and Risk in Hydraulic Fracturing Operations*, benchmarks 24 companies engaged in hydraulic fracturing against investor needs for disclosure of operational impacts and mitigation efforts. (See full company list below). While scores varied, no firm succeeded in disclosing information on even half of the selected 32 indicators related to management of toxic chemicals, water and waste, air emissions, community impacts, and governance. Even the highest scoring company, Encana Corporation (ECA) provided sufficient disclosure on just 14 of the 32 indicators. The lowest scoring companies were: BHP Billiton Ltd. (BHP) (2 of out 32 indicators); BP plc (BP) (2 out of 32 indicators); Exxon Mobil Corporation (XOM) (2 out of 32 indicators); Occidental Petroleum Corporation (OXY) (2 out of 32 indicators); Southwestern Energy Co. (SWN) (2 out of 32 indicators); and, in last place, QEP Resources, Inc. (QEP) (1 out of 32 indicators). (See full rankings below.) The report notes that measurement and disclosure of best management practices and impacts is the primary means by which investors can assess how companies are managing the impacts of their hydraulic fracturing operations on communities and the environment. "The results of this scorecard show that companies are failing to rigorously disclose the impacts of their hydraulic fracturing operations on communities and the environment", said Richard Liroff, executive director of IEHN. "Data on key metrics remain largely absent, making it difficult for investors and the public to assess and compare companies' performance." "Leaks, spills, and explosions continue to make headlines and demonstrate the risks of hydraulic fracturing," noted Lucia von Reusner, shareholder advocate for Green Century Capital Management. "Unfortunately

companies are failing to provide enough evidence to assure shareholders and the public regarding steps being taken to protect communities and the environment from the adverse impacts of hydraulic fracturing."

Institutional investors have been pressing oil and gas companies since 2009 for greater disclosure of their risk management practices. Investors have engaged over two dozen companies, filing nearly 40 shareholder proposals on these issues to date. The shareholder proposals have led to improved disclosures at many of the companies, but the scorecard report notes that much of this disclosure is narrative and qualitative in form, while quantifiable data are lacking.

"The oil and gas industry's hydraulic fracturing operations are under intense scrutiny for potential harm to neighboring communities and the environment – from air and water pollution to increased noise, traffic, and crime," said Danielle Fugere, president of As You Sow. "If companies are not tracking these potential problems, it is difficult to demonstrate to investors, regulators, or the public that the problems are being avoided or resolved."

Of the 32 indicators against which companies were scored, companies performed best on questions regarding disclosures on broader qualitative policies but worst on those questions about quantitative goals and progress metrics. The authors point to reports urging greater quantitative disclosure from authoritative voices such as the International Energy Agency and the Natural Gas Subcommittee of the U.S. Secretary of Energy's Advisory Board as evidence of the need for more rigorous reporting.

"We believe there is a great deal of good work being done in the industry to improve environmental performance of hydraulic fracturing operations and also lower their costs," said Steven Heim, a managing director of Boston Common Asset Management. "Absent disclosure however, investors have no way of knowing and crediting those companies making meaningful efforts to adopt best practices and mitigate their impacts on communities and the environment."

The industry most commonly reported on three metrics: whether executive compensation is linked to health, environment, and safety performance (71 percent); use of pipelines to transport water in lieu of diesel trucks to lower air emissions (62 percent); and company policies on use of non-potable water for hydraulic fracturing (46 percent). The report notes that companies are least transparent on their process for systematically identifying and addressing operational impacts on local communities, even though unaddressed community concerns are among the leading drivers of bans and moratoria.

COMPANY	SCORE (OUT OF POSSIBLE 32 POINTS)
Encana Corp. (ECA)	14
Apache Corp. (APA)	10
Ultra Petroleum Corp. (UPL)*	10
Hess Corp. (HES)	8
Noble Energy, Inc. (NBL)	7
Royal Dutch Shell plc (RDS)	7
EOG Resources, Inc. (EOG)	6
Cabot Oil & Gas Corp. (COG)	5
Chesapeake Energy Corp. (CHK)	5
ConocoPhillips Corp. (COP)	5

CONSOL Energy, Inc. (CNX)	5
EQT Corp. (EQT)	5
Anadarko Petroleum Corp. (APC)	4
Devon Energy Corp. (DVN)	4
Chevron Corp. (CVX)	3
Range Resources Corp. (RRC)	3
Talisman Energy, Inc. (TLM)	3
WPX Energy, Inc. (WPX)	3
BHP Billiton Ltd. (BHP)	2
BP plc (BP)	2
Exxon Mobil Corp. (XOM)	2
Occidental Petroleum Corp. (OXY)	2
Southwestern Energy Co. (SWN)	2
QEP Resources, Inc. (QEP)	1

*"Many of the questions in the scorecard seek play-by-play disclosure. Ultra Petroleum reports that it has active completion operations in only one play in 2012 and 2013".

The report also highlights noteworthy practices disclosed by 13 companies. These include: Apache Corp.'s review of its chemical use with the goal of relying solely on safer alternatives designated under US EPA's "Design for the Environment" Program; Anadarko Petroleum Corp.'s use of "green completions" at wells to reduce methane emissions by 2 billion cubic feet annually; Encana's use of treated industrial effluent for fracturing in the Haynesville Shale; and Devon Energy Corp.'s replacing 700 "high-bleed" valves with valves reducing methane emissions by about 50 metric tons of CO2 equivalent per valve. Devon plans to replace 3,000 additional valves, recouping the cost of each within two months.

Legal Pressures related to HF Disclosures

Outlet	**Date**	***Title* / Quotes**
Great Falls Tribune	January 19, 2017	*Fracking chemicals focus of lawsuit seeking more disclosure* A lawsuit against the Board of Oil and Gas seeks to require more disclosure of chemicals used in hydraulic fracturing jobs in Montana, arguing the state's own records fail to provide key information to landowners, but a state official says current rules are sufficient. The lawsuit seeks to reform rules requiring disclosure of the types of chemicals used during "fracking," the process of pumping large volumes of water, sand and chemicals at high pressure to free oil and gas trapped in porous rock. "In Montana there's no ability for the public to scrutinize these trade secret claims," said Katherine O'Brien, an Earthjustice attorney, who is representing the plaintiffs, Montana Environmental Information Center, Natural Resources Defense Council and seven individuals. Operators currently can cite trade secrets to avoid disclosing specific chemicals, she said. In Wyoming, by contrast, oil and gas operators must explain in an affidavit why the chemicals involved are a trade secret, and then the state's oil and gas supervisor makes a ruling whether a trade secret exists, O'Brien said. In Montana, oil and gas operators don't have to prove that the chemical mixture is in fact a trade secret, O'Brien said. "The board's fracking chemical rules in contrast just create an honor system" O'Brien said. In an effort to provide more transparency, the Montana Board of Oil and Gas passed new rules in 2011 that required companies to publicly disclose the generic names of chemicals they pump into the ground to remove oil and gas from rock. "The board feels that the disclosure requirements adopted in 2011 are adequate," said Jim Halvorson, administrator for Montana Board of Oil and Gas. The plaintiffs in the lawsuit petitioned the board in July 2016 to close what they call gaps in the disclosure rules and require operators to disclose specific chemical information before fracking occurs and justify trade secret claims. "The framework for exempting trade secrets under the Board's current disclosure rules contravenes the fundamental purpose of the constitutional right-to-know provision and violates the specific requirements established by the Supreme Court to implement that right when alleged trade secret information is at issue," the lawsuit says. Under current rules, oil and gas operators are not required to share specific ingredients of a fracking operation until after the job is completed, O'Brien said. That's a problem for landowners with property near the operation if they want to educate themselves about the risk, O'Brien said. Also, under a trade secret provision, some chemicals are exempt from disclosure, even to board members, and even after the job is completed, O'Brien said. "The board's longstanding position is we need to know as much information as we can about the well location at the time a well is permitted," said Halvorson of the Board of Oil and Gas. "Because an aquifer at risk from hydraulic fracturing could also be at risk from any number of activities related to drilling and production operations. Isolating a requirement to hydraulic fracturing activities doesn't allow the board the opportunity to review potential risks from any other activities.
The Philadelphia Inquirer	August 26, 2012.	*Long fight over fracking still divides Pa. town* The DEP's investigation eventually concluded that Cabot's poorly constructed wells were to blame. It said Cabot's contractors had failed to properly seal off the wells with concrete. Natural gas was able to migrate upward through voids outside the steel casing that lined the wells, providing a pathway for methane to leak into shallow aquifers and then into private water wells. But the DEP's investigation took a long time to reach a conclusion, and Cabot's response to the residents seemed cold and indifferent. Some Dimock residents, who were angry they had signed leases for small

		sums before the scale of the Marcellus discovery was known, sued Cabot in November 2009, claiming their property and health were affected. The DEP concluded that 18 water wells serving 19 households had been contaminated and ordered Cabot to fix its gas wells. When the repairs failed to eliminate the methane problem, it ordered Cabot to plug three wells in 2010. "The evidence that we had marshalled at that point was in my view pretty overwhelming," said Hanger. Investigators could actually see natural gas bubbling to the surface around the wells. The DEP's experience in Dimock prompted the state to rewrite its well-construction standards, and to enlarge the area that drillers are presumed liable for impairing water quality, from 1,000 feet to 2,500 feet from a gas well. Drillers now typically test water in private wells within a half-mile of their drill sites, to establish a baseline should problems arise. Even after Cabot was forced to repair its wells, methane continued to be a problem with some Dimock residents. The Rendell administration ordered Cabot to pay for a $12 million pipeline to bring fresh water to 19 households. Cabot objected, and so did some residents in Susquehanna County, who saw the project as excessive, and feared they would be left paying the cost. "The pipeline made no sense," said Bill Aileo, a retired Army lawyer who organized a group called Enough Is Enough to protest the expensive pipeline project. The incoming Corbett administration was certain to kill the pipeline project, so Hanger negotiated an alternative agreement with Cabot. The company would set aside $4.1 million to pay each of the 19 households two times the value of their homes and install a water-treatment system to remove methane from their water. The families that weren't part of the lawsuit accepted Cabot's money, but only one of the 11 families in the lawsuit agreed to accept the offer of a water system. "You sort of have to give them the opportunity to fix your water," said Ely, explaining why he was the only litigant to accept the system. "It's all about the water; it's not about the money." Ely walked a visitor last week through the $30,000 system, which is contained in a shed outside his house. Though Cabot tests his system weekly, he still does not trust it. "Once your water is bad, it's hard to get back to drinking it," he said. But extensive testing conducted by the state and the U.S. Environmental Protection Agency found that the water posed no health risks. <u>Though the tests showed the presence of some contaminants - arsenic, barium, sodium, manganese - none of the materials were linked to drilling. The high methane levels can be controlled by a treatment system</u>.
Reuters	September 26, 2017.	*Cabot Oil & Gas Co. [COG.N] has settled a lawsuit filed by two families in Dimock* HARRISBURG, Pa. (Reuters) – <u>Cabot Oil & Gas Co. [COG.N] has settled a lawsuit filed by two families in Dimock, Pennsylvania, who alleged their homes’ drinking water became contaminated with methane not long after the company began drilling for natural gas in 2007</u>. The Ely and Hulbert families initially won $4.2 million in damages in a federal jury trial in Scranton last year, but Magistrate Judge Martin Carlson threw out the verdict as unjustified and ordered the parties to begin settlement talks. The terms of the settlement have not been made public. Leslie Lewis, the New York lawyer who represented the families, declined on Tuesday to comment on the terms. “After nine long years, the plaintiffs are happy and relieved to put the matter behind them,” Lewis told Reuters. Neither Cabot Oil & Gas spokesman George Stark nor the company’s lead lawyer, Stephen Dillard, could be reached for comment on Tuesday.

OA3 – Summary of other Major Changes in State-Level Oil & Gas Regulations related to HF

State	Wastewater Disposal					HF Drilling Standards		
	Discharge Prohibited	**Injection Well**	**Pit Siting**	**Pit Liner**	**Pit Freeboard**	**Well Casing**	**BOP (Blowout Control)**	**Mechanical Integrity Test**
Arkansas			*RULE B-17* 2010/10/31			*RULE B-18* 2006/9/16	*RULE B-16* 2006/10/15	
Colorado		*RULE 905* 2009/4/1	*RULE 603-604* 2013/8/1	*RULE 904* 2009/4/1		*RULE 317* 2014/9/30 (3)		*RULE 326* 2014/9/30
Kansas	*RULE 28-29-1600/28-29-1608* 2013/10/11			*RULE 82-3-601* 2004/4/23		*RULE 82-3-105/106* 2002/10/29		*RULE 82-3-1005* 2004/7/1
Kentucky		*Section 805 KAR 1:110* 2008/2/4					*Section 805 KAR 1:130* 2007/8/9	
Louisiana	*Title 43 Part XIX Subpart 1 Chapter 3 Section 313* 2007/8/1	*Title 43 Part XIX Subpart 1 Chapter 3 Section 315* 2000/12/1		*Title 43 Part XIX Subpart 1 Chapter 3 Section 313* 2007/8/1		*Title 43 Part XIX Subpart 1 Chapter 3 Section 109* 1999/8/1	*Title 43 Part XIX Subpart 1 Chapter 3 Section 111* 2008/12/1	
Mississippi	*RULE 45 SECTION III 7* 1995/7/1				*RULE 45 SECTION III 3-7* 1995/7/1	*RULE 13* 1972/1/1	*RULE 13* 2014/6/16	
Montana		*RULE 36.22.1226* 1992/4/1		*RULE 36.22.1226* 1992/4/1		*RULE 36.22.1001* 1992/4/1	*RULE 36.22.1014* 1992/4/1	*RULE 13* 1996/5/10
New Mexico		*RULE 19.015.0035* 2008/12/1	*RULE 19.15.17.10* 2013/6/28	*RULE 19.15.17.11* 2013/6/28	*RULE 19.15.17.11* 2013/6/28 (2)	*RULE 19.15.16* 2008/12/1		
North Dakota	*RULE 43-02-03-19.2* 2012/4/1					*RULE 43-02-03-21* 2012/4/1	*RULE 43-02-03-23* 2002/7/1	*RULE 43-02-03-22* 2012/4/1
Ohio						*RULE 1501:9-9-03* 2005/8/11		
Oklahoma	*RULE 165:10-7-16* 2010/8/21	*RULE 165:10-5-5* 2009/7/11		*RULE 165:10-7-16* 1999/7/1	*RULE 165:10-7-16* 2008/7/11	*RULE 165:10-3-4* 2011/7/11		*RULE 165:10-3-4* 1981/12/2

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2011/2/14</td><td></td></tr>
<tr><td>Wyoming</td><td></td><td>CHAPTER 4 SECTION 4
2005/1/1</td><td>CHAPTER 4 SECTION 1
2015/6/4</td><td>CHAPTER 4 SECTION 1
2015/6/4</td><td></td><td>CHAPTER 3 SECTION 4
2010/8/17</td><td>CHAPTER 3 SECTION 28
2010/8/17</td><td>CHAPTER 18 SECTION 9
2018/11/13</td></tr>
</table>

(1) The same Section includes an additional provision on the overflow system.
(2) The same Section/Rule/Code includes an additional provision on the leak detections system.
(3) The same Section/Rule includes an additional provision on proximity to water bodies.
(4) Section 3.8 of the same regulation includes an additional provision on proximity to water bodies.

This table presents a summary of other major changes in the O&G state legislations over hydraulic fracturing (HF) along with the respective adoption dates. Besides disclosure rules, there are two major aspects of HF legislations that might influence the environmental impact of HF, namely, wastewater disposal, and HF construction and operating standards. As wastewater disposal and HF standards are two major areas that include various regulations targeting different aspects of HF activities, we further divide them into sub-categories that, to our best knowledge, capture the essence of these regulations. For example, under wastewater disposal rules, we read all the related regulatory changes and identified the most prevalent and relevant changes in the 15 states in the sample, i.e., discharge prohibited (whether discharge or land-spread is allowed with a permit), injection well (whether there are substantial rules regulating injection well usage for wastewater disposal), pit siting (whether there are substantial restrictions to the location of the pits), pit liner (whether pits must be lined), pit freeboard (whether pits must have freeboard). We followed the same procedure to classify the rules on HF standards. We then hand-collected the effective dates of the corresponding sub-category regulatory changes from the regulatory texts either from the official state legislation website or Nexis Uni, a research database that contains the administrative codes, regulatory texts, and regulatory tracking for all U.S. states. The cells in the table record the corresponding regulatory change as well as its effective date. Using the data in this table we build the three variables used in Table 5 in the paper: *HUC10_HF×CUM_WASTEWATER* counts the cumulative number of regulations related to wastewater disposals at a point in time; *HUC10_HF×CUM_HF_STANDARDS* counts the cumulative number of regulations on HF drilling standards; HUC10_HF×CUM_HF_REG combines the two previous counts for regulations related to wastewater disposal and HF drilling standards.

OA4 – Summary of the Trade Secret Regulations

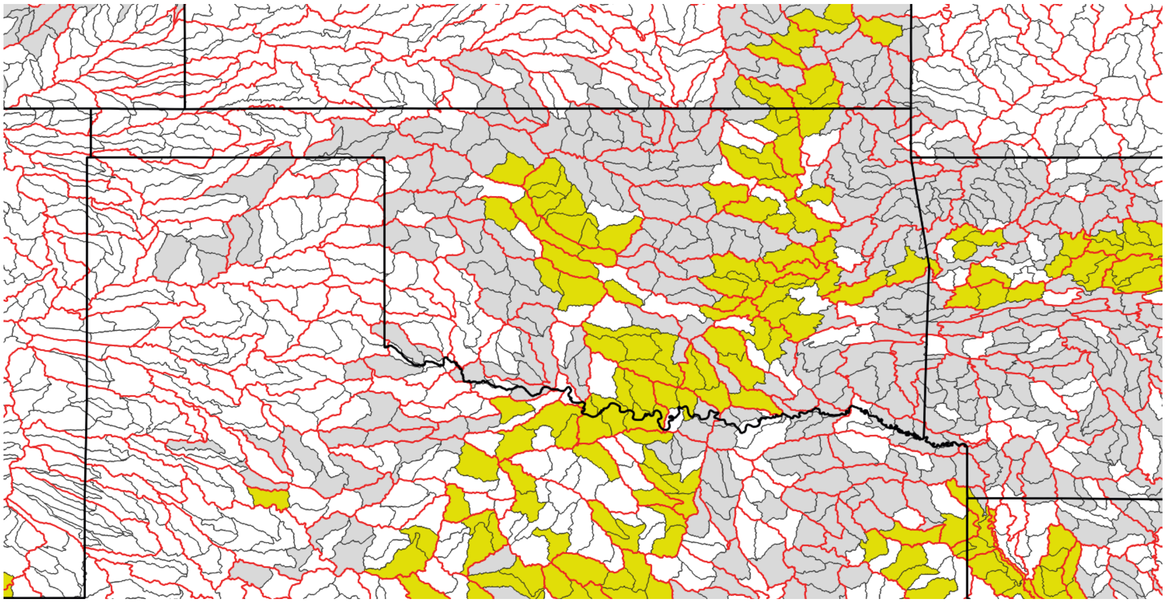
	(1) Submission to claim trade secret	(2) Factual justification	(3) Obligation to provide trade secret information	(4) Process for evaluating trade secret claim	(5) Standards for showing trade secret protection is justified
Arkansas[1]	1	1	1	0	1
Colorado[2]	1	1	0	0	1
Kansas[3]	1	1	0	0	0
Kentucky[4]	1	1	1	0	0
Louisiana[5]	0	0	0	0	0
Mississippi[6]	1	1	0	0	0
Montana[7]	0	0	0	0	0
New Mexico[8]	0	0	0	0	0
North Dakota[9]	1	0	0	0	1
Ohio[10]	1	1	0	0	0
Oklahoma[11]	1	0	0	0	1
Pennsylvania[12]	1	0	0	0	0
Texas[13]	0	0	0	0	1
Utah[14]	0	0	0	0	0
West Virginia[15]	1	0	1	0	0
Wyoming[16]	1	1	1	1	1

1 *Arkansas Oil&Gas Commission Rule B-19*
2 *Colorado Oil&Gas Conservation Commission Rule 205A*
3 *Kansas Admin. Reg. 82-3-1401*
4 *Kentucky Revised Statutes Chapter 353.6604*
5 *Louisiana Administrative Code Title 43, Part XIX, §118.2.a*
6 *Mississippi Oil&Gas Board Rule 1.26*
7 *Mont. Admin. R. 36.22.608, 36.22.1015 & 1016*
8 *New Mexico Code R. 19.15.16.19 (b)*
9 *North Dakota Admin. Code 43-02-03-27.1 (1)(g)&(2)(i)*
10 *Senate Bill 315*
11 *Revised Oklahoma Admin. Code. 165:10-3-10*
12 *Pa. Legis. Serv. 2012-13 (HB 1950) §3222.1*
13 *Texas Admin. Code 3.29*
14 *Utah Admin. Code 649-3-39*
15 *CSR 8-5.6&8-10.1*
16 *Wyoming Oil&Gas Conservation Commission Rules, Chapter 3,45*

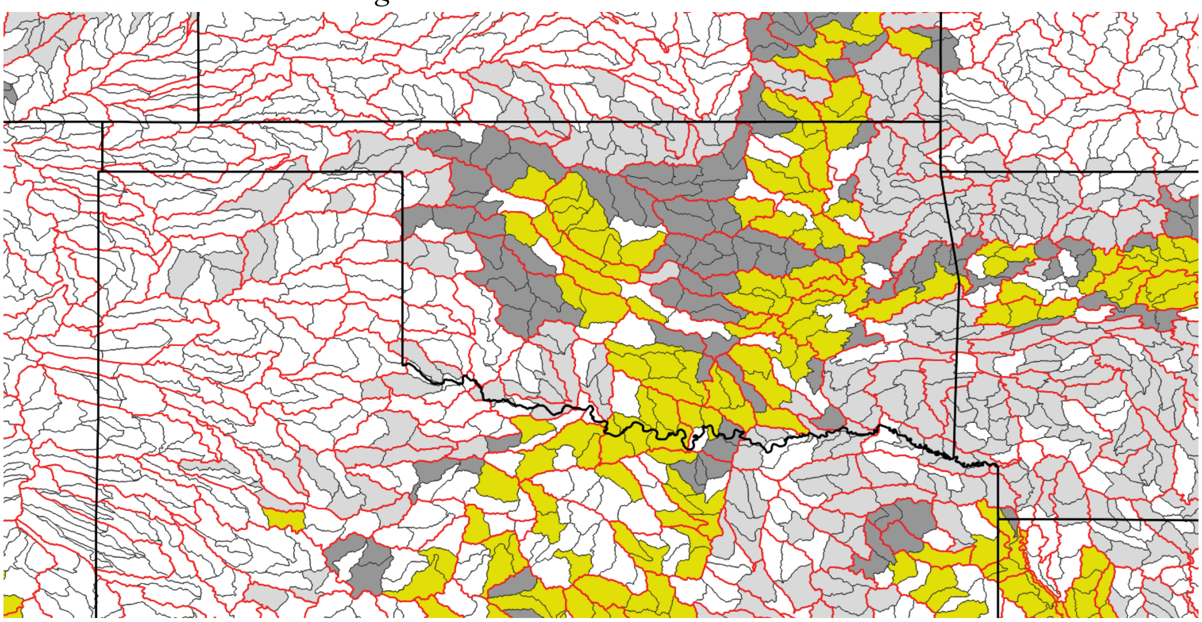
This table presents a summary of the trade secrets on the chemicals used by HF operators. Using McFeeley (2012) and cross-checking with states' regulations, we identify five conditions that vary across states when operators submit the claim for a trade-secret exemption: (1) the trade secret exemption requires the submission of a formal claim request; (2) the submission requires a factual justification; (3) operators have to provide supporting information (for example from suppliers and manufacturers who claim the trade secret); (4) there is a process for evaluating the trade secret claim; (5) operators have to follow specific standards to prove that the trade secret exemption is justified. For example, Arkansas and Colorado both require standards borrowed by the Emergency Planning and Community Right to Know Act.

OB1. Identification Maps

Panel A: Within state design



Panel B: Within sub-basin design



The figure illustrates how our identification strategy exploits variation across treated and control watersheds (HUC10s) using Oklahoma as an example. Panel A visually shows the within-state design. Watersheds with HF in the pre-period (treatment) are in yellow. Watersheds with no HF in the pre-period (control) are in light gray. Watersheds with no water measurements are in white. The black (red) lines depict HUC10 (HUC8) borders.

Panel B visually shows the within-HUC8 design. Watersheds with HF in the pre-period (treatment) are in yellow. Watersheds with no HF in the pre-period (control) are in dark gray. Watersheds with no water measurements are in white. HUC10s that do not contribute to identification in this design are in light gray. The black (red) lines depict HUC10 (HUC8) borders.

OB2. Robustness to Sample Selection Choices

We examine whether our inferences are robust to alternative sample selection choices. Specifically, we re-estimate Eq. (1) for the following alternative samples: (i) Using all HUC10s in treated states; (ii) all HUC10s that are in treated HUC4s with HF activity; (iii) all HUC10s in treated states or HUC4s (essentially combining (i) and (ii)). A HUC4 is treated if it is at least partially in a state that adopts a disclosure mandate. In our main analysis, we exclude control HUC10s from treated HUC4s that are not in a treated state. The results in Table B1 are aligned with the paper's main inferences.

Table B1 – Disclosure Mandates and Water Quality

	All Ions pooled (μg/l)					
	Sample: *HUC10s in Treated States*		Sample: *HUC10s in HUC4s with HF Activity*		Sample: *HUC10s in HUC4s with HF Activity or in Treated States*	
	(1)	(2)	(3)	(4)	(5)	(6)
HUC10_HF×POST	**-0.2492***** **[0.0447]**	**-0.0985***** **[0.0373]**	**-0.1801***** **[0.0396]**	**-0.0959***** **[0.0363]**	**-0.2394***** **[0.0432]**	**-0.0831**** **[0.0330]**
Observations	451,431	417,731	393,512	370,425	522,599	487,793
R-squared	0.949	0.962	0.960	0.970	0.952	0.964
Treatment Sample	HUC10s with HF at least in the pre-disclosure period					
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes

This table reports OLS estimates for the impact of the disclosure mandates on ion concentrations In Columns (1) – (2), the sample includes all HUC10s in treated states. In Columns (3) – (4), the sample includes all HUC10s located over treated sub-regions (HUC4s). In Columns (5) – (6), the sample includes all HUC10s in treated states or treated HUC4s. Standard errors (in parentheses) clustered by watershed (HUC10) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB3. Other Robustness Tests

OB.3.1 Clustering of standard errors

We examine whether our inferences are robust to alternative clustering choices. Specifically, we re-estimate Eq. (1) for the following clustering strategies: (i) HUC8-state level; (ii) state-level. Note that HUC8s can cross state lines. The effects in Table B2 remain statistically significant even with the fairly conservative clustering by state.

Table B2 – Disclosure Mandates and Water Quality

	All Ions pooled (μg/l)			
	Clustering at the HUC8-State Level		*Clustering at the State-Level*	
	(1)	(2)	(3)	(4)
HUC10_HF×POST	**-0.1802***** **[0.0462]**	**-0.0982**** **[0.0459]**	**-0.1802*** **[0.0916]**	**-0.0982*** **[0.0539]**
Observations	334,713	312,294	334,713	312,294
R-squared	0.957	0.969	0.957	0.969
	HUC10s with HF at least in the pre-disclosure period			
Monitoring station FE	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes

This table reports OLS estimates for the impact of the disclosure mandates on ion concentrations The sample includes a treatment sample of HUC10s with HF at least in the pre-disclosure period and a control sample of HUC10s without HF in the pre- and post-disclosure period and located over Sub-Region (HUC4s) in treated states. In Columns (1) – (2), standard errors (in parentheses) clustered by sub-basin (HUC8)-state are reported below the coefficients. In Columns (3) – (4), standard errors (in parentheses) clustered by state are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB.3.2 Truncation of ion concentration measurements

We examine whether our inferences are robust to alternative truncation choices for the ion concentration measurements. Specifically, we re-estimate Eq. (1) for the following truncation choices: (i) we truncate the sample at the 95th percentile per ion at the HUC4 level; (ii) we truncate the sample at the 99th percentile per ion; (iii) we truncate the sample at the 95th percentile per ion. The results in Table B4 are aligned with the paper's main inferences.

Table B4 – Disclosure Mandates and Water Quality

	All Ions pooled (μg/l) truncation at P95 by HUC4		All Ions pooled (μg/l) truncation at P99 over the full sample		All Ions pooled (μg/l) truncation at P95 over the full sample	
	(1)	(2)	(3)	(4)	(5)	(6)
HUC10_HF×POST	**-0.1346***** **[0.0365]**	**-0.0821**** **[0.0373]**	**-0.1433***** **[0.0371]**	**-0.0921**** **[0.0358]**	**-0.1367***** **[0.0371]**	**-0.0767**** **[0.0371]**
Observations	309,748	288,073	324,055	302,164	316,928	295,673
R-squared	0.961	0.972	0.961	0.971	0.960	0.971
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes

This table reports OLS estimates for the impact of the disclosure mandates on ion concentrations. The sample includes a treatment sample of HUC10s with HF in the pre-period and a control sample of HUC10s without HF in the pre- and post-disclosure period and located over sub-regions (HUC4s) in treated states. Standard errors (in parentheses) clustered by watershed (HUC10) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB.3.3 Alternative ways of dealing with missing ion concentration measurements

We examine whether our inferences are robust to alternative ways of dealing with missing ion concentration measurements. Some water measurements are reported as missing in the NWIS and STORET databases with a flag stating that the measurement has been taken, but the concentration value is *below the detection level (BDL)*, *not detected (ND)* or *not reported (NR)*. In our main analyses (V1):

a) We replace a missing measurement value with the numerical value reported in the "Result Detection Condition Text", following Vidic et al. (2013). There are only very few of these assignments in our sample. In the raw data, for Barium, we have 48 observations for which the value has been replaced, for Chloride we have 213 replacements, for Bromide we have 53 replacements, and for Strontium we have 8 replacements;

b) We assign a value of zero to any measurement, for which the "Result Detection Condition Text" shows "Not Detected";

c) We assign a missing value, if the "Result Detection Condition Text" equals "Not Reported" or "Present Below Quantification Limit", but only if condition a) does not apply.[35]

In the second version (V2), we assign missing values to any measurement that has a non-missing "Result Detection Condition Text." This approach basically eliminates all concentrations marked as BDL/LD/ND/NR, which is similar to using only uncensored data, as discussed in Niu et al. (2018). While this approach avoids the use of ambiguous data, it could work in favor of finding results. This is why it is not our preferred version. We use V2 only to gauge the sensitivity of our results to different ways of dealing with BDL/LD/ND/NR measurements.

[35] We do the same for measurements for which the "Result Detection Condition Text" equals "NA", "Present Above Quantification Limit" and "Systematic Contamination". But these cases do not end up in our sample.

In the third version (V3), we also include readings where the database indicates that the ion was present but below the detection limit and code them as zeros. This approach is the most inclusive:

a) Same as V1;

b) We assign a value of zero to any measurement, for which the "Result Detection Condition Text" equals "Not Detected" or "Present Below Quantification Limit";

c) We assign a value of missing if the "Result Detection Condition Text" flag equals to "Not Reported", but only if condition a) does not apply.

We then re-estimate Eq. (1) using V2 and V3. Table B5 shows results in line with our main inferences and suggests that our choice of measurement (V1) for the main analysis is conservative.

Table B5 – Disclosure of Mandates and Water Quality

	All Ions pooled (μg/l)			
	Concentration Version 2		*Concentration Version 3*	
	(1)	(2)	(3)	(4)
HUC10_HF×POST	**-0.0694***** **[0.0168]**	**-0.0553**** **[0.0279]**	**-0.1302***** **[0.0424]**	**-0.0692*** **[0.0475]**
Observations	319,941	298,001	347,922	324,373
R-squared	0.982	0.987	0.961	0.972
Monitoring station FE	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes

This table reports OLS estimates for the impact of the disclosure mandates on ion concentrations using measurements from V2 or V3. The sample includes a treatment sample of HUC10s with HF at least in the pre-disclosure period and a control sample of HUC10s without HF in the pre- and post-disclosure period and located over sub-regions (HUC4s) in treated states. Standard errors (in parentheses) clustered by watershed (HUC10) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB4. Controlling for Agricultural Activity

We provide a robustness test controlling for agricultural activity, which is another source of water pollution. We collect data on the fraction of land devoted to agriculture from the Census of Agriculture (National Agricultural Statistics Service) and compute the fraction of land in a HUC10 devoted to agricultural activity in 2007. Then, we split the treatment sample of HUC10s with HF in the pre-period into two non-overlapping groups based on the sample median of this variable. HUC10s with an above (below) the median level of agriculture are classified in the *High_Agr* group (*Low_Agr* group). Table B6 reports OLS coefficients estimating Eq. (1) and replacing the variable, *POST×HUC10_HF*, with two non-overlapping variables marking observations in the post-disclosure period in the respective group, *High_Agr* (*Low_Agr*). Table B6 suggests that our results do not stem from areas with more agriculture.

Table B6 – HF Activity and Water Quality – Controlling for Agricultural Activity

	Bromide (μg/l) (1)	Chloride (μg/l) (2)	Barium (μg/l) (3)	Strontium (μg/l) (4)	All Ions pooled (μg/l) (5)
POST×HUC10_HF×High_Agr	0.0233 [0.1079]	**-0.2043**** **[0.1026]**	**-0.1177**** **[0.0499]**	0.0032 [0.0336]	**-0.1486**** **[0.0654]**
POST×HUC10_HF×Low_Agr	**-0.1914***** **[0.0681]**	**-0.1813***** **[0.0396]**	**-0.0706*** **[0.0388]**	**-0.0716***** **[0.0260]**	**-0.1486***** **[0.0294]**
Observations	7,333	125,596	49,063	30,226	212,218
R-squared	0.875	0.852	0.794	0.964	0.950
Treatment Sample	HUC10s with HF at least in the pre-disclosure period				
Monitoring station FE	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes
HUC8×Month	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	Yes	Yes	Yes	Yes

This Table reports OLS estimates from an alternative version of Eq. (1) in which we replace the interaction variable, *POST×HUC10_HF,* with two non-overlapping variables marking observations in the post-disclosure period in HUC10s with an above (below) median level of land devoted to agricultural activity, *High_Agr* (*Low_Agr*), in the pre-disclosure period. *HUC10_HF* marks treated watersheds (HUC10s). *POST* is a binary variable marking water quality observations in the post-disclosure period. The sample includes a treatment sample of HUC10s with HF at least in the pre-disclosure period and a control sample of HUC10s without HF in the pre- and post-disclosure period and located over sub-regions (HUC4s) in treated states. Standard errors (in parentheses) clustered by watershed (HUC10) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB5. Disclosure Mandates and Public Pressure

The core idea of the paper is that disclosure regulation creates public pressure, which in turn incentivizes HF operators to change their behaviors. In this section, we provide further evidence that disclosure regulation increases public pressure. The analyses are in the spirit of a first-stage model and show that the disclosure mandates are associated with increases in public pressure. We use two proxies to measure changes in public pressure.

Our first proxy is based on media coverage of HF-related environmental consequences or water impact around the adoption of the disclosure mandates. We identify and download newspaper articles from Lexis-Nexis between January 2005 and December 2016, which contain the following keywords in the headline: "Hydraulic fracturing" and ("*pollut*" or "*health*" or "*contaminat*" or "*environment*" or "*water*") or "*Fracturing*" and ("*pollut*" or "*health*" or "*contaminat*" or "*environment*" or "*water*") or "*Fracking*" and ("*pollut*" or "*health*" or "*contaminat*" or "*environment*" or "*water*") or "*Fracing*" & ("*pollut*" | "*health*" or "*contaminat*" or "*environment*" or "*water*"). Next, we separate local and national newspapers and assign local newspapers to the counties in which each newspaper circulates following Gentzkow and Shapiro (2010). We then count the number of articles by county-month-year and take the natural logarithm. The second proxy is based on state-specific Google search trends for the term "fracking."

We restrict the sample to counties located over shales in the treated states and regress the two proxies on a binary indicator variable marking those months after the disclosure regulation has come into force, *POST,* and county and year-month FEs. The inferences are based on standard errors clustered at the state-level.

Table B7 reports the estimation results. We observe a significant increase in the number of newspaper articles discussing HF as a source of water pollution after the disclosure mandate

(Column (1)). Moreover, the estimated coefficient is virtually unaffected when we control for HF activity (Column (2)) suggesting that the increase in media coverage is due to the new disclosure regime and not driven by an increase in HF activity over time. We observe a greater increase in media coverage in counties where the population is more educated (Columns (3)), which is what we would expect to see.

We obtain similar results using Google search trends.[36] We observe a significant increase in Google searches after the disclosure mandates come into force (Column (4)). Again, the estimated coefficient is virtually unaffected when we control for HF activity (Column (5)) suggesting that the increase in media coverage is due to the new disclosure regime and not driven by an increase in HF activity over time. Lastly, we observe a greater increase in Google searches when the population is more educated (Column (6)), which is reassuring.

Taken together, the results in Table B7 suggest the disclosure mandates increase public pressure. In Section V.E, we then examine whether the water quality effects of the disclosure mandates are larger in areas with greater increases in public pressure to show that mandatory disclosure operates through public pressure.

[36] We do not include county and month×year fixed effects when we use Google search trends as a dependent variable because these trends are standardized by state and time.

Table B7 – Disclosure Mandates and Public Pressure

	Log(1+#newspaper articles)			*Google Searches*		
	(1)	(2)	(3)	(4)	(5)	(6)
POST	**0.1077***** **[0.0270]**	**0.1077***** **[0.0268]**		**27.4992***** **[2.2367]**	**27.4971***** **[2.2459]**	
#WELLS_HF		**0.0013**** **[0.0005]**			0.0018 [0.0561]	
POST_HIGH_EDUC			**0.1690***** **[0.0524]**			**31.6911***** **[2.9368]**
POST_LOW_EDUC			**0.0436*** **[0.0228]**			**22.4456***** **[3.8477]**
Observations	6,732	6,732	6,732	6,732	6,732	6,732
R-squared	0.354	0.355	0.363	0.312	0.312	0.327
	Counties over shales					
County FE	Yes	Yes	Yes	No	No	No
Month×Year FE	Yes	Yes	Yes	No	No	No

This table reports OLS estimates of the impact of the disclosure mandates on public pressure, measured as either media coverage or google searches. The dependent variable in Column (1)–(3) is the logarithm of one plus the number of newspaper articles pointing to HF as a source of water pollution by county-year-month. The dependent variable in Column (4)–(6) are Google searches for the term "fracking". We do not include county or month×year fixed effects in these models since Google searches are standardized by state and time. In Columns (2) and (4) we control for the number of newly fractured HF wells in a county-year-month. In Columns (3) and (6) we replace the *Post* binary variable with two non-overlapping binary variables marking in the post-disclosure period counties with an above (below) the pre-disclosure period median level of education, *POST_HIGH_EDUC* (*POST_LOW_EDUC*). The level of education is the share of the population that has at least a college degree. *POST* is a binary variable marking observations in the post-disclosure period. *#WELLS_HF* is the number of new wells being spudded in a given HUC10-Month-Year. The sample comprises counties over shales. Standard errors (in parentheses) clustered by state are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB6. Patterns in Water Measurement

In this section, we explore patterns in water measurement. Given the increase in public pressure, it would not be surprising if water measurements increase with mandatory disclosure. We re-shape the data at the HUC10-month level and code up a variable counting the number of water quality readings (for any of the four chemicals) in a given month. We assign a value of zero to the HUC10-months with no water readings. Then, we regress the number of water quality readings on *HUC10_HF×POST*. Table B8, Columns (1) and (3) show that, within state, there is an increase in the frequency of water measurement in HUC10s with HF relative to HUC10s without HF. However, as shown in Columns (2) and (4), this association is no longer present in the tighter within-HUC8 design. Next, we add the number of new wells being spudded in a given HUC10-month-year (*#WELLS_HF*). The results suggest that new wells do not systematically increase water measurement. Based on Table B8, it is unlikely that patterns in water measurement play into our main results.

Table B8 – Patterns in Water Measurements

	#readings (1)	#readings (2)	#readings (3)	#readings (4)
HUC10_HF×POST	**0.2187****	0.0099	**0.2122****	0.0055
	[0.0925]	[0.1104]	**[0.0925]**	[0.1107]
#WELLS_HF			0.0266	0.0182
			[0.0169]	[0.0152]
Observations	455,616	432,768	455,616	432,768
R-squared	0.224	0.466	0.224	0.466
HUC10 FE	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes

This table reports OLS estimates from models predicting water measurement at the HUC10-Month-Year level. *#readings* is a variable counting the number of water quality readings (for any of the four chemicals) in a given month. *HUC10_HF* marks treated watersheds (HUC10s). *POST* is a binary variable marking observations in the post-disclosure period. *#WELLS_HF* is the number of new wells being spudded in a given HUC10-month-year. Standard errors (in parentheses) clustered by watershed (HUC10) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB7. WLS to give more weight to areas with more data

Since water quality data can be sparse (see Tables 1 and 2), it is possible that we cannot estimate reliable ion concentration baselines for some geographic areas. As our estimation is at the HUC10 level, we re-estimate Eq. (1) by WLS using as weights the number of HUC10s in each state-year-month (in the models with state×year×month FEs) and the number of HUC10s in each HUC8-year-month (in the models with HUC8×year×month FEs). In this way, we give more weight to areas with more data where ion concentration baselines can be better estimated. Table B9 shows that the results are similar using WLS models.

Table B9 – Disclosure Mandates and Water Quality – WLS

	Bromide (µg/l)		Chloride (µg/l)		Barium (µg/l)		Strontium (µg/l)		All Ions pooled (µg/l)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HUC10_HF×POST	**-0.1559****	0.0655	**-0.1430*****	-0.0812	**-0.0718****	**-0.0564***	**-0.0553****	-0.0398	**-0.1204*****	**-0.0701***
	[0.0729]	[0.1343]	**[0.0436]**	[0.0574]	**[0.0296]**	**[0.0326]**	**[0.0243]**	[0.0313]	**[0.0338]**	**[0.0399]**
Observations	15,783	14,538	188,329	176,729	72,703	65,812	48,536	46,308	325,351	303,387
R-squared	0.835	0.897	0.865	0.895	0.820	0.822	0.962	0.971	0.959	0.967
Treatment Sample	HUC10s with HF activity in the pre-disclosure period									
Full Sample	All HUC10s in sub-regions (HUC4s) in treated states with some HF activity									
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Table B9 reports WLS coefficients estimating Eq. (1). We use as weights either the number of HUC10s in each State-year-month (Columns (1), (3), (5), (7), (9)) or the number of HUC10s in each HUC8-year-month (Columns (2), (4), (6), (8), (10)). The models in Columns (9)-(10) pool all four ion concentrations in one model, as described in Section IV. In Columns (1)-(10), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB8. Endogeneity of Disclosure Adoption Dates

In this section, we explore the potential endogeneity of the adoption dates for the disclosure mandates. We propose four tests. First, we examine whether our results are robust to lagged changes in ion concentrations since states might choose to adopt the disclosure requirements in response to shocks to local water quality. We augment Eq. (1) by including the lagged change of ion concentration at the HUC10 level (i.e., % change in the average ion concentration in a given HUC10 between year $t-1$ and year $t-2$). Table B10 shows that our results continue to hold when we control for lagged changes in ion concentrations.

Second, we examine whether we can predict the relative timing of states' disclosure rules based on variables that reflect prior public pressure, economic and political differences, and HF activity intensity in the state. Such correlations could indicate that the relative timing of the disclosure mandates is not plausibly exogenous. To test this, we compute the difference (in days) between each state's disclosure implementation date and January 2010. We then regress this variable on the state-level differences in the timing of the peak in Google searches (relative to January 2010 or the global minimum between January 2010 and December 2020), income per capita as of 2010, the fraction of people with a college degree as of 2010, employment rate as of 2010, the total number of HF wells fractured up to 2010, an indicator variable marking whether the state was leaning democratic in the 2010 house election. The results in Table B11 do not reveal significant associations, suggesting that it is difficult to predict when states adopt the rules, consistent with the assumption that states' relative timing is plausibly exogenous.

Third, we run a test in the spirit of Altonji, Elder, and Taber (2005). We first identify variables that capture local factors to which lawmakers might respond when introducing the disclosure mandates. We propose the following variables: the monthly fracking-related google searches at the state-level, the monthly number of newspaper articles pointing to HF as a source of water pollution by county, the monthly cumulative number of HF wells in a state, and the number of water readings in a state-year-month. These variables should broadly capture HF-related pressures that lawmakers might have experienced due to HF activity in their state.

Next, we exclude the variable of interest (i.e., *HUC10_HF×POST*) from Eq. (1) and instead add these variables to Eq. (1). We store the predicted values (for the water measurements) from these regressions and then re-estimate Eq. (1) by replacing actual ion concentrations with the predicted values. If our results were largely driven by local factors to which state lawmakers respond, we should see that using the predicted values produces very similar results. However, the results in Table B12 show, especially for the tighter within-HUC8 model, that the predicted values generated with these local factors explain only a small portion of the effect estimated in Table 3 (i.e., roughly 2.2 percent of effect in the within-HUC8 models 10 and 12). In un-tabulated analyses, we also include the controls for other HF regulations (from Table 5) that were adopted within 360 days before or after the respective state's disclosure mandate in the estimation of the predicted values. We obtain similar results.

Four, we employ the methodology proposed by Oster (2019) to more formally assess the role of the local factors to which lawmakers might respond. The key idea of the test proposed by Oster (2019) is that the potential omitted variable bias in a model is proportional to the movement in the coefficient of interest between the baseline model and a model that includes potential *observed* confounders (which in turn are informative about potential *unobserved* confounders), relative to the change in the explanatory power of the two models.

To implement this statistic, we estimate an alternative version of Eq. (1) in which we include the potential confounders considered in Table B12. This regression yields an R-squared$_{\text{controlled}}$ of

0.9548 and a coefficient on *HUC10_HF×POST* (i.e., $\beta_{controlled}$) of –0.1086 (*t*-stat -3.04). We then use these estimates to compute the δ (i.e., relative degree of selection) using the following formula: $\delta = \beta_{controlled} \times (\text{R-squared}_{controlled} - \text{R-squared}_{uncontrolled}) / [(\beta_{uncontrolled} - \beta_{controlled}) \times (\text{R-squared}_{MAX} - \text{R-squared}_{controlled})]$, where $\beta_{uncontrolled}$ and $\text{R-squared}_{uncontrolled}$ are the coefficient on *HUC10_HF×POST* and the R-squared from Table 3 Column (9). We assume an R-squared_{MAX} equal to 0.96. We obtain a δ of 1.75. This value suggests that there would have to be a relatively large degree of selection by unobservables to explain our results, which is reassuring.

Table B10 – Disclosure Mandates and Water Quality – Controlling for Lagged Changes in Water Quality

	Bromide (µg/l)		Chloride (µg/l)		Barium (µg/l)		Strontium (µg/l)		All Ions pooled (µg/l)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HUC10_HF×POST	**-0.1167***	0.0493	**-0.1926*****	**-0.1166****	**-0.0969*****	**-0.0589***	**-0.0448****	-0.0382	**-0.1509*****	**-0.0928****
	[0.0685]	[0.1193]	**[0.0551]**	**[0.0517]**	**[0.0352]**	**[0.0346]**	**[0.0223]**	[0.0290]	**[0.0386]**	**[0.0363]**
Δ Ions Concentrations[t-1]	**0.4120****	**0.2164****	0.0938	0.0508	0.0009	0.0008	**-0.0020****	**-0.0022*****	0.0031	0.0015
	[0.2027]	**[0.0993]**	[0.0718]	[0.0538]	[0.0008]	[0.0007]	**[0.0010]**	**[0.0005]**	[0.0024]	[0.0011]
Observations	15,783	14,538	188,329	176,729	72,703	65,812	48,536	46,308	325,351	303,387
R-squared	0.860	0.916	0.865	0.903	0.834	0.867	0.968	0.976	0.961	0.971
Treatment Sample	HUC10s with HF activity in the pre-disclosure period									
Full Sample	All HUC10s in sub-regions (HUC4s) in treated states with some HF activity									
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

Table B10 reports OLS coefficients estimating Eq. (1) controlling for lagged changes in ion concentration. The models in Columns (9)-(10) pool all four ion concentrations in one model, as described in Section IV. In Columns (1)-(10), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure period that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. *Δ Ions Concentrations[t-1]* is % change in the average ion concentration in a given HUC10 between year t – 1 and year t – 2. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table B11 – Analysis of the Relative Timing of the Adoption Dates

	Disclosure Timing (1)	Disclosure Timing (2)	Disclosure Timing (3)	Disclosure Timing (4)
GS_peak relative_2010	0.1727		-0.0246	
	[2.1635]		[2.1972]	
GS_peak relative_min		-0.8960		-0.9549
		[2.8306]		[2.8564]
Income_per_Capita_2010	-0.6387	-0.9785	-2.4775	-2.6264
	[5.3356]	[4.8012]	[5.7718]	[5.1725]
College_2010	1.4989	1.9195	0.9993	1.2207
	[5.2509]	[4.7582]	[5.3349]	[4.8617]
Democratic_House_2010	30.0562	31.7567	36.8161	39.5207
	[55.6495]	[55.2309]	[56.7358]	[56.3728]
Employment_Rate_2010	-232.3729	-215.9353	-102.3224	-88.9070
	[489.7814]	[486.3205]	[515.9006]	[510.1809]
HF_Total_Count_2010			0.0031	0.0031
			[0.0035]	[0.0035]
Observations	16	16	16	16
R-squared	0.176	0.183	0.243	0.252

This table reports OLS estimates from models predicting timing of the disclosure rules (relative to Jan 2010). *Disclosure Timing* is the difference (in days) between each state disclosure implementation date and January 2010; *GS_peak relative_2010* is state-level difference in timing of peak in Google searches relative to the January 2010; *GS_peak relative_min* is state-level difference in timing of peak in Google searches relative to the global minimum between January 2010 and December 2020; *Income_per_Capita_2010* is the state-level income per capita as of 2010; *College_2010* is the state-level fraction of people with a college degree as of 2010; *Democratic_House_2010* is dummy marking whether the state is leaning democratic in 2010 house election; *Employment_Rate_2010* is the state-level employment rate as of 2010; *HF_Total_Count_2010* is total number of HF wells fractured up to 2010. Standard errors (in parentheses) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table B12 – Gauging the Endogeneity of Adoption Dates (in spirit of Altonji et al. 2005)

.	All Ions pooled (μg/l) (1)	$\widehat{\text{All Ions}}$ pooled (μg/l) (2)	All Ions pooled (μg/l) (3)	$\widehat{\text{All Ions}}$ pooled (μg/l) (4)	All Ions pooled (μg/l) (5)	$\widehat{\text{All Ions}}$ pooled (μg/l) (6)	All Ions pooled (μg/l) (7)	$\widehat{\text{All Ions}}$ pooled (μg/l) (8)
HUC10_HF×GS_HF	**-0.0011*****		-0.0003		**-0.0009****		-0.0003	
	[0.0004]		[0.0005]		**[0.0004]**		[0.0005]	
HUC10_HF×Local Media Coverage	-0.0074		0.0086		0.0057		0.0100	
	[0.0295]		[0.0562]		[0.0325]		[0.0574]	
HUC10_HF×CUM_WELLS_HF	**-0.0002***		0.0002		-0.0001		0.0002	
	[0.0001]		[0.0001]		[0.0001]		[0.0001]	
HUC10_HF×#Readings	**0.0004****		0.0004		**0.0004****		0.0004	
	[0.0002]		[0.0002]		**[0.0002]**		[0.0002]	
HUC10_HF×POST		**-0.0316*****		-0.0017		**-0.0236*****		-0.0015
		[0.0017]		[0.0018]		**[0.0013]**		[0.0018]
Observations	325,351	325,351	303,387	303,387	211,273	211,273	198,258	198,258
R-squared	0.961	0.995	0.971	0.999	0.962	0.994	0.972	0.998
Coef. *HUC10_HF×POST* (Table 3)		**-0.1509*****		**-0.0928****		**-0.1476*****		**-0.0925****
Treatment Sample	HUC10s with HF activity in the pre-disclosure period							
Full Sample	All HUC10s in sub-regions (HUC4s) in treated states with some HF activity				HUC10s over shales in treated states			
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	Yes	No	No	Yes	Yes	No	No
HUC8×Month	Yes	Yes	No	No	Yes	Yes	No	No
HUC8×Month×Year FE	No	No	Yes	Yes	No	No	Yes	Yes

This table reports OLS estimates from a test in the spirit of Altonji, Elder, and Taber (2005). In Columns (1), (3), (5), (7) we estimate an alternative version of Eq. (1) where we add the following variables: the monthly fracking-related google searches at the state-level (*GS_HF*); the monthly number of newspaper articles pointing to HF as a source of pollution by county (*Local Media Coverage*); the monthly cumulative number of HF wells in a state (*CUM_WELLS_HF*); the number of water readings in a state-year-month (*#Readings*). In Columns (2), (4), (6), (8) we re-estimate Eq. (1) by replacing Ions concentration measures with predicted values from Columns (1), (3), (5), (7). *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB9. Robustness Tests for Staggered Diff-in-Diff Analyses with Heterogeneous Effects

A recent literature in econometrics (D'Chaisemartin and D'Haultfoeuille, 2022) highlights that difference-in-differences (DiD) analyses with two-way fixed effects (one for time and one for group) can produce biased estimates in the presence of heterogeneous treatment effects. With staggered treatments, the problem arises because DiD estimates based on two-way fixed effects are essentially weighted averages of many comparisons, including those that use post-treatment observations from earlier treatments as controls for later-treated observations, and vice versa. Heterogeneity in treatment effects can lead to negative weights attached to specific group-period estimates. We thus assess whether our inferences are affected by these potential issues, considering that Table 11 documents heterogeneous treatment effects across areas.

To gauge this issue and circumvent the comparison problem, we employ a "stacked" regression approach proposed by Cengiz et al. (2019). Specifically, we estimate Eq. (1) 16 × 2 times (i.e., two per each state) using two alternative control samples: (i) control HUC10s in the state; (ii) all control HUC10s (across all states). This approach exploits only not-yet treated watersheds and never-treated watersheds as controls. Already-treated watersheds are removed from the sample. We find that the averaged coefficients from these regressions are, if anything, larger than those reported in Table 3. Moreover, the weighted averaged coefficients from these regressions (using as weights the numbers of HUC10s in the state) are very similar to those reported in Table 3.

To further explore the issue, we execute the diagnostic test proposed by de Chaisemartin and D'Haultfoeuille (2020). When estimating the weights of the group-period clusters for model 9 (10) in Table 3, we find that 792 of the 2,709 ATTs receive a negative weight (1,450 out of 13,763 ATTs in the within-HUC8 model). We investigate the source of the negative weights and find that they are particularly frequent after 2016 (>50 percent). As all states adopted their mandates before

2016, we can remove years after 2016 from the analysis. After removing these later years, only 305 ATTs out of 2,790 receive negative weights in the within-state model, which sum to only -0.027. For the within-HUC8 model, the number drops to 457 out of 13,763, which sum to -0.011. Reassuringly, our main results in Table 3 and inferences do not change when excluding years after 2016.

OB10. Changes in the Dissemination of HF Disclosures via FracFocus

To link the improvements in water quality to the adoption of the disclosure rules, we exploit inter alia changes in the dissemination of the HF disclosures via FracFocus (see Section V.E). After the initial creation in 2011, FracFocus has implemented several changes to its website to improve the dissemination of the HF disclosures. We identify three major changes during our sample period. In June 2013, the release of FracFocus 2.0 allows "users to more efficiently search for well site chemical information". In July 2015, FracFocus starts releasing disclosure data to the public in machine-readable (SQL) format. In June 2016, the release of FracFocus 3.0 provides a stronger "validation processes to improve data integrity, a new format for reporting company data entry, and newly designed forms to improve the company and regulatory agency user experiences when checking and completing disclosures." We exploit each of these three changes and examine whether these changes are associated with further improvements in water quality (Table 11 and Section V.E.).

OC1. Descriptive Information on the Disclosed Chemicals used in Fracking Fluids

The table below reports the most common hazardous chemicals reported in the disclosures for HF fluids (Chloride-related hazardous chemicals are reported in **bold**). Hazardous chemicals are those (i) regulated as primary contaminants by the Safe Drinking Water Act; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on HF operations (USEPA, 2012a, 2014).

Table C1 – Most Common Hazardous Chemicals in the Disclosure for HF Fluids

Chemical name	Toxicology
1,4-dioxane	Dioxane is irritating to the eyes and respiratory tract. Exposure may cause damage to the central nervous system, liver and kidneys. Dioxane is classified by the National Toxicology Program as "reasonably anticipated to be a human carcinogen". It is also classified by the IARC as a Group 2B carcinogen: *possibly carcinogenic to humans* because it is a known carcinogen in other animals. The United States Environmental Protection Agency classifies dioxane as a probable human carcinogen, and a known irritant at concentrations significantly higher than those found in commercial product.
Acrylamide	Acrylamide is classified as an extremely hazardous substance in the United States as defined in Section 302 of the U.S. Emergency Planning and Community Right-to-Know Act (42 U.S.C. 11002) and is subject to strict reporting requirements by facilities which produce, store, or use it in significant quantities. Acrylamide is considered a potential occupational carcinogen by U.S. government agencies and classified as a Group 2A carcinogen by the IARC. The Occupational Safety and Health Administration and the National Institute for Occupational Safety and Health have set dermal occupational exposure limits at 0.03 mg/m^3 over an eight-hour workday.
Benzyl chloride	Benzyl chloride is an alkylating agent. Indicative of its high reactivity (relative to alkyl chlorides), benzyl chloride reacts with water in a hydrolysis reaction to form benzyl alcohol and hydrochloric acid. In contact with mucous membranes, hydrolysis produces hydrochloric acid. Thus, benzyl chloride is a lachrymator and has been used in chemical warfare. It is also very irritating to the skin. It is classified as an extremely hazardous substance in the United States as defined in Section 302 of the U.S. Emergency Planning and Community Right-to-Know Act (42 U.S.C. 11002) and is subject to strict reporting requirements by facilities which produce, store, or use it in significant quantities.
Calcium chloride anhydrous	Although non-toxic in small quantities when wet, the strongly hygroscopic properties of the non-hydrated salt present some hazards. Calcium chloride can act as an irritant by desiccating moist skin. Solid calcium chloride dissolves exothermically, and burns can result in the mouth and esophagus if it is ingested. Ingestion of concentrated solutions or solid products may cause gastrointestinal irritation or ulceration. Consumption of calcium chloride can lead to hypercalcemia.
Chlorine dioxide	Chlorine dioxide is toxic, and limits on human exposure are required to ensure its safe use. The United States Environmental Protection Agency has set a maximum level of 0.8 mg/L for chlorine dioxide in drinking water. The Occupational Safety and Health Administration (OSHA), an agency of the United States Department of Labor, has set an 8-hour permissible exposure limit of 0.1 ppm in air (0.3 mg/m^3) for people working with chlorine dioxide.

Choline chloride	Irritating to eyes, respiratory system and skin. Toxic to aquatic organisms. Accidental ingestion of the material may be damaging to the health of the individual. Nausea, vomiting, gastro-intestinal discomfort and diarrhea have been reported after large doses of choline.
Cupric chloride	Cupric chloride can be toxic. Only concentrations below 5 ppm are allowed in drinking water by the US Environmental Protection Agency.
Dazomet	Dazomet is irritating to the eyes and its degradation product, MITC, is a dermal sensitizer. Dazomet is very toxic to aquatic organisms, and acutely toxic to mammals. Exposure to dazomet can occur through several means; interaction with unincorporated granules, inhalation of its decomposition product, MITC, and/or water runoff.
Didecyl dimethyl ammonium chloride	In mice this disinfectant was found to cause infertility and birth defects when combined with Alkyl (60% C14, 25% C12, 15% C16) dimethyl benzyl ammonium chloride (ADBAC). These studies contradict the older toxicology data set on quaternary ammonia compounds which was reviewed by the U.S. Environmental Protection Agency (U.S. EPA) and the EU Commission.
Dimethylformamide	Reactions including the use of sodium hydride in DMF as a solvent are somewhat hazardous; exothermic decompositions have been reported at temperatures as low as 26 °C. On a laboratory scale any thermal runaway is (usually) quickly noticed and brought under control with an ice bath and this remains a popular combination of reagents.
Ethylene glycol	Ethylene glycol has relatively high mammalian toxicity when ingested, roughly on par with methanol. Upon ingestion, ethylene glycol is oxidized to glycolic acid, which is, in turn, oxidized to oxalic acid, which is toxic. It and its toxic byproducts first affect the central nervous system, then the heart, and finally the kidneys. Ingestion of sufficient amounts is fatal if untreated. Several deaths are recorded annually in the U.S. alone.
Ethylene glycol mono-n-butyl ether	2-Butoxyethanol has a low acute toxicity, with LD_{50} of 2.5 g/kg in rats. Laboratory tests by the U.S. National Toxicology Program have shown that only sustained exposure to high concentrations (100–500 ppm) of 2-butoxyethanol can cause adrenal tumors in animals. OSHA does not regulate 2-butoxyethanol as a carcinogen.
Ehylene oxide	Ethylene oxide causes acute poisoning, accompanied by a variety of symptoms. Central nervous system effects are frequently associated with human exposure to ethylene oxide in occupational settings. Headache, nausea, and vomiting have been reported. Peripheral neuropathy, impaired hand-eye coordination and memory loss have been reported in more recent case studies of chronically-exposed workers at estimated average exposure levels as low as 3 ppm (with possible short-term peaks as high as 700 ppm). The metabolism of ethylene oxide is not completely known. Data from animal studies indicate two possible pathways for the metabolism of ethylene oxide: hydrolysis to ethylene glycol and glutathione conjugation to form mercapturic acid and meththio-metabolites. Ethylene oxide easily penetrates through ordinary clothing and footwear, causing skin irritation and dermatitis with the formation of blisters, fever and leukocytosis.
Formaldehyde	In view of its widespread use, toxicity, and volatility, formaldehyde poses a significant danger to human health. In 2011, the US National Toxicology Program described formaldehyde as "known to be a human carcinogen". The CDC considers formaldehyde as a systemic poison. Formaldehyde poisoning can cause permanent changes in the nervous system's functions.
Formic acid	Formic acid has low toxicity (hence its use as a food additive), with an LD_{50} of 1.8 g/kg (tested orally on mice). The concentrated acid is corrosive to the skin. Formic acid is readily metabolized and eliminated by the body. Nonetheless, it has specific toxic effects; the formic acid and formaldehyde produced as metabolites of methanol are responsible for

	the optic nerve damage, causing blindness, seen in methanol poisoning. Chronic exposure in humans may cause kidney damage. Another possible effect of chronic exposure is development of a skin allergy that manifests upon re-exposure to the chemical. Concentrated formic acid slowly decomposes to carbon monoxide and water, leading to pressure buildup in the containing vessel. The hazards of solutions of formic acid depend on the concentration. The principal danger from formic acid is from skin or eye contact with the concentrated liquid or vapors. The U.S. OSHA Permissible Exposure Level (PEL) of formic acid vapor in the work environment is 5 parts per million parts of air (ppm).
Hydrochloric acid	Being a strong acid, hydrochloric acid is corrosive to living tissue and to many materials, but not to rubber. Typically, rubber protective gloves and related protective gear are used when handling concentrated solutions.
Isopropyl alcohol	Isopropyl alcohol vapor is denser than air and is flammable, with a flammability range of between 2 and 12.7% in air. Isopropyl alcohol causes eye irritation and is a potential allergen. Isopropyl alcohol, via its metabolites, is somewhat more toxic than ethanol, but considerably less toxic than ethylene glycol or methanol. Death from ingestion or absorption of even relatively large quantities is rare. Both isopropyl alcohol and its metabolite, acetone, act as central nervous system (CNS) depressants. Poisoning can occur from ingestion, inhalation, or skin absorption. Symptoms of isopropyl alcohol poisoning include flushing, headache, dizziness, CNS depression, nausea, vomiting, anesthesia, hypothermia, low blood pressure, shock, respiratory depression, and coma. Overdoses may cause a fruity odor on the breath as a result of its metabolism to acetone. Isopropyl alcohol does not cause an anion gap acidosis, but it produces an osmolal gap between the calculated and measured osmolalities of serum, as do the other alcohols. Isopropyl alcohol is oxidized to form acetone by alcohol dehydrogenase in the liver and has a biological half-life in humans between 2.5 and 8.0 hours.
Magnesium nitrate	May cause irritation of the digestive tract. May be harmful if swallowed. Ingestion of nitrate containing compounds can lead to methemoglobinemia. Inhalation: Causes respiratory tract irritation.
Methyl isobutyl ketone	Exposure to high concentrations can cause you to feel dizzy and lightheaded, and to pass out. Prolonged contact can cause a skin rash, dryness and redness. Methyl Isobutyl Ketone may damage the liver and kidneys.
Naphthalene	Exposure to large amounts of naphthalene may damage or destroy red blood cells, most commonly in people with the inherited condition known as glucose-6-phosphate dehydrogenase (G6PD) deficiency, which over 400 million people suffer from. Humans, in particular children, have developed the condition known as hemolytic anemia, after ingesting mothballs or deodorant blocks containing naphthalene. Symptoms include fatigue, lack of appetite, restlessness, and pale skin. Exposure to large amounts of naphthalene may cause confusion, nausea, vomiting, diarrhea, blood in the urine, and jaundice (yellow coloration of the skin due to dysfunction of the liver). The International Agency for Research on Cancer (IARC) classifies naphthalene as possibly carcinogenic to humans and animals (Group 2B). Under California's Proposition 65, naphthalene is listed as "known to the State to cause cancer". A probable mechanism for the carcinogenic effects of mothballs and some types of air fresheners containing naphthalene has been identified. US government agencies have set occupational exposure limits to naphthalene exposure. The Occupational Safety and Health Administration has set a permissible exposure limit at 10 ppm (50 mg/m^3) over an eight-hour time-weighted

	average. The National Institute for Occupational Safety and Health has set a recommended exposure limit at 10 ppm (50 mg/m^3) over an eight-hour time-weighted average, as well as a short-term exposure limit at 15 ppm (75 mg/m^3). Naphthalene's minimum odor threshold is 0.084 ppm for humans.
Phosphoric acid	Phosphoric acid is not a strong acid. However, at moderate concentrations phosphoric acid solutions are irritating to the skin. Contact with concentrated solutions can cause severe skin burns and permanent eye damage. A link has been shown between long-term regular cola intake and osteoporosis in later middle age in women (but not men).
Sulfuric acid	Sulfuric acid can cause very severe burns, especially when it is at high concentrations. In common with other corrosive acids and alkali, it readily decomposes proteins and lipids through amide and ester hydrolysis upon contact with living tissues, such as skin and flesh. In addition, it exhibits a strong dehydrating property on carbohydrates, liberating extra heat and causing secondary thermal burns. Accordingly, it rapidly attacks the cornea and can induce permanent blindness if splashed onto eyes. If ingested, it damages internal organs irreversibly and may even be fatal.
Titanium dioxide	Titanium dioxide dust, when inhaled, has been classified by the International Agency for Research on Cancer (IARC) as an IARC Group 2B carcinogen, meaning it is *possibly carcinogenic to humans*.
Xylenes	Xylene is flammable but of modest acute toxicity, with LD_{50} ranges from 200 to 5000 mg/kg for animals. Oral LD_{50} for rats is 4300 mg/kg. The principal mechanism of detoxification is oxidation to methylbenzoic acid and hydroxylation to hydroxylene. The main effect of inhaling xylene vapor is depression of the central nervous system (CNS), with symptoms such as headache, dizziness, nausea and vomiting. At an exposure of 100 ppm, one may experience nausea or a headache. At an exposure between 200 and 500 ppm, symptoms can include feeling "high", dizziness, weakness, irritability, vomiting, and slowed reaction time.

Table C2 – Descriptive Statistics for the Chemical Variables used in Table 9

Variables	N	Mean	p25	p50	p75	SD
All Hazardous Chemicals	15,608	0.0096	0.0002	0.0015	0.0044	0.0401
Chloride-related Chemicals	15,608	0.0045	0.0000	0.0009	0.0031	0.0259

Table OC2 reports descriptive statistics on the variables used in Table 9. The variables are constructed at the HUC10 level, averaging over all HF well disclosures for each HUC10-month-year. We compute averages for the amount of all hazardous chemicals, chloride-related chemicals, respectively. For each HF well, we scale the respective amount by the total amount of fluids injected. Hazardous chemicals are those (i) regulated as primary contaminants by the Safe Drinking Water Act; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on HF operations (USEPA, 2012a, 2014). For the pre-period, we use voluntary disclosures to calculate HUC10-month-year averages, following Fetter (2017).

OC2. Descriptive Statistics for the Spill Data

The table below reports descriptive statistics for the variables used in Table 10. Our sample includes 2,667 spills from Colorado, North Dakota, New Mexico and Pennsylvania between January 2005 and December 2015. We only retain spills of HF chemicals and wastewater.

Table C3. Descriptive Statistics for the Spill Data used in Table 10

Variables	N	Mean	p25	p50	p75	SD
All incidents	7,562	0.172	0.000	0.000	0.000	0.413
Wastewater disposal incidents	6,440	0.093	0.000	0.000	0.000	0.283

Table OC3 reports descriptive statistics for the dependent variables used in Table 10. *All incidents* is the logarithm of one plus the number of HF-related incidents in a given HUC10-month-year. *Wastewater disposal incidents* is the logarithm of one plus the number of disposal of wastewater incidents in a given HUC10-month-year.

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