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

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This draft: December 2021

**Abstract**

The rise of shale gas and tight oil development has triggered a major debate about hydraulic fracturing (HF). In an effort to mitigate risks from HF in unconventional development, many U.S. states have introduced disclosure mandates for HF fluids. In this paper, we study the effects of this important regulatory initiative on HF activity and its environmental impact. We find significant improvements in water quality, examining salts that are considered signatures for HF impact, after the disclosure mandates are introduced. We document effects along the extensive margin (less HF activity) and the intensive margin (less per-HF well impact). Most of the improvement comes from the intensive margin. Supporting this interpretation, we find that, after the introduction of disclosure, operators pollute less per unit of production, use fewer toxic chemicals, and that there are fewer spills related to the handling of HF fluids and wastewater. We also explore possible mechanisms through which disclosure regulation can be effective and find that public pressure likely plays an important role. Taken together, our empirical assessment of a major regulatory initiative for HF provides novel evidence on how disclosure mandates can help to internalize negative and fairly widespread external effects.

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

*Key Words:* Reporting regulation, Real effects, Transparency, Pollution, Sustainability, Corporate Social Responsibility, Externalities, Unconventional oil & gas development, Fracking

* We would like to thank Marianne Bertrand, Thomas Covert, Michael Greenstone, Ryan Kellogg, Chris Hansen, Matthias Breuer, Susan Brantley, Joseph Shapiro, Thomas Bourveau, and workshop participants at Chicago Booth Micro Lunch, Goethe University Frankfurt, Columbia Business School, University of Mannheim, Bocconi and Ludwig-Maximilians-Universität München. We also gratefully acknowledge the excellent research assistance of Tom Kim, Igor Kuznetsov, Alessandro Maimone, Fabian Nagel, Christopher Nance, Claudia Serra, and Zirui Song.

## 1. Introduction

Unconventional development of shale gas and tight oil combines horizontal drilling with hydraulic fracturing (HF), which is the high-pressure injection of water mixed with chemical additives and propping agents like sand to create fractures in low-permeability formations, allowing gas or oil to flow. Some view HF as the most important change in the energy sector since the introduction of nuclear energy, as it has dramatically increased U.S. energy production and lowered energy prices for consumers (e.g., Mason *et al.*, 2015, Bartik *et al.*, 2019, Black *et al.*, 2021). But the rise of HF has also triggered a major public debate about associated health and environmental risks, including air and water pollution (e.g., Jackson *et al.*, 2014, Currie *et al.*, 2017). Chief among them are concerns about the HF fluids (e.g., EPA, 2016, Vengosh *et al.*, 2017) and the large amounts of wastewater generated by HF due to their potential impact on water quality (Vidic *et al.*, 2013, Vengosh *et al.*, 2014, Bonetti *et al.*, 2021).

In an effort to mitigate these concerns and potential water pollution, 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 the composition of the HF fluids, including the chemicals used.[1] Considering that HF is exempt from the Underground Injection Control provisions of the Safe Drinking Water Act (SDWA), the disclosure rule was hailed as an important step in regulating the industry, although many voiced concerns about its effectiveness in making HF safer (e.g., McFeeley, 2012, Tiemann and Vann, 2015). Our study provides the first empirical assessment of these state disclosure rules for HF fluids on drilling activity and surface water pollution. Such an assessment is important given the environmental and social costs associated with water pollution (Entrekin *et al.*, 2011, Keiser and Shapiro, 2019a, Keiser and Shapiro, 2019b, Hill and Ma, 2021).

[1] State rules vary but generally regulate the information about the HF fluids that must be disclosed (e.g., ingredient name, chemical abstract service (CAS) number, concentration in the fluid, supplier name, and trade name), what trade secret exemptions, if any, are given, when and where the disclosure must be made.

The states' use of disclosure rules to address environmental externalities from HF is in line with a general trend towards using disclosure regulation as a policy tool (Fung *et al.*, 2007, Dranove and Jin, 2010, Leuz and Wysocki, 2016). This push is particularly prevalent in the area of corporate social responsibility and sustainability (Christensen *et al.*, 2021). The underlying rationale is that disclosure regulation creates transparency about corporate impacts, say on the environment, which in turn enables stakeholders or the general public to impose additional costs on polluting firms.[2] In other words, the goal is to impose an implicit tax on polluting firms via disclosure, which in turn provides incentives to reduce pollution or to invest in cleaner practices or technologies (Pigou, 1920, Baumol, 1972, Baumol and Oates, 1988, Aghion *et al.*, 1998, Goolsbee, 2004, Acemoglu *et al.*, 2012).[3] At present, however, there is still limited evidence on the extent to which mandated disclosure achieves this goal as well as its mechanism, especially when it comes to behaviors with widespread negative externalities. We investigate these issues for disclosure regulation of HF fluids and surface water pollution.

The disclosure rules for HF wells were imposed by states at different points in time allowing us to perform staggered difference-in-differences analyses with respect to water quality and drilling activity. Although it might seem natural to analyze changes in the composition of HF fluids around the introduction of the disclosure rules, this analysis is not feasible because pre-disclosure information on the HF fluids is not available for most wells.[4] For this reason, we use water quality data to examine changes in the environmental impact of unconventional oil and gas development induced by the states' HF disclosure rules. The scientific basis for this analysis is grounded on several recent studies documenting the impact of HF wells and spills on water quality (Hill and Ma, 2017, Agarwal *et al.*, 2020, Bonetti *et al.*,

2 In the Online Appendix, we provide anecdotal evidence on how HF disclosure can impose costs on operators.

3 There are several margins along which HF well operators can reduce water pollution. For instance, they can reduce drilling, substitute less hazardous chemicals, handle wastewaters in safer ways, etc.

4 Some operators provided this information voluntarily, which we exploit in one of our analyses. However, the sample of voluntary disclosures is limited and likely selected. See also Fetter et al. (2018).

2021).

Our sample comprises a large geo-coded database of 139,396 HF wells from 14 states and 299,654 surface water-quality observations from 1,913 watersheds (HUC10s)[5] 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). We use these four ions because they 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 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).

We estimate panel regressions with monitoring station fixed effects to control for differences in local water quality. In addition, we use state-year-month fixed effects or alternatively HUC8-year-month fixed effects. Thus, the identification of the disclosure effects comes from differences in the pre- and post-disclosure evolution of ion concentrations in watersheds (HUC10s) with HF activity in the pre-disclosure period and control watersheds without such HF activity that are in the same state or the same subbasin (HUC8). To further reduce the degree of heterogeneity between treatment and control watersheds, we also estimate models restricting 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

[5] 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.

concentrations in watersheds with HF activity, the estimated coefficients correspond to watershed-level decreases in chemical concentrations of 7,999.12 μg/l for $Cl^{-}$, 6.21 μg/l for Ba, and 19.78 μg/l for Sr. These effects are economically significant, ranging from around 4.4 percent for Sr to 16.6 percent for $Cl^{-}$.

We do not find similar declines when we examine three other water quality proxies (dissolved oxygen, phosphorus and fecal coliforms) that are not as indicative of HF-related impacts. Their concentration levels could be related to other economic activities that impact surface water, such as agriculture, and hence this analysis gauges how well our model controls for economic activity related to HF as well as other potential confounds. We also examine water quality changes around the HF disclosure rules for watersheds with conventional drilling in the pre-period. As expected, the estimated effects do not mimic the results for HF wells. Additionally, we search for and code other state regulatory changes that apply to HF activity and could affect water quality as well. For instance, there are rules for wastewater disposal (e.g., pit siting and lining) and HF drilling standards (e.g., well casing and blowout preventer). The concern is that these other regulatory changes overlap with the disclosure rules and confound our estimates. However, we find that controlling for these other HF regulations, individually or jointly, does not alter our inferences for HF disclosure regulation.

Next, we analyze the margins along which HF operators adjust their practices to shed more light on how disclosure regulation improves water quality. Specifically, we examine whether the documented improvements come from changes in HF drilling activity (extensive margin) and/or changes in drilling practices and technology reducing the per-well impact on water quality (intensive margin). With respect to the former, we study the effect of disclosure regulation on HF well entry per watershed and month. We also estimate this effect relative to new vertical wells (conventional drilling activity) as well as controlling for other HF regulations. Our results suggest that HF well entry per watershed and month decline by roughly

3.5 percent.

For adjustments along the intensive margin, we provide a series of analyses. First, we investigate whether wells spudded in the post-disclosure period exhibit smaller per-well effects than wells spudded in the pre-disclosure period. We estimate the per-well effect on ions concentrations and find that, after the disclosure mandate, the estimates are smaller and generally insignificant. The estimated coefficients correspond to a decrease in the average per-well effect of 1.41 for $Br^-$, 67.55 μg/l for $Cl^-$, 0.03 μg/l for Ba, 0.81 μg/l for Sr. Moreover, we show that the spike in ion concentrations between 91 and 180 days after well spudding, documented in Bonetti *et al.* (2021), is smaller after mandatory disclosure. Second, we analyze the level of oil & gas production scaled by the ion concentration level at the watershed level, which is essentially an environmental performance or efficiency measure. Consistent with our per-well analyses and improvements in HF practices, we find that oil & gas production per unit of water pollution increases after the disclosure regime becomes effective. Third, we examine changes in the HF fluids around the introduction of the disclosure regulation. We find a significant 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 spills and accidents, which are likely a key pathway by which HF wells affect water quality (Agarwal *et al.*, 2020). The new disclosure requirements could also make HF operators exercise more care in their practices. Consistent with this idea, we detect a significant decline in the number of HF-related incidents (e.g., spills, leaks and accidents), especially related to the handling of wastewater and fracking pits. Taken together, our evidence along the intensive margin suggests that, after disclosure, HF practices and technology improve, reducing the surface water impact from new HF wells.

To continue our mechanism exploration, we study heterogeneity in the estimated treatment effects, exploiting variation in the state disclosure rules as well as in the channels through which disclosure regulation could operate. Both sets of analyses tie the estimated effects even closer to the disclosure regulation. First, state rules differ in their strictness, as indicated by the extent to which they offer trade secret exemptions and the required timeliness of the disclosure. These features plausibly alter the costs to and pressures on operators. Consistent with this notion, we find that larger increases in water quality after the introduction of disclosure regulation for states that offer fewer trade secret exemptions and require timelier disclosure. This evidence is also consistent with work in regulatory economics, highlighting the role of implementation and enforcement for regulatory outcomes (Magat and Viscusi, 1990, Djankov *et al.*, 2003, Schleifer, 2005, Christensen *et al.*, 2013, Christensen *et al.*, 2016).

Second, pressure on HF well operators can likely come from two sources. One is the public pressure from environmental groups, local communities and the general public (Freedman *et al.*, 2012, Board and Meyer-ter-Vehn, 2013, Johnson, 2020). Another source is litigation risk once operators have to disclose the composition of the HF fluids (Olmstead and Richardson, 2014). Knowing the ingredients makes it more likely that a contamination can be tied back to a particular operator or HF well (Watson, 2021). Moreover, publicly traded well operators are likely to face more public scrutiny and higher litigation risks than private operators (e.g., Gande and Lewis, 2009). Consistent with these ideas, we find larger decreases in ion concentrations in counties with a higher presence of local newspapers as well as more educated and wealthier households and in watersheds in which a larger fraction of wells is owned by publicly traded firms. These results are in line with prior work on disclosure regulation showing its effectiveness depends on the ability of users to understand the disclosed information and exert pressure (e.g., Pargal and Wheeler, 1996, Caplin and Dean, 2015, Dyreng *et al.*, 2016, Christensen *et al.*, 2017, Johnson, 2020).

This study makes several contributions to the literature. First, we provide an empirical assessment of HF disclosure regulation with respect to surface water quality. Unconventional development of shale gas and tight oil has significantly boosted U.S. energy production but has also been highly controversial due to its potential environmental risks, especially for surface waters. Our results show that state disclosure rules of HF fluids have significantly reduced the environmental impact of HF wells on U.S. surface waters by both reducing the number of new HF wells and the per-well impact. 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 important because, unlike the aforementioned acts, disclosure regulation does not directly regulate the amount of economic activity or environmental pollution.

In terms of the setting, our paper is closely related to the studies by (Fetter, 2017, Fetter, 2018). The former shows that, after the introduction of the state disclosure rules, well operators report using fewer hazardous chemicals in their HF fluids, as compared to prior voluntary disclosures. The latter examines whether the disclosure rules facilitate learning and imitation across operators, using the chemical mix of the HF fluids. They find that, following disclosure, firms' chemical choices converge to the mix of more productive wells. Although these findings are consistent with ours, improvements in firms' disclosures do not necessarily imply better practices or fewer environmental impacts. As such, our evidence on water quality, HF-related incidents and drilling activity complements the findings in Fetter (2017) and Fetter et al. (2018) on the disclosed chemical mix and firm learning. Moreover, our mechanism evidence, for instance, on the role of public scrutiny suggests that likely multiple channels are likely at play.

Second, we contribute to a burgeoning literature on whether and how disclosure regulation can be used for public policy to drive changes in economic behavior (e.g., Fung *et al.*, 2007, Dranove and Jin, 2010, Christensen *et al.*, 2021).[6] Much of this literature has focused on the

[6] There is also a growing literature in accounting on the real effects of disclosure and reporting regulation. See

effects of information dissemination about socially undesirable behaviors or outcomes (e.g., Bennear and Olmstead, 2008, Delmas *et al.*, 2010, Dyreng *et al.*, 2016, Christensen *et al.*, 2017, Chen *et al.*, 2018, Johnson, 2020, Buntaine *et al.*, 2022) or on quality disclosures in consumer-facing settings (e.g., Dranove *et al.*, 2003, Jin and Leslie, 2003). It is less clear that the demonstrated real effects from these settings carry over to settings in which firms provide disclosures about more widespread negative externalities (such as air and water pollution).

In this regard, our paper is more closely related to recent studies on mandated carbon disclosures or extraction payment disclosures (e.g., Rauter, 2020, Downar *et al.*, 2021, Tomar, 2021). Rauter (2020) examines how mandatory extraction payment disclosures affect fiscal contributions and investment in oil, gas and mining firms in foreign host countries. He finds that treated firms make higher payments to host countries, but also decrease their investments relatively to the control group of non-disclosing firms. Downar *et al.* (2021) and Tomar (2021) examine the effects of mandatory reporting on corporate GHG emissions in the UK and in the U.S., respectively, and document that mandatory disclosure leads to a reduction in subsequent GHG emissions. Unlike in these studies, the HF disclosure mandate does not reveal the activity itself. Instead, our paper shows that even technical disclosures about a known activity that are addressed mainly to local communities and the general public on a "right to know" basis can be effective at providing incentives to firms to internalize negative externalities.

## 2. Empirical Setting and Institutional Details

### *2.1 Hydraulic Fracturing and Water Quality*

Unconventional development has tapped into large oil and gas 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 (U.S. Energy Information Agency, 2018). However, despite its important

Leuz and Wysocki (2016) and Roychowdhury et al. (2019) for extensive reviews of this literature.

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). 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) document large-scale evidence of significant increases in shale gas-related contaminants at ground-water intake locations of community water systems that are in close proximity 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 (1) discharges of inadequately treated wastewater at disposal sites, (2) on-site accidents, leaks, mishandling or spills of HF fluid or produced waters, (Vidic *et al.*, 2013, Vengosh *et al.*, 2014, EPA, 2016, Agarwal *et al.*, 2020) and (3) direct disposal of untreated wastewaters.

### *2.2 HF Chemicals Disclosure Regulation*

Although HF remains subject to the Clean Water Act, it is exempted from some SDWA provisions on underground injections, which regulate monitoring, recordkeeping and reporting requirements for any injection of chemicals endangering drinking water sources (except for diesel fuel). Because of this exemption, granted by the 2005 Energy Policy Act, 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).[7] These rules were adopted at different points between 2010 and 2013 (Table 1, Panel A and Figure 1).

Disclosures of HF fluids are reported to a state agency or 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 requirements vary only slightly with respect to the required information. They generally specify what information about the chemicals used in HF fluids must be disclosed. Typical disclosures are the ingredient name (plus the trade name if applicable), the chemical abstract service number, the concentration in the fracturing fluid (typically the maximum concentration in any fracturing stage), and the supplier name (see Appendix for an example). When submitting the HF fluids filing, operators must also provide information on the well name, operator, location (state, county, latitude and longitude) and some additional information, such as the vertical depth and the volume of water used. State rules stipulate when the disclosure must be made relative to the spudding or completion of the HF well. The timelines of the filings vary across states and is set anywhere between 20 and 120 days from well spudding or well completion (for details, see Konschnik and Dayalu, 2016).

All states allow operators to obtain trade secrets exemptions for the disclosure of chemicals that are considered confidential business information under the Uniform Trade Secrets Act. The prerequisites and procedures to obtain such an exemption vary across states (McFeeley, 2012).[9] If granted, the HF fluid disclosure filed with FracFocus still provides the concentration of the chemical used, but the name and chemical abstract service number are omitted.

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[7] States may also have other relevant regulations, such as HF drilling standards and rules for wastewater pits and disposal. See Online Appendix Table OA3 for details on these regulations.

[8] State rules specify whether the disclosures must be made to a state agency or to the general public via FracFocus. In our sample, all states mandate disclosure to the public through FracFocus (Konschnik and Dayalu, 2016).

[9] The prerequisites and procedures to claim a trade secret exemption can entail the following elements: (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, Table OA4.

### 2.3 *Channels for Real Effects of Disclosure Regulation*

Although disclosure regulation for the HF fluids does not restrict or prescribe specific practices, it could nevertheless change HF operators' behavior through a number of channels and ultimately alter the environmental impact of HF wells. The key idea behind all these (non-mutually exclusive) channels is that the disclosure enables stakeholders or the general public to impose costs on HF operators, which in turn provides incentives to change behavior, be it to drill less, to change the composition of the HF fluids or to operate in a cleaner, safer and more careful fashion.

First, knowing the composition of the HF fluids can increase liability risk for HF activity, making it easier to identify responsible operators and to establish causation, which plays a key role in litigation (Olmstead and Richardson, 2014). Second, investors in oil & gas companies could use HF fluid disclosures to pressure firms to change their practices, especially if they entail litigation risks that are ultimately borne by investors. 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, Friedman and Heinle, 2016, Christensen *et al.*, 2017), for example to use less hazardous chemicals in the drilling process. Third, the disclosures can be used by local communities and environmental NGOs to protest against HF activity. Public pressure and shaming can impose reputational costs on HF operators (Johnson, 2020). In addition, public opposition to unconventional development could lead to stricter regulation (e.g., bans or higher regulatory burdens) and the threat of such regulation could motivate operators to adjust their behaviors.

In the Online Appendix (Table OA1), we provide anecdotal evidence illustrating the demand for information on the HF fluids by local communities, environmental groups and activists, policymakers and regulators, the media as well as plaintiffs in HF-related lawsuits. In addition, NGOs monitor surface water using specific indicators associated with the chemical signatures of HF flowback and produced water. This evidence supports the relevance of these channels in our setting.

A fourth and separate channel is that HF operators can learn for the disclosures of other operators and imitate high-productivity practices and fluid mixes. To the extent that higher productivity practices are also cleaner, such benchmark learning can lower the environmental impact, at least in the short run (e.g., Fetter *et al.*, 2018, Tomar, 2021). However, the competitive costs from the disclosures can reduce HF operators' incentives to innovate in the long-run (e.g., Fetter *et al.*, 2018, Breuer *et al.*, 2021).

## 3. Data

We collect data from several sources. We measure surface water quality using the concentrations of four ions: $Br^{-}$, $Cl^{-}$, Ba, and Sr. These ions are regarded as highly specific signatures of flowback and produced waters (Entrekin *et al.*, 2011, Vidic *et al.*, 2013, Rosenblum *et al.*, 2017) as deep formation brines mobilized by HF contain highly elevated concentrations of all these four ions (Vengosh *et al.*, 2014, Brantley *et al.*, 2014, Blondes *et al.*, 2018). Thus, they could indicate a contamination related to HF wells, if and when it exists. Furthermore, these ions have been measured and tracked with reasonable frequency over a long period in publicly available data, allowing us to estimate reliable baseline concentrations. The data come from the EPA (STORET data), USGS (NWIS data), the Shale Network (Shale Network, 2015), Susquehanna River Basin Commission, and from the PA DEP (SAC046). The STORET data and the NWIS data contribute by far the most observations to the sample. Surface-water observations include rivers, lakes, streams, and ponds. The data provide information on the latitude/longitude of each water monitoring station, the ion, the type of surface water (e.g., rivers, lakes), the sampling method, and it identifies the agency in charge of the monitoring station.[10] The data were downloaded in September 2021.

[10] Following Keiser and Shapiro (2018), we identify each monitoring site by latitude and longitude because

Data on the location and spud date for each hydraulic fracturing well are obtained from three databases: (1) WellDatabase; (2) Enverus (formerly Drillinginfo), and, for Pennsylvania, (3) from the Pennsylvania Department of Environmental Protection (PADEP) and the Pennsylvania Department of Conservation of Natural Resources (PADCNR). WellDatabase and Enverus are widely used as a data source in many empirical studies on the O&G industry. WellDatabase and Enverus collect oil and natural gas production information from various state agencies for each well. We complement WellDatabase and Enverus information with data from the Pennsylvania Department of Environmental Protection (PADEP) and the Pennsylvania Department of Conservation of Natural Resources (PADCNR). Enverus, PADEP and PADCNR provide information on the latitude/longitude of each well, the type of each well (horizontal vs. vertical), the production type of each well, and the spud date. We use only wells with non-missing information on latitude/longitude, spud date, type of well, and type of production. In our main analyses, we combine the three databases together to make the sample of wells as comprehensive as possible, essentially requiring that a well is recorded in at least one of the three databases to be included in the sample. If a well appears only in one of the three databases, then we use the spud date recorded by the database. If a well appears in more than one database, and the well is recorded with different spud dates in the different databases, we first rely on the PADEP and PADCNR spud date if the well exists at least in them, then on the WellDatabase spud date if the well exists at least in it but not in the PADEP and PADCNR, and finally on the Enverus spud date if the well exists only in the latter.[11]

Data on the adoption dates of the disclosure mandates have been obtained from the state websites. We carefully review the text of the laws introducing the disclosure requirements and cross-validated these dates with those reported in the FracFocus repository.

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monitoring sites are often assigned different codes in the different repositories, and/or their assigned names may change over time.

[11] We design such a spud date computation procedure after carefully reviewing the three databases. PADEP and PADCNR appear to be the most reliable source followed by WellDatabase and DrillingInfo.

To assemble the estimation sample, we assign each monitoring station and HF well to a watershed (HUC10)[12] 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 impact of HF wells are detectable mostly within watersheds (Agarwal *et al.*, 2020, Bonetti *et al.*, 2021). For this reason, we analyze variation in ion concentrations across areas with and without HF activity at the watershed level.

We retain only water readings from monitoring stations located in states that have adopted HF fluids disclosure mandates and are located in HUC4s (sub-region) with at least one active HF well over the sample period, focusing essentially on geographic areas for which HF is relevant. We further require complete 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 by Ion-Sub-Basin-Year-Month to allow for the estimation of our models. These sample requirements yield a sample of 299,654 surface water quality measurements from January 2006 to September 2019 across watersheds with and without HF activity across 14 states with disclosure of HF fluids mandates.

The distribution of ion observations and HF activity across U.S. states with HF is reported in Table 1. Figure 1 plots the time trend in HF activity in the U.S. along with the timing of the disclosure regulation entry-into-force dates across states. Figure 2 shows HUC10s where HF activity occurs, the locations of HF wells and water monitoring stations.

Data on daily precipitation and temperature come from the Wolfram Schlenker's Daily

[12] 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. The United States is divided and sub-divided into successively smaller hydrologic units. There are six levels in the hierarchy, represented by hydrologic unit codes (HUC) from 2 to 12 digits long, called regions (HUC2), sub-regions (HUC4), basins (HUC6), subbasins (HUC8), watersheds (HUC10), and sub-watersheds (HUC12).

Weather Data for Contiguous States.[13] 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 for the 2.5x2.5 mile grid, in which each monitoring station is located.

The final sample of water quality observations is made of two sub-samples: (i) a treatment sample of HUC10s with at least one active HF well in the pre-disclosure period; (ii) a control sample of HUC10s with no HF in the pre-disclosure period, and located in treated states within HUC4s with HF activity. Descriptive statistics for the surface water quality observations in the two groups are reported in Table 2, Panels A-B. All ions 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 per ion at the HUC4 level, to allow for some regional variation in ion concentrations.[14] 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.[15] The distribution of observations across HUC10s are reported in Table 2, Panel C. Ion measurements can be sparsely distributed, except for $Cl^{-}$, which is available for most states. On average, there are 16 monitoring stations per HUC10, ranging from 8 for $Br^{-}$ to 16 for Sr. The average number of measurements per ion in a HUC10 ranges from 39 for $Br^{-}$ to 89 for $Cl^{-}$.

## 4. Research Design

In our main analyses, we test if the adoption of the disclosure mandates of HF fluids is

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13 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'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).

14 E.g., for $Cl^{-}$, most of the truncated observations are located in New Mexico, near the Pecos River Valley.

15 There is no consensus in the literature on how to model concentrations in regressions. Keiser and Shapiro (2017) 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. Our inferences are not materially affected if we do not log concentrations, and instead use decile ranks or some form of outlier treatment.

associated with improvements in water quality, measured as concentrations of $Br^-$, $Cl^-$, Ba, and Sr. We test this prediction using a panel dataset with daily (with gaps) monitoring station-level observations of ion concentrations. The panel dataset allows us to exploit variation in the entry-into-force dates of the disclosures of HF fluids across U.S. states. 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, $State_s(HUC8_h) \times Month_m$ x $Year_t$ is (alternatively) State (or Sub-basin)-Month-Year fixed effect, $HUC8_h \times Month_m$ is a Subbasin-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 on the day a water quality measurement is drawn, in Celsius,[16] and $\varepsilon_{ikd}$ is the error term. *HUC10_HF* is a binary time-invariant variable marking watersheds with HF wells at least in the pre-disclosure period. *POST* is a binary variable marking water quality observations in the post-disclosure period. The key variable of interest, given by the interaction term, *HUC10_HF×POST*, captures the impact of the disclosure mandate on ion concentrations in HUC10s in which HF occurs relative to the change in ion concentration in which HF does not occur. If the disclosure mandate leads to a reduction in ion concentration, we expect a negative coefficient on *HUC10_HF×POST*. Our inferences are based on clustered standard errors at the HUC10-level to allow for any arbitrary correlation in the error terms within a HUC10.

[16] 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].

Our fixed effect structure controls flexibly for arbitrary changes in the average concentration in a state (HUC8) in a given month and the average concentration at the monitoring station. Thus, Eq. (1) examines whether the disclosure mandate is associated with a reduction in ion concentration in a given watershed, after controlling: (i) for 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, but also for the effects of economic development associated with the rise of HF,[17] (ii) for time-invariant heterogeneity in the characteristics of the water monitoring stations (and their locations) due to the way water quality is measured, the type of monitor, the type of water body, the location of the monitor, including natural brine migration at this location, and (iii) for local weather at the time of the water measurement.

Our empirical strategy encompassing a treatment and control sample is akin to a Difference-in-Difference-in-Differences (DDD) in which we compare the pre-and post-disclosure evolution in ion concentration of treated- and non-treated HUC10s in the same state (HUC8) across all states (HUC8s). In this way, we first benchmark the change in water quality between the pre- and post-disclosure period across homogenous areas and then compare these within state (HUC8) changes across states (HUC8s). We estimate Eq. (1) over a treatment sample that includes HUC10s with HF at least in the pre-disclosure period (requiring at least one active well by HUC10 in the pre-disclosure period), and a control sample that includes HUC10s with no HF wells in the pre-disclosure period and located over Sub-Region (HUC4s) in treated states. This approach allows us to assign the treatment and control groups based on HF activity existing in the pre-disclosure period.

[17] The Online Appendix OB1 provides a visualization of how the identification strategy exploits variation across treated and control watersheds using Pennsylvania as an example, for both the within-State and the within-HUC8 specifications.

## 5. Results

### *5.1 Average Water Quality Effects*

We begin our analysis by presenting the results from the estimation of Eq. (1) in Table 3. The explanatory power of the regressions is high with the $R^2$ ranging between 86.8 to 99.5 percent, suggesting that our models capture most of the variation in ion concentrations across watersheds and through time. When we examine each ion separately, we observe reductions in the concentrations of $Cl^-$, Ba, Sr in the within state models [Columns (3), (5) and (7)] and in the within HUC8 models for Ba and $Cl^-$ [Column (4) and (6)]. For $Br^-$, the reductions in concentrations are negative, although above the conventional level of significance.

When we pool all the ions together [Columns (9) – (12)], we document that the coefficient on *HUC10_HF×POST* is negative and significant, irrespective of the fixed effects structure.[18] The results still hold when we further and non-parametrically reduce heterogeneity between treated and control watersheds by restricting the sample to watersheds over shales [Columns (11) and (12)]. Taken together, the results from Table 3 suggest that the adoption of the disclosure mandate is followed by an improvement in water quality.[19]

The estimated effects are economically significant. Using the within state models as a benchmark, the magnitudes range between 4.37 percent for Sr, to 16.59 percent of $Cl^-$. As a way to further gauge the magnitudes, we translate the percentage effects into µg/l decreases. The average decrease in concentration in the treated HUC10s relative to the un-treated HUC10s in the same state amounts to 7,999.12 µg/l for $Cl^-$, 6.21 µg/l for Ba, and 19.78 µg/l for Sr.

Next, we present evidence on the timing of the impact of the disclosure regulation on ion concentration. This analysis also explores the existence of any pre-mandate differential trends

[18] When we combine all the ions together, we estimate one regression for all ions and include a fixed effect for each ion as well as interactions for the ion indicator and the controls and fixed effects, so that they are specific to each ion. This model is akin to running a SUR (seemingly unrelated regression) model. The model produces an average estimate over all ions, but by pooling all ions we harness more power.

[19] In the Online Appendix, Section OB2, we test whether our inferences are robust to alternative sampling selection choices.

across the treated and control HUC10s and of any delay in the impact. Operationally, we estimate Eq. (1) replacing the variable, *POST,* with separate indicator variables, $D_t$, corresponding to the years around the implementation of the disclosure requirements in each state in the sample. In particular, $t$=0 indicates the year of the disclosure regulation implementation, $t$=–$s$ indicates $s$ years before $t$=0, and $t$=+$s$ indicates $s$ years after $t$=0 ($s$=1, 2, 3). We omit $D_{-1}$ (i.e., the indicator for year $t$=–1), which serves as benchmark. The treatment sample is made of HUC10s with at least one active HF well in the pre-disclosure period. We include State-Month-Year or HUC8-Month fixed effects, monitoring station fixed effects, and the weather controls.

Figure 3 plots the coefficients from the temporal analysis for all the ions pooled together, together with their 95% confidence intervals. Because year $t$=–1 serves as benchmark, the coefficient on $D_{-1}$ is zero, with no confidence interval. Figure 3 reveals that the decrease in ion concentration kicks in the year of the entry-into-force of the disclosure regulation and does not reverse after the adoption of the disclosure rules. In the adoption year, however, the estimated coefficient is smaller and less significant than those in the subsequent years. This small delay in the impact of the disclosure regulation is consistent with disclosures being available to the public between 20 and 120 days from the well completion or spudding date, and with the evidence that the water-impacts of new drilled wells occurs within 90-180 days after a well spudding. Moreover, we do not detect significant pre-disclosure differences in the trends across treated and control HUC10s in the years before the adoption of the disclosure rules.

We gauge the sensitivity of the results with respecting to: (i) sample composition; (ii) clustering of the standard errors; (iii) truncation of the chemical concentration measures; (iv) functional form of the ion concentration measures; (iv) computation of the ion concentration measures. These sensitivity tests in Online Appendix (Section OB3) show that our findings and estimated magnitudes are robust to a wide range of alternative design choices.[20]

*5.2 Assessing Robustness of the Average Effect on Water Quality*

In this section, we conduct a battery of additional analyses to rule out alternative explanations, and thus better link the decrease in ion concentrations to the disclosure mandate.

We first conduct two "placebo" tests. If the results reported in Table 3 were driven by trends in water quality that Eq. (1) failed to properly account for, then we would detect similar results if we used counterfactuals for the HF wells or for the ion concentrations.

First, we replace the dependent variables and examine changes in the concentration of analytes not directly affected by HF activity but by other economic activities, e.g., agriculture. Specifically, we use the following three analytes: (i) Dissolved oxygen (DO), (ii) Fecal Coliforms, (iii) Phosphorus. Given that these three analytes are not directly related to HF activity, but can still contribute to water quality, they represent a quite natural counterfactual. Table 4, Panel A, shows that the adoption of the disclosure mandate is not associated with a statistically significant change in the concentration of analytes not directly related to HF activity.[21]

Second, we examine the effect of the disclosure mandate on ion concentrations in watersheds where conventional drilling occurs. Given that the disclosure mandate only applies to HF wells, conventional wells provide a powerful counterfactual for HF activity. To do so, we re-estimate the analyses in Table 3, but define the treatment sample based on the existence of conventional wells instead of HF wells. Table 4, Panel B, shows that the disclosure mandate does not significantly affect concentrations in HUC10s in which conventional drilling occurs

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[20] In untabulated analyses, we use WLS models instead of OLS models, giving more weight to observations from sub-basins and months for which we have more water measurements and hence better baselines. The results continue to hold. Second, we also add lagged changes in ion concentrations to control for mean reversion in case states implement the disclosure requirements in response to shocks to local water quality. Again, the results are unchanged.

[21] The Online Appendix, Section OB4 reports additional tests considering whether our results reflect trends in water pollution coming from agricultural activity.

relative to HUC10s in which conventional drilling does not occur.[22]

Another source of concern is related to the impact of concurrent regulations. Almost all states in our sample have introduced many other regulatory provisions on drilling activity over the sample period, including rules on wastewater management and/or HF standards (e.g., well casing).[23] As a result, the water quality effects we documented in Table 3 can be affected by these competing regulations rather than by the disclosure rules.

To explore this possibility, we first estimate an alternative version of Eq. (1) in which we replace the interaction variable, *HUC10_HF×POST*, with three alternative interaction variables: (ii) *HUC10_HF×CUM_WASTEWATER,* which cumulates over time the number of regulations related to wastewater handling standards (i.e., the variable increases by one when a new regulation over wastewater handling is introduced in a state) in watersheds with HF wells at least in the pre-disclosure period; (ii) *HUC10_HF×CUM_HF_STANDARDS*, which cumulates over time the number of regulations on drilling standards (i.e., the variable increases by one when a new regulation over drilling standards is introduced in a state) in watersheds with HF wells at least in the pre-disclosure period; (iii) *HUC10_HF×CUM_HF_REG,* which cumulates over time the number of regulations related to drilling standards or wastewater handling standards (i.e., the variable increases by one when a new regulation over wastewater handling or on drilling standards is introduced in a state) in watersheds with HF wells at least

22 Bromide is an exception, being an important component of clear drilling muds in conventional developments. We detect a significant reduction in Bromide concentrations in the within-state model. Similarly, Bonetti et al. (2021) detect a significant association between conventional wells and bromide concentrations. It is possible that the HF disclosure mandates or other concurrent regulations affect the impact that conventional drilling practices have on this ion. Consistent with this conjecture, the coefficient is no longer significant once we control for other concurrent regulations.

23 We obtain these concurrent regulations on the O&G industry by manually inspecting the administrative codes and other laws adopted by the states in our sample. These regulations include provisions prohibiting 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 only very recently. However, many of them have been adopted around the time of the disclosure implementation dates. Five states (Pennsylvania, North Dakota, Montana, Utah, and Ohio) have introduced the disclosure requirements for HF fluids along with other regulatory amendments. Appendix OA3 describes these regulatory changes in more detail and provides their respective implementation dates.

in the pre-disclosure period. These three variables intend to capture the change in the strictness of the regulatory framework over drilling activity.

Table 5, Columns (1)–(3) and (7)–(9), reports the results.[24] We document that these concurrent regulations on drilling standards or wastewater handling standards are also associated with improvements in water quality, although the magnitudes on these concurrent regulations are lower than those documented for the disclosure impacts.

More importantly, when we include in the model the interaction term capturing the impact of the disclosure mandates, *HUC10_HF×POST,* we still document negative and statistically significant disclosure impacts in all the specifications [Columns (4)–(6) and (10)–(12)], with little attenuation in the magnitudes relative to the estimates reported in Table 3. This evidence suggests that the documented patterns are not mainly driven by other regulatory changes that can affect HF activity and water quality.[25]

### 5.3 *Extensive and Intensive Margin*

The evidence provided so far points to an increase in water quality after the disclosure mandates. We now turn to examine through which margin such an effect occurs. This increase in water quality may come from less HF activity in the post-disclosure period relative to the pre-disclosure period (*extensive* margin) and/or from HF operators shifting to a less-water polluting technology (*intensive* margin).[26]

To examine the impact of the disclosure mandate over the extensive margin (i.e., well entry), we restrict the sample to HUC10s over shales. To further reduce the degree of economic development heterogeneity across watersheds, we also propose a specification in which we

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

[25] An important caveat to the interpretation of the results in Table 5 is that these models are "centered" around the disclosure adoption dates, i.e., the "treatment" and "control" samples are defined by the existence of HF wells before the disclosure adoption dates. This empirical choice adds noise to the estimation of the coefficients on the concurrent regulation variables, likely explaining why these coefficients are no longer significant once we include in the models the disclosure variable.

[26] Note that Eq. (1) is capturing the average *total* increase in water quality. For this reason, the model cannot separate the two margins.

restrict the sample to HUC8s crossing at least two contiguous states. We measure well entry by taking the natural logarithm of the number of new HF wells spudded by HUC10-Month-Year. We include HUC10 fixed effects, and alternatively, Region×Month×Year FE or Shale×Month×Year FE.[27] These fixed effects are meant to further reduce heterogeneity in economic development or HF trends across watersheds, essentially focusing on within-region or within-shale variation.

Table 6, Columns (1)–(4), documents a decrease in well entry, irrespective of the fixed effects employed [Region×Month×Year, Columns (1)–(2), or Shale×Month×Year, Columns (3)–(4)] or estimation sample [shales, Columns (1)–(3), or HUC8s crossing at least two states, Columns (2)–(4)].

In Table 6, Columns (5)–(6), we estimate the decrease in HF wells entry relative to Conventional wells. Since the latter wells are not subject to the disclosure rules, they represent a useful control sample to account for general trends in economic activity in a given area. We thus code the dependent variable as the difference between the number of new HF wells spudded by HUC10-Month-Year, and the number of new Conventional wells spudded by HUC10-Month-Year. However, since Conventional wells are subject to some of the concurrent regulations over drilling activity, we control by these by including in the model *CUM_HF_REG*. We still observe a decrease in HF wells entry relative to Conventional wells entry. Figure 4, Panels A and B, plot coefficients from the estimation of the models in Column 5 and in Column 6 of Table 6, respectively, breaking down the effect by quarter relative to the disclosure mandate. Figure 4 indicates that well entry effect does not reverse over time.

Regarding the economic significance of the decrease in well entry, and using the coefficient in Column (4), our estimates imply a reduction in well entry of 0.04 per HUC10-

[27] There are 30 shales in our sample. These shales can be further classified into five macro regions: North-East, South-Mid-West, South-West, Mountain, North-West. As the sample of this analysis includes only "treated" HUC10s, we cannot impose State-Month-Year or HUC8-Month-Year fixed effects, given the lack of a control group in the estimation sample.

Year-Month, given an average well entry by HUC10-Year-Month of 0.72. Overall, this evidence suggests that the adoption of the disclosure regulation for HF fluids is associated with a marginal decrease in HF activity.

To quantify the impact of the disclosure on the *intensive* margin, we estimate the per-well effect on ion concentrations for the pre- and post-disclosure period, separately. This analysis can inform about the extent to which the increase in water quality comes from HF wells spudded after the disclosure mandate are less polluting than the wells spudded in the pre-disclosure period. Operationally, we restrict the estimation sample to HUC10s with HF in both the pre-and post-disclosure period, and modify Eq. (1) by replacing *HUC10_HF×POST* with two variables counting the number of new HF wells within a HUC10 that were spudded 120 days before a given water quality reading is drawn separately for the pre-disclosure period (*#WELL_HUC10_HF_PRE*) and post-disclosure period (*#WELL_HUC10_HF_POST*).

Table 7 reports the results. We find that there is a positive and significant effect of the number of new wells on concentrations in the period before the disclosure mandate for $Br^-$, $Cl^-$ and Ba and for all ions pooled together. For the wells spudded in the post disclosure period, the coefficients are smaller and not significant, suggesting that the per-well effect decreases after the disclosure mandate. The changes in the per-well effects are economically significant. The estimated coefficients correspond to an average per-well decrease in water pollution after the disclosure mandate of 1.41 for $Br^-$, 67.55 μg/l for $Cl^-$, 0.03 μg/l for Ba, 0.81 μg/l for Sr. The results from this analysis suggest that the increase in water quality comes from wells spudded after the disclosure mandate being less polluting than the wells spudded in the pre-disclosure period. Figure 5 plots the coefficients for HF well counts calculated over fixed time intervals around the well spud dates for the pre- and post-disclosure period, respectively. Consistent with the findings in Bonetti et al. (2021), the coefficient spikes in the window [91, 180], which ties the changes in water quality to the unconventional development process, is less pronounced after the disclosure mandate.

To better relate the decrease in ion concentrations from the intensive and extensive margins with the total decrease in concentrations, we do a magnitude decomposition exercise. For $Cl^{-}$, we first multiply the average per-well decrease in pollution after the disclosure mandate (i.e., 67.55 μg/l) with the average number of wells per HUC10 in the pre-disclosure period (i.e., 47) and obtain a total decrease in concentration over the intensive margin of 3,174.85μg/l. We then compare this decrease with the decrease over the extensive margin by multiplying the per-well increase in concentration in the pre-disclosure period (i.e., 367.84 μg/l) with the decrease in the number of wells in the post-disclosure period relative to the pre-disclosure period HUC10 average number of wells (i.e., 1.2). This computation gives a total decrease in concentration over the extensive margin of 441.41 μg/l. If we then take the ratio between the total decrease in concentration over the intensive margin and the total decrease in concentration over the two margins, we obtain that around 88 percent of the decrease comes from the intensive margin.

### *5.4 Analyses of the Changes in HF Operators' Practices*

In this section, we examine changes in HF operator behaviors to more directly link the increase in water quality after the disclosure mandates with HF operator actions.[28]

First, we examine whether HF wells start to rely on a less water-polluting technology after the disclosure mandates. Even if we cannot directly observe the changes in the technology used by HF operators, we can estimate the effect of the disclosure mandate on the level of production per unit of contamination (ratio between oil and gas production and ion concentrations). This variable is a good proxy for the overall level of environmental performance of the HF wells (Wang and Shen, 2016). The dependent variable is the ratio between oil and gas production

[28] Note that these tests cannot fully disentangle whether the decrease in water pollution comes from the use of fewer toxic chemicals, fewer spills, or a more careful handling of flowback and produced water in pits/disposal wells.

(bbl) by HUC10-Year-Month and ion concentrations (μg/l). Table 8, Column (1), reports OLS estimates of the impact of the disclosure mandates over a treatment sample that includes HUC10s with HF in the pre-disclosure period [Columns (1)-(2)] and over a treatment sample that includes HUC10s with HF in the pre- and post-disclosure periods [Columns (3)-(4)]. For ease of exposition, we report the results for the all ions pooled model. We observe that after the disclosure mandate, HF wells improve their environmental performance (e.g. pollute less per unit of production). This evidence suggests that HF activity becomes less polluting after the disclosure mandate.

Second, we examine whether operators start to employ less hazardous chemicals in the post-disclosure period. We use data on the chemicals disclosed by wells from Konschnik and Dayalu (2016), and code a dependent variable capturing the amount of hazardous chemicals in the HF fluids. To do so, we collapsed the sample at the HUC10-Month-Year level and compute the HUC10-Month-Year average of the total amount of hazardous chemicals disclosed by each HF well, scaled by the total amount of fluids injected. 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). Voluntary disclosers are used to calculate the HUC10-Year-Month averages of the total amount of hazardous chemicals in the pre-disclosure period.[29] We then compute a separate dependent variable considering only Chloride-related hazardous chemicals to better link the chemicals used in HF wells with the way in which we measure water contamination, and a separate dependent variable considering only the water consumed in the drilling process. The estimation sample includes only HUC10-Month-Year observations with at least one disclosing HF well. Table 9 reports the estimation results. We

[29] Voluntary disclosers are not located in all watersheds. Thus, we first compute the pre-disclosure average at the HUC8 level using data from the voluntary adopters, and then use these averages to compute the HUC10-Month-Year average of the total amount of hazardous chemicals in the pre-disclosure period.

document a decrease in the amount of hazardous chemicals disclosed [Columns (1)-(2)] and also a decrease in the amount of water consumed in the process [Column (3)]. The results suggest that wells use less hazardous chemicals and less water in the post-disclosure period.

Third, we examine the effect of the disclosure regulation on the probability of HF-related incidents. If the disclosure rules provide incentives to improve the safety of the drilling process and the management of HF-related waste, then we should observe less HF-related incidents (e.g., spills) after the adoption. To do so, we collect data on major spills from Brantley et al. (2014) and Patterson *et al.*, (2017). We have to limit this analysis to Pennsylvania, Colorado, New Mexico, and North Dakota, since the data are available only for these states. We then count the number of recorded HF-incidents for each HUC10-Month-Year. To examine whether the improvements in water quality after the disclosure mandate are coming from a change in the way operators handle wastewater, we separately count the number of HF-incidents related to wastewater management. Table 10 reports the results. We observe that the adoption of the disclosure rules leads to a decrease in the number of HF-incidents in general and HF-incidents related to wastewater management in particular.[30]

### *5.5 Heterogeneity in the Average Effect on Water Quality*

In this section, we exploit several sources of cross-sectional variation to explore under which regulatory and economic circumstances the disclosure mandate is more effective at curbing the environmental impact of HF activity. We start by examining whether the effect of the disclosure mandates on ion concentrations differs depending on the strictness of states' disclosure rules.

First, we consider how easy it is for the HF operators to withhold the identity of some of the chemicals by relying on trade secret exemptions (McFeeley, 2012). If operators can easily

[30] Given the small sample in the analyses reported in Tables 9 and 10, using a more demanding fixed effect structure substantially reduces power. Nevertheless, the results are directionally consistent in Column 1 and similar in Columns 2 and 3 if we employ the same fixed effects we use in Table 6.

apply for, and obtain, these exemptions, costs arising from the disclosure mandates may be negligible. 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. Operators can withhold the identifying name of some chemicals, but they still need to report the amount / percentages associated with the non-disclosed chemical. To measure how easy it is for an operator to obtain a trade secret exemption within the disclosure mandate, 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 higher the number of conditions required, the more difficult is for operators to obtain the trade secret exemption. The Online Appendix (Table OA4) describes in detail the trade secret framework for each of the state in our sample.[31] Table 11, Column (1), reports the estimates from the estimation of Eq. (1) in which the sample has been split in two groups based on whether a state has two or more (none or one) conditions for trade secret exemptions, *High Group* (*Low Group*). The results (for all ions pooled) suggest that the effect of the disclosure mandate is larger in states in which is more difficult to obtain a trade secret exemption.

Second, we examine whether the effect of the disclosure mandate depends on disclosure timeliness required by the regulations. The timing for filing information on the chemicals used varies substantially across states. Since the HF wells water-impacts are mostly detectable in the short-term (Bonetti et al., 2021), timelier disclosures can make local communities in a better position to link HF activity with changes in water quality. We measure disclosure timeliness

[31] Not all the states require that the five conditions need 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.

as the number of days between the spud date and regulatory filing date for each of the states in our sample. Then, we estimate Eq. (1) by replacing the variable, *POST×HUC10_HF,* with two non-overlapping variables marking observations in the post-disclosure period in states with a below (*High Group*) [*above (Low Group)*] the sample median timeliness (#days between the spud date and the regulatory filing date). Table 11, Column (2) reports the results (for all ions pooled) showing that the effect of the disclosure mandate is greater in states in which the disclosure is timelier.

Besides considering the heterogeneity in the characteristics of the disclosure mandates across states, the effectiveness of the regulation depends on the ability of the disclosure users to process the information disclosed in a way that is costly for the HF operators. To operationalize this construct, we introduce partition variables capturing the information processing costs of users and/or their ability to exert pressure on HF operators.

First, we test whether the decrease in water pollution after the disclosure mandate depends on newspaper scrutiny of HF water consequences. High media coverage can make the fairly technical disclosures of HF fluids easier to understand for the average household and spread out the disclosure contents, thus making the threat of public shaming more credible. Table 11, Column (3) reports the coefficients from the estimation of Eq. (1) in which we replace *POST×HUC10_HF* with two non-overlapping variables marking observations in the post-disclosure period in counties with an *above* (*below*) the sample median presence of local newspapers in the year leading up to the adoption of the disclosure mandate. The results show that the effect of the disclosure on ion concentrations is larger in counties in which newspaper presence is greater.[32]

[32] In un-tabulated results, we use the amount of news about HF-related environmental consequences in the year before the adoption of the disclosure mandates as a source of cross-sectional variation. The results are virtually unchanged. In the Online Appendix, Section OB5, we further show that after the disclosure mandates there is an increase in the number of newspaper articles pointing to HF as a source of water pollution and this increase is greater in counties where the population is more educated or wealthier, suggesting that HF disclosures are being used by the public.

Second, we examine whether the increase in water quality depends on the level of education and wealth in a county. More educated and richer households are in a better position to understand the water-quality implications of the disclosures. Thus, we expect to observe greater improvements in water quality in counties where the population is more educated and wealthier. Table 11, Column (4), reports OLS coefficients from the estimation of Eq. (1) in which we replace the variable, *POST×HUC10_HF,* with two non-overlapping variables marking observations in the post-disclosure period in counties with an *above* (*below*) the sample median fraction of population with at least a college degree and an *above* (*below*) the sample median income per capita. The results indicate that the effect of the disclosure mandate is greater in more educated/wealthier counties.

Third, we expect HF operators owned by public firms to react stronger to the disclosure mandates than HF operators owned by private firms because the former are exposed to greater potential reputational damage and vulnerability to litigation. Moreover, HF operators owned by public firms face pressure from shareholders and investors to improve their practices (as shown in the Online Appendix, Table OA1).[33] Table 11, Column (5), reports OLS coefficients from the estimation of equation (1) in which we replace the variable, *POST×HUC10_HF,* with two non-overlapping variables marking observations in the post-disclosure period in watersheds with an *above* (*below*) the sample median fraction of wells owned by publicly traded operators [*High* (*Low*) *Group*]. The results indicate that the effect of the disclosure mandate is greater when HF operators are owned by public firms.[34]

## 6. Conclusion

The rise of shale gas and tight oil development has triggered a major public debate about hydraulic fracturing (HF). In an effort to mitigate shale gas development risks, many state

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[33] This test should be read with an important caveat in mind. The level of pollution may be different across public vs. private operators.

[34] An important caveat to these analyses is that these cross-sectional partitioning variables are highly correlated among them and likely overlapping. As such, the tenor of the inferences from Table 11 is descriptive at best.

legislators in the U.S. have implemented rules mandating disclosures about the composition of HF fluids for newly fractured wells. In this paper, we study the effects of this disclosure regulation on drilling activity and water quality. We document a substantial decline in ion concentrations that are related to HF after the disclosure mandates are introduced. Moreover, we observe this water quality effect comes from the extensive margin (less HF) as well as the intensive margin (less per-well pollution), though the effects are particularly pronounced along the intensive margin. Specifically, operators pollute less per unit of production, use fewer toxic chemicals, and are less likely to experience incidents related to the handling of wastewater. Moreover, we provide some evidence pointing to litigation concerns and public pressure as possible mechanisms through with the disclosure of HF fluids can shape HF operators.

We acknowledge that we cannot precisely pinpoint the specific mechanisms through which disclosure operates in shaping HF operators' behavior. However, our results provide novel evidence for HF and unconventional development that disclosure mandates can provide firms with incentives to internalize negative externalities.

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**Figure 1 – Trends in HF Activity and Disclosure Mandates over Time**

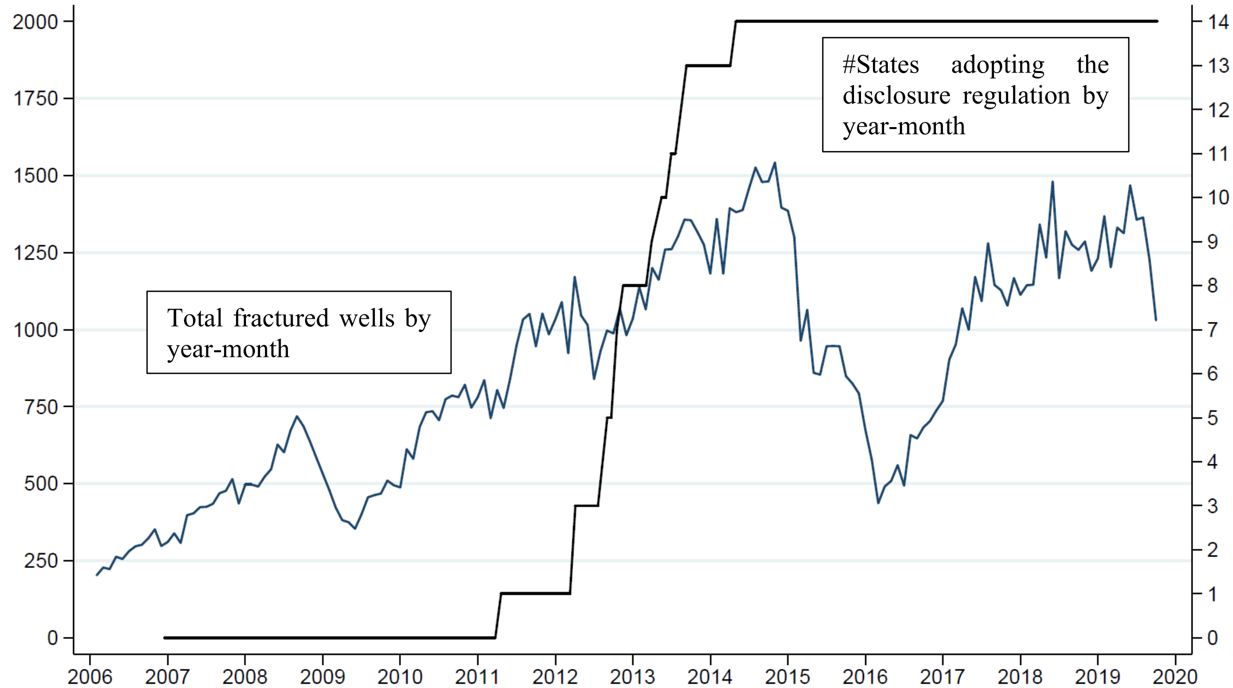
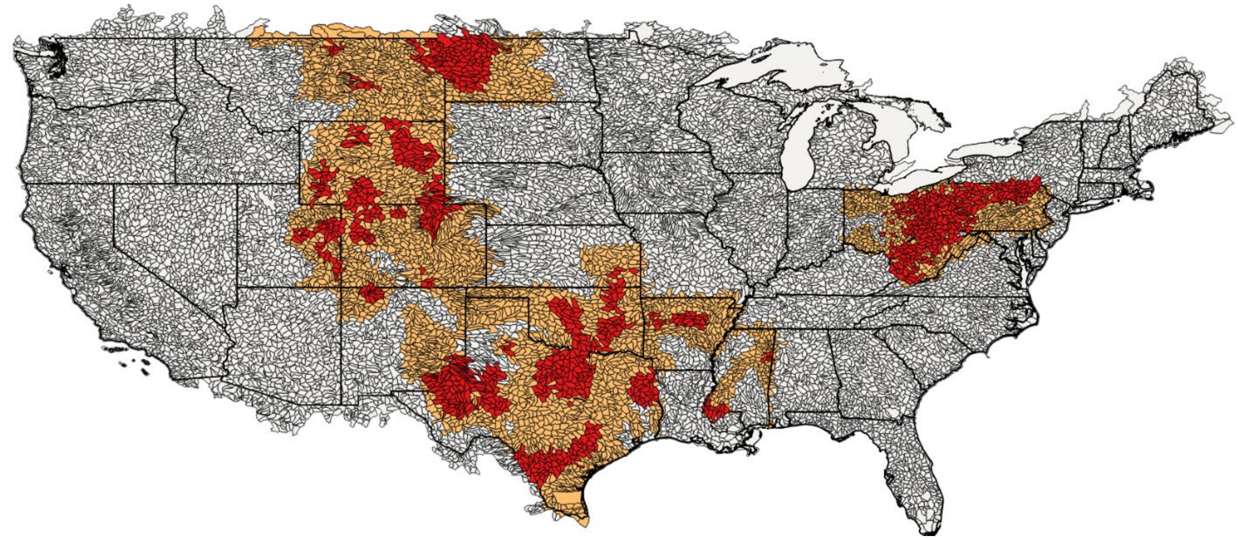



Figure 1 plots time trends in HF activity in the U.S. along with the timing of the disclosure regulation entry-into-force dates across states. The *left-y* axis shows total fractured wells by spud year/month. The *right-y* axis shows the cumulative number of sample states adopting the disclosure regulation by year and month. The *x* axis shows the year. Data on total fractured wells come from 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*

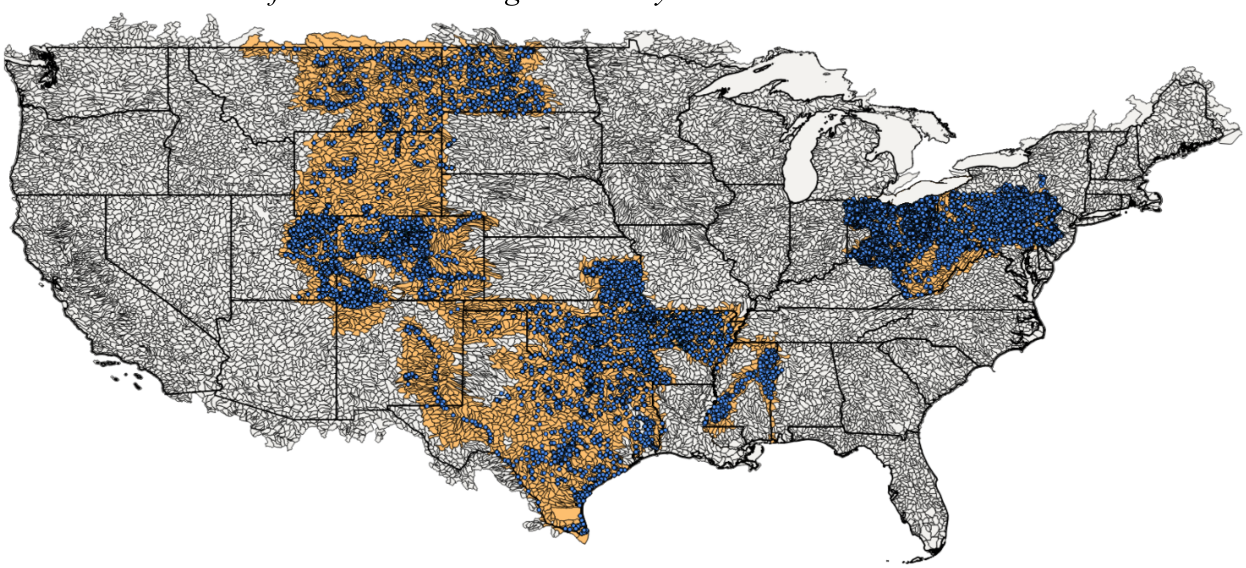
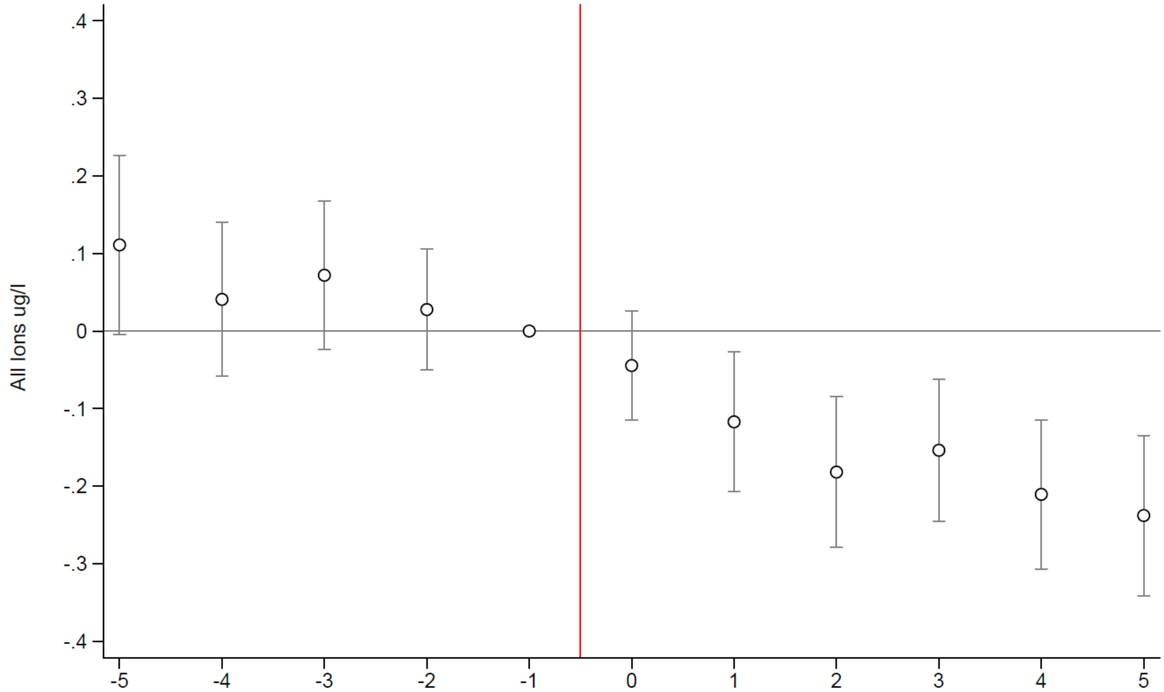


Figure 2 shows the distribution of HF activity in the sample, and the location of water quality monitoring stations across watersheds (HUC10). Watersheds in the treatment sample are colored in red. Watersheds in the control sample are colored in ocher. Blue dots mark the location of monitoring stations. Data on the location of wells come from 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 – Temporal Analysis**

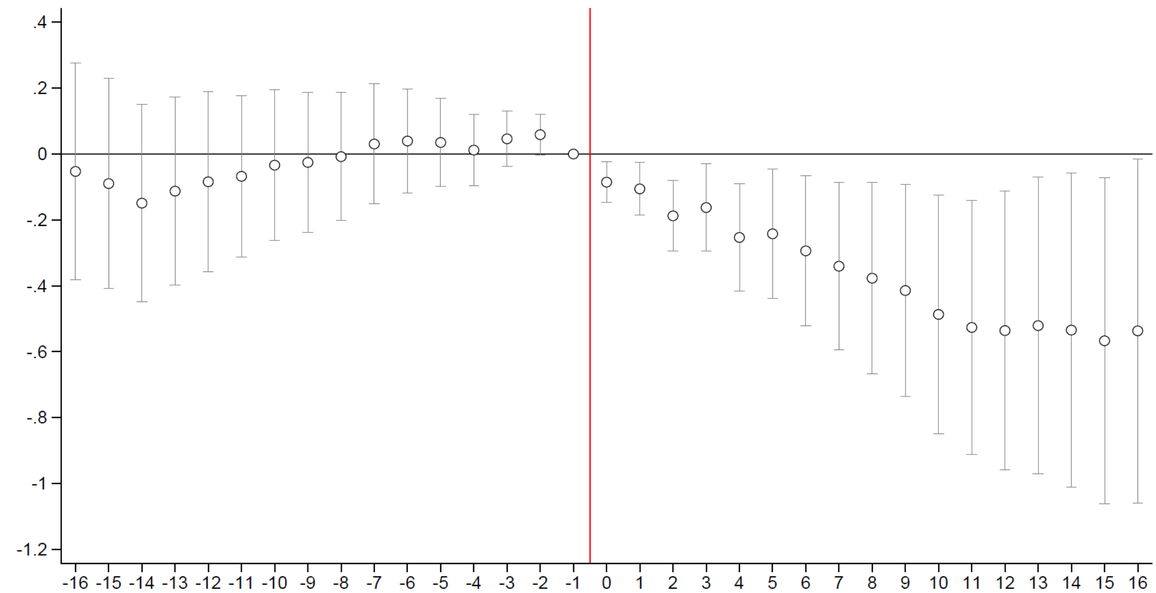



Year Relative to Disclosure Mandate

Figure 3 plots OLS coefficients from the estimation of Eq. (1), together with the respective 95% confidence interval, adding indicators for the years relative to the disclosure mandate. The coefficient for the year before the disclosure mandate is omitted from the regression and therefore serves as benchmark. The figure plots coefficients from the model in Column 11 in Table 3.

**Figure 4 – Extensive Margin**

*Panel A – Full sample*




*Panel B – HUC8s crossing state lines*

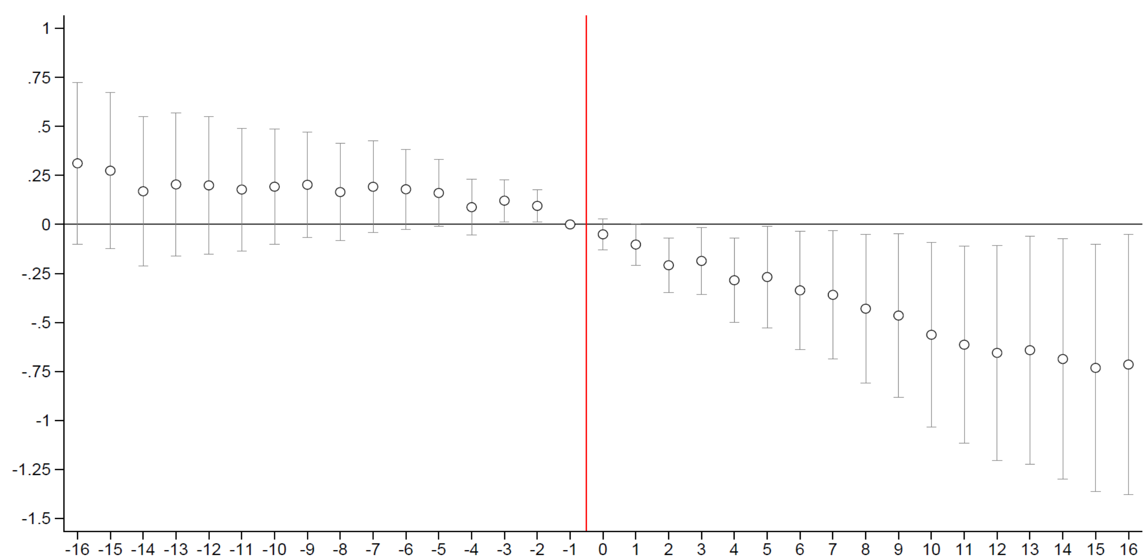



Figure 4, Panels A and B, plot coefficients from the estimation of the model in Column 5 and the model in Column 6 of Table 6, respectively, together with the respective 95% confidence interval, adding indicators for the quarter relative to the disclosure mandate. The coefficient for the quarter before the disclosure mandate is omitted from the model and therefore serves as benchmark.

**Figure 5 – Intensive Margin**

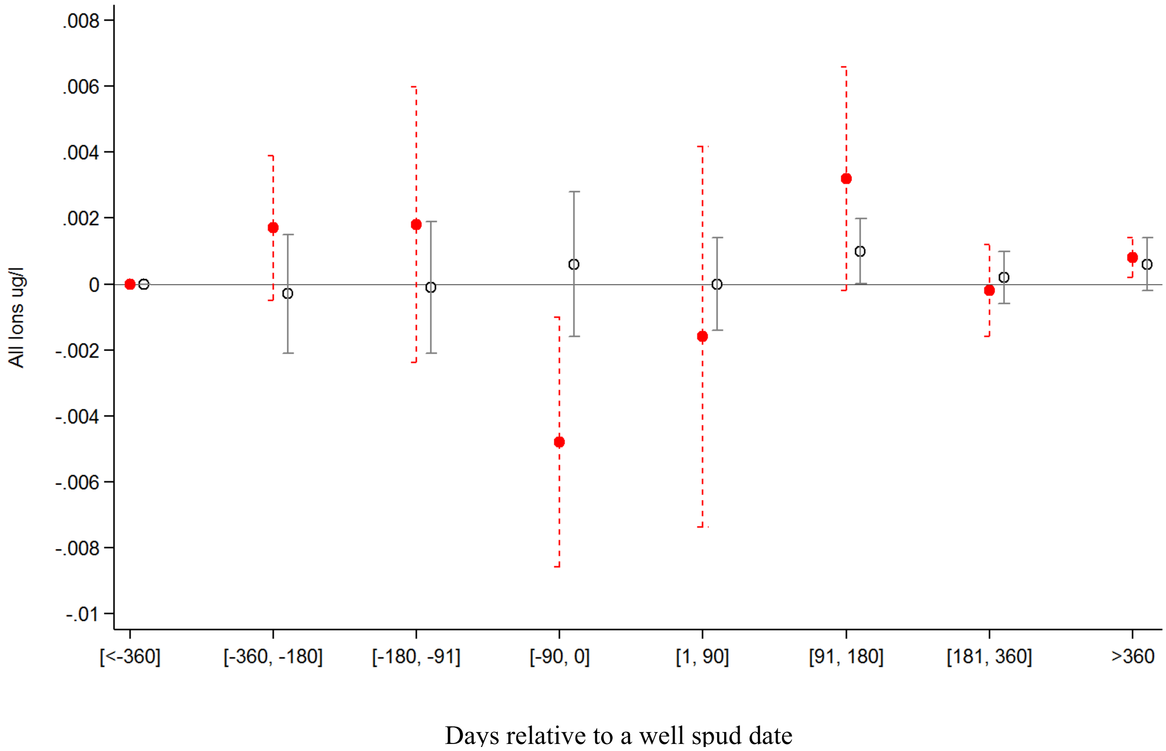



Figure 5 plots OLS coefficients for separate HF well counts calculated over fixed intervals around the well spud dates for the pre- and post-disclosure period, respectively. The red [gray] dots marks estimated coefficients in the pre [post]-disclosure period.

**Table 1 – Sample Composition and Descriptive Statistics**

*Panel A: Sample composition and dates of the disclosure mandates*

| State | Unique monitoring | Unique wells | N | Entry-into-force |
|---|---|---|---|---|
| Arkansas | 896 | 6,472 | 39,937 | 09-Feb-2013 |
| Colorado | 1,298 | 10,343 | 23,438 | 01-Apr-2012 |
| Kansas | 379 | 432 | 10,341 | 02-Dec-2013 |
| Mississippi | 82 | 1,063 | 1,431 | 04-Mar-2013 |
| Montana | 499 | 1,380 | 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 | 3,035 | 68,148 | 10-Sep-2012 |
| Oklahoma | 477 | 8,290 | 12,804 | 01-Jan-2013 |
| Pennsylvania | 2,066 | 12,319 | 88,122 | 16-Apr-2012 |
| Texas | 722 | 54,467 | 10,549 | 01-Feb-2012 |
| Utah | 650 | 1,421 | 12,982 | 01-Nov-2012 |
| West Virginia | 92 | 4,053 | 1,080 | 29-Aug-2011 |
| Wyoming | 176 | 7,408 | 8,033 | 17-Aug-2010 |

*Panel B: Number of HUC10s in the treatment and control sample*

| | **Bromide** | **Chloride** | **Barium** | **Strontium** |
|---|---|---|---|---|
| # HUC10s with HF in the pre | 156 | 505 | 329 | 214 |
| # HUC10s without HF in the pre | 251 | 1,383 | 765 | 403 |

**Table 2 – Descriptive Statistics on Surface Water Quality (µ/l)**

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

| **Bromide** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
|---|---|---|---|---|---|---|
| Concentration | 6,007 | 119.998 | 30.840 | 58.620 | 100.000 | 339.140 |
| Ln(Concentration) | 6,007 | 4.112 | 3.461 | 4.088 | 4.615 | 1.094 |
| **Chloride** | | | | | | |
| Concentration | 43,394 | 50,989.800 | 5,700.000 | 15,400.000 | 41,100.000 | 182,833.900 |
| Ln(Concentration) | 43,394 | 9.626 | 8.648 | 9.642 | 10.624 | 1.653 |
| **Barium** | | | | | | |
| Concentration | 24,470 | 53.388 | 31.000 | 43.200 | 63.000 | 77.547 |
| Ln(Concentration) | 24,470 | 3.691 | 3.466 | 3.789 | 4.159 | 0.907 |
| **Strontium** | | | | | | |
| Concentration | 21,136 | 289.884 | 48.000 | 142.000 | 282.000 | 521.400 |
| Ln(Concentration) | 21,136 | 4.890 | 3.912 | 4.977 | 5.652 | 1.224 |

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

| **Bromide** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
|---|---|---|---|---|---|---|
| Concentration | 9,602 | 219.816 | 20.367 | 44.137 | 100.000 | 1,795.457 |
| Ln(Concentration) | 9,602 | 3.959 | 3.063 | 3.810 | 4.615 | 71.158 |
| **Chloride** | | | | | | |
| Concentration | 125,944 | 110,353.20 | 5,280.000 | 16,000.000 | 38,900.000 | 1,030,305.00 |
| Ln(Concentration) | 125,944 | 9.372 | 8.572 | 9.680 | 10.569 | 2.146 |
| **Barium** | | | | | | |
| Concentration | 42,960 | 57.980 | 31.450 | 49.000 | 73.000 | 52.099 |
| Ln(Concentration) | 42,960 | 3.725 | 3.480 | 3.912 | 4.304 | 1.074 |
| **Strontium** | | | | | | |
| Concentration | 26,465 | 717.344 | 79.000 | 260.000 | 671.000 | 1,373.011 |
| Ln(Concentration) | 26,465 | 5.373 | 4.382 | 5.565 | 6.510 | 1.752 |

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

*Panel C – Distribution of surface water quality observations*

| **Unique HUC10 by state** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
|---|---|---|---|---|---|---|
| | 1,928 | 180 | 136 | 171 | 243 | 72 |
| | | | | | | |
| **Unique HUC10 by state/ion** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
| Bromide | 401 | 80 | 31 | 70 | 148 | 54 |
| Chloride | 1,900 | 179 | 135 | 171 | 242 | 71 |
| Barium | 1,099 | 138 | 92 | 130 | 199 | 69 |
| Strontium | 620 | 150 | 57 | 183 | 230 | 87 |
| | | | | | | |
| **Unique monitoring stations by HUC10** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
| | 11,813 | 16 | 6 | 13 | 22 | 13 |
| | | | | | | |
| **Unique monitoring stations by HUC10/ion** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
| Bromide | 1,365 | 8 | 3 | 5 | 9 | 8 |
| Chloride | 11,453 | 15 | 6 | 12 | 21 | 13 |
| Barium | 6,467 | 14 | 5 | 11 | 20 | 11 |
| Strontium | 4,751 | 16 | 7 | 14 | 22 | 12 |
| | | | | | | |
| **Water quality observations by HUC10/ion** | **N** | **Mean** | **p25** | **p50** | **p75** | **SD** |
| Bromide | 15,504 | 39 | 4 | 12 | 42 | 63 |
| Chloride | 169,339 | 89 | 12 | 38 | 114 | 152 |
| Barium | 67,269 | 61 | 11 | 40 | 85 | 73 |
| Strontium | 47,542 | 77 | 15 | 49 | 106 | 91 |

Table 2, Panel C, presents statistics on the distribution of surface water quality observations in the sample.

**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* | -0.1111 | -0.0065 | **-0.1814*****| **-0.1098**** | **-0.1047***** | **-0.0738**** | **-0.0447**** | -0.0384 | **-0.1443***** | **-0.0918**** | **-0.1461***** | **-0.0916**** |
| | [0.0700] | [0.0515] | **[0.0550]** | **[0.0530]** | **[0.0345]** | **[0.0348]** | **[0.0223]** | [0.0290] | **[0.0381]** | **[0.0367]** | **[0.0418]** | **[0.0369]** |
| Observations | 15,504 | 14,284 | 169,339 | 158,789 | 67,269 | 60,782 | 47,542 | 45,374 | 299,654 | 279,229 | 220,500 | 206,458 |
| R-squared | 0.979 | 0.988 | 0.868 | 0.906 | 0.975 | 0.980 | 0.993 | 0.995 | 0.961 | 0.971 | 0.964 | 0.973 |
| Treatment Sample | HUC10s with HF activity in the pre-disclosure period | | | | | | | | | | | |
| 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 state disclosure mandates on the respective ion concentrations. The models in Columns 9–12 pool all four ion concentrations, as described in Section 4. In Columns 1–10, the sample consists of a treatment sample of HUC10s with HF activity in the pre-disclosure period and a control sample of HUC10s without HF activity in the pre-disclosure period that are located within sub-regions (HUC4s) in treated states. In Columns 11–12, the sample again consists of a treatment sample of HUC10s with HF activity in the pre-disclosure period, but the control sample of HUC10s without HF activity in the pre-disclosure period is 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. 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**
*Panel A – Analytes that are less indicative of HF impact*

| | Dissolved oxygen (DO) | | Fecal Coliform (μg/l) | | Phosphorus (μg/l) | | All Analytes pooled | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| *HUC10_HF×POST* | -0.0209 | 0.0223 | -0.0477 | 0.1501 | -0.0215 | -0.0493 | -0.0237 | -0.0097 |
| | [0.0150] | [0.0136] | [0.1821] | [0.5996] | [0.0444] | [0.0494] | [0.0262] | [0.0305] |
| Observations | 105,731 | 100,186 | 20,433 | 19,239 | 105,333 | 99,290 | 231,497 | 218,715 |
| R-squared | 0.505 | 0.635 | 0.565 | 0.637 | 0.759 | 0.817 | 0.914 | 0.937 |
| 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 directly related to HF. The sample consists of a treatment sample of HUC10s with HF activity in the pre-disclosure period and a control sample of HUC10s without HF activity in the pre-disclosure period that are located within sub-regions (HUC4s) 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. 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* | **-0.1946**** | -0.2063 | -0.0247 | -0.0072 | -0.0290 | 0.0199 | 0.0110 | 0.0113 | -0.0269 | -0.0043 |
| | **[0.0889]** | [0.1482] | [0.0427] | [0.0673] | [0.0255] | [0.0291] | [0.0444] | [0.0469] | [0.0322] | [0.0458] |
| Observations | 15,446 | 13,382 | 135,915 | 125,441 | 40,870 | 36,030 | 22,195 | 19,934 | 214,426 | 194,787 |
| R-squared | 0.971 | 0.985 | 0.878 | 0.913 | 0.977 | 0.981 | 0.984 | 0.990 | 0.954 | 0.966 |
| 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 conventional wells around the introduction of the disclosure mandates. The sample consists of a treatment sample of HUC10s with conventional drilling in the pre-disclosure period and a control sample of HUC10s without conventional drilling in the pre-disclosure period that are located within sub-regions (HUC4s) in treated states. *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. 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* | | | | **-0.1237**$^{***}$ | **-0.1688**$^{***}$ | **-0.1357**$^{**}$ | | | | **-0.0812**$^{**}$ | **-0.0929**$^{*}$ | **-0.0814**$^{*}$ |
| | | | | **[0.04324]** | **[0.0648]** | **[0.0554]** | | | | **[0.0390]** | **[0.0496]** | **[0.0454]** |
| *HUC10_HF×CUM_WASTEWATER* | **-0.0327**$^{***}$ | | | -0.0117 | | | **-0.0182**$^{**}$ | | | -0.0062 | | |
| | **[0.00773]** | | | [0.00797] | | | **[0.0075]** | | | [0.0070] | | |
| *HUC10_HF×CUM_HF_STANDARDS* | | **-0.0279**$^{***}$ | | | 0.0100 | | | **-0.0194**$^{**}$ | | | 0.0004 | |
| | | **[0.0058]** | | | [0.0128] | | | **[0.0079]** | | | [0.0109] | |
| *HUC10_HF×CUM_HF_REG* | | | **-0.0182**$^{***}$ | | | -0.0021 | | | **-0.0121**$^{***}$ | | | -0.0027 |
| | | | **[0.00368]** | | | [0.0056] | | | **[0.0046]** | | | [0.0051] |
| Observations | 299,654 | 299,654 | 299,654 | 279,229 | 299,654 | 299,654 | 279,229 | 279,229 | 279,229 | 279,229 | 279,229 | 279,229 |
| R-squared | 0.961 | 0.961 | 0.961 | 0.971 | 0.961 | 0.961 | 0.971 | 0.971 | 0.971 | 0.971 | 0.971 | 0.971 |
| Coef. *HUC10_HF×POST* (Table 3) | | | | **-0.1443** | **-0.1443** | **-0.1443** | | | | **-0.0918** | **-0.0918** | **-0.0918** |
| 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 an alternative version of Eq. (1), in which we replace the variable, *POST*, with three alternative variables: (i) *CUM_WASTEWATER,* which counts the number of regulations related to wastewater handling (i.e., the variable is cumulative and increases by one when a new regulation for wastewater handling is introduced in a state); (ii) *CUM_HF_STANDARDS,* which counts the number of HF drilling standards (i.e., the variable is cumulative and increases by one when a new HF drilling standard is introduced in a state); (iii) *CUM_HF_REG,* which counts the number of all other HF regulations, including HF drilling and wastewater handling standards (i.e., the variable is cumulative and increases by one when a new HF regulation is introduced in a state). The sample consists of a treatment sample of HUC10s with HF activity in the pre-disclosure period and a control sample of HUC10s without HF in the pre-disclosure period that are located within sub-regions (HUC4s) 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. 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 – Well Entry – Extensive Margin**

| | #HF wells (1) | #HF wells (2) | #HF wells (3) | #HF wells (4) | #[HF – V] wells (5) | #[HF – V] wells (6) |
|---|---|---|---|---|---|---|
| *POST* | **-0.0631*****<br>**[0.0205]** | **-0.0483***<br>**[0.0288]** | **-0.0559*****<br>**[0.0168]** | **-0.0354***<br>**[0.0198]** | **-0.0605****<br>**[0.0275]** | **-0.0926*****<br>**[0.0291]** |
| *CUM_HF_REG* | | | | | **0.0631*****<br>**[0.0115]** | **0.06569****<br>**[0.0128]** |
| Observations | 197,316 | 112,455 | 197,694 | 112,644 | 197,316 | 112,644 |
| R-squared | 0.470 | 0.464 | 0.384 | 0.389 | 0.482 | 0.440 |
| 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 estimates for the impact of the disclosure mandates on HF well entry. The sample comprises HUC10s in treatment states over shales. The dependent variable is the natural logarithm of one plus the number of new HF wells (or the number of HF wells minus the number of conventional vertical wells) spudded in a given HUC10-Year-Month. In Columns 1–4, we report the results for HF wells. In Columns 5–6, we report the results for HF well entry, relative to conventional well entry. In addition, we control for changes in other HF regulations. In Columns (2), (4) and (6) the sample comprises HUC10s in HUC8s that are located in at least two states (i.e., crossing state lines). *POST* is a binary variable marking water quality observations in the post-disclosure period. In Columns 1–2, we include Region x Month x Year fixed effects in the model. In Columns 3–6, we include Shale x Month x 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 Effects)**

| | 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* | **0.0061*** | 0.0014 | -0.0004 | -0.0018 | 0.0010 |
| | **[0.0036]** | [0.0018] | [0.0012] | [0.0017] | [0.0013] |
| *#WELL_HUC10_HF_PRE* | **0.0821***** | **0.0076*** | **0.0094*** | 0.0062 | **0.0084**** |
| | **[0.0156]** | **[0.0042]** | **[0.0055]** | [0.0056] | **[0.0038]** |
| Observations | 4,797 | 31,119 | 16,081 | 15,555 | 67,552 |
| R-squared | 0.893 | 0.922 | 0.892 | 0.980 | 0.986 |
| F-Test | 0.000 | 0.179 | 0.091 | 0.204 | 0.060 |
| 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 estimates for the per-well effects of new HF wells on ion concentrations, separately for the pre- and the post-disclosure periods. For the intensive margin analysis, the sample consists of HUC10s with HF activity in the pre- and post-disclosure periods. *#WELL_HUC10_HF_POST* (*PRE*) is a cumulative well count variable, which increases by one when a new HF well in HUC10 is spudded. Given findings in Bonetti et al. (2021) and in Figure 5, we align water measurements with well counts that are lagged by 120 days before the respective water quality reading. 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)

| | Oil&Gas Production / All Ions (μg/l) (1) | Oil&Gas Production / All Ions (μg/l) (2) | Oil&Gas Production / All Ions (μg/l) (3) | Oil&Gas Production / All Ions Pooled (μg/l) (4) |
|---|---|---|---|---|
| *HUC10_HF×POST* | **51.0362*****<br>**[17.8636]** | **25.2824***<br>**[15.2585]** | **57.2864*****<br>**[19.8810]** | **35.0907***<br>**[19.7886]** |
| Observations | 243,328 | 227,076 | 224,520 | 207,810 |
| R-squared | 0.944 | 0.964 | 0.944 | 0.964 |
| 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 estimates from an alternative version of Eq. (1), for which the dependent variable is the ratio of the average Oil&Gas production (bbl) in a given HUC10-Month-Year and the sum of the four ion concentrations (μg/l). Columns 1–2 report OLS estimates for the impact of disclosure mandates on this ratio for sample consisting of a treatment sample of HUC10s with HF activity in the pre-disclosure period (and non-missing oil and gas production data) and a control sample of HUC10s without HF in the pre-disclosure period that are located within sub-regions (HUC4s) in treated states. Columns 3–4 report OLS estimates for the impact of disclosure mandates on the ratio of the Oil&Gas production (bbl) and ion concentrations (μg/l) for a sample consisting of the treatment HUC10s with HF activity in the pre- and post-disclosure period (and non-missing oil and gas production data) and a control HUC10s without HF in the pre-disclosure period that are located within sub-regions (HUC4s) in treated states. *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 Fracking Fluids**

| | All Hazardous Chemicals (1) | Chloride-related Chemicals (2) | Water Consumed (3) |
|---|---|---|---|
| *POST* | **-0.0802**** | **-0.1115***** | **-0.0339**** |
| | **[0.0400]** | **[0.0428]** | **[0.0165]** |
| Observations | 8,824 | 6,054 | 6,054 |
| R-squared | 0.401 | 0.355 | 0.525 |
| Sample | HUC10s over shales | | |
| HUC10 FE | Yes | Yes | Yes |
| Month×Year FE | Yes | Yes | Yes |

Table 9 reports OLS estimates for the impact of the disclosure mandates on the chemicals used for HF wells. Data on chemicals used are disclosed by well operators are from Konschnik and Dayalu (2016). The dependent variable is constructed at the HUC10 level, averaging for each HUC10-Month-Year the amount of hazardous chemicals, chloride-related chemicals, and water consumed, respectively, as disclosed by each HF well scaled 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 fracturing 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 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 10 – HF-Related Incidents**

| | All incidents | | Wastewater disposal incidents | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *POST* | **-0.1474*****<br>**[0.0308]** | **-0.0884****<br>**[0.0367]** | **-0.1443*****<br>**[0.0308]** | **-0.0894****<br>**[0.0371]** |
| Observations | 6,480 | 4,320 | 6,440 | 4,280 |
| R-squared | 0.187 | 0.207 | 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 estimates for the impact of the disclosure mandates on HF-related incidents such as spills, leaks and accidents. The sample comprises HUC10s over shales. The dependent variable is the logarithm of one plus the number of HF-related incidents in a given HUC10-Year-Month. Columns 1–2 report the results for all HF-related incidents. Columns 3–4 report the results using only spills related to the disposal of wastewater. In Columns 2 and 4, the sample comprises HUC10s in HUC8s that are located in at least two neighboring states, i.e., crossing state lines. *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 11 – HF Activity and Water Quality – Cross Sectional Analyses

| | All Ions Pooled (µg/l) | | | | |
|---|---|---|---|---|---|
| | *Partitioning based on Disclosure Features:* | | *Partitioning based on Public Pressure / Litigation Risk:* | | |
| | *Trade Secret Exemptions* | *Disclosure Timeliness* | *Media Scrutiny* | *Households Education & Income* | *Publicly Owned Operators* |
| | (1) | (2) | (3) | (4) | (5) |
| *POST×HUC10_HF×High Group* | **-0.2428*****<br>**[0.0866]** | **-0.2853*****<br>**[0.0975]** | **-0.1513*****<br>**[0.0526]** | **-0.2044*****<br>**[0.0499]** | **-0.1853*****<br>**[0.0536]** |
| *POST×HUC10_HF×Low Group* | **-0.0846*****<br>**[0.0307]** | **-0.0610*****<br>**[0.0198]** | **-0.0899****<br>**[0.0370]** | -0.0561<br>[0.0366] | **-0.1111*****<br>**[0.0389]** |
| Observations | 299,654 | 299,654 | 299,978 | 195,211 | 299,654 |
| R-squared | 0.961 | 0.961 | 0.962 | 0.952 | 0.961 |
| Treatment Sample | HUC10s with HF activity 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 |

Table 11 reports OLS estimates from an alternative version of Eq. (1), for which we split the key variable of interest, *POST×HUC10_HF,* by two non-overlapping interaction variables marking observations in the post-disclosure period that fall into the *High Group* and into the *Low Group*, respectively. The high/low splits are set for: (1) 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; (2) states, for which the required disclosures need to be more timely, based on a *below* (*above*) the sample median split on the #days between the spud date and the required regulatory filing date; (3) counties with an *above* (*below*) the sample median presence of local newspapers in the year up to the adoption of the disclosure mandate, i.e., counting newspapers operating in the 360 days before the disclosure mandate adoption dates; (4) counties with an *above* (*below*) the sample median fraction of households with at least a college degree and also an *above* (*below*) the sample median income per capita; (5) HUC10s with an *above* (*below*) the sample median fraction of wells owned by publicly traded operators. *HUC10_HF* is an indicator variable marking treated watersheds (HUC10s). The sample includes treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF in the pre-disclosure period that are located within sub-regions (HUC4s) in treated states. *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.

## 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 |

FracFocus Chemical Disclosure Registry

**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 disclosure mandates have been adopted in the state. 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 the 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 A

This Appendix provides descriptive and anecdotal evidence on the set of conditions for the link between the adoption of HF disclosure and changes in the HF operators' practices, on the mechanisms (i.e., potential benefits/costs) through which the disclosure affects HF operators practices, as well as background information on other concurrent regulatory changes that can affect our inferences.

**Table OA1: Demand for HF Disclosures**
*Panel A: Call for more transparency on the HF Fluids*
*Panel B: Demand from policy makers and regulators*
*Panel C: Demand from local community, NGOs, and environmental activists*
*Panel D: Demand from potential plaintiffs*
*Panel E: Demand from shareholders*

**Table OA2: How HF Disclosures Impose Costs on HF Operators**
*Panel A: Liability risk (causation)*
*Panel B: Public shaming*
*Panel C: Regulatory risk*
*Panel D: Investors response*

**Table OA.3 Summary of Other Major Changes in the State-Level Oil and Gas Regulations**

**Table OA.4 Summary of the Trade Secret State-Level Regulations**

**Table OA1: Demand for HF Disclosures**

*Panel A: Call for more transparency on the HF Fluids*

| Outlet | Date | *Title* / Quotes |
|---|---|---|
| Pennlive | September 5, 2010 | *'Gasland,' a documentary about the natural gas industry in Pennsylvania, is a national hit*<br>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.<br>(…)<br>**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?**<br>**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 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*<br>(…) <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.<br><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*<br>(…) <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. (…) |

*Panel B: Demand from policy makers and regulators*

The Obama Administration took disclosure of HF in its hands and attempted to introduce federal legislation on this matter, as highlighted by the following extracts below:

| **Outlet** | **Date** | ***Title* / Quotes** |
|---|---|---|
| Reuters | January 25, 2012 | *Obama backs shale gas drilling*<br>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.<br>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.<br>Obama said the administration would move forward with rules that would require companies to disclose chemicals used during the fracking process on public lands. 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*<br>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.<br>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.<br>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.<br>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. The final rule hews closely to a draft that has lingered since the Obama administration proposed it in May 2013. 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.<br>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. |

*Panel C: Demand from local communities, NGOs, and environmental activists*

Environmental NGOs and local community put pressure on states and authorities to increase the enforcement and effectiveness of disclosure rules, as narrated in the following example:

| **Outlet** | **Date** | ***Title* / Quotes** |
|---|---|---|
| The Bismarck Tribune | April 1, 2012 | *Environmentalists sue over fracking fluids*<br>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." |

*Panel D: Demand from potential plaintiffs*

In case of accidents, health issues for humans and animals, it is argued that potential parties involved may use the information to prove the existence of causation. In the following example, an article in a local newspaper explains how landowners (in the proximity of HF wells) may use HF disclosures.

| **Outlet** | **Date** | ***Title* / Quotes** |
|---|---|---|
| Great Falls Tribune | January 19, 2017 | *Fracking chemicals focus of lawsuit seeking more disclosure*<br>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.<br>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.<br>The first recorded hydraulic fracturing operation in Montana was in the 1950s, Halvorson said.<br>"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.<br>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.<br>The plaintiffs<br>Montana Environmental Information Center, Natural Resources Defense<br>Council, Dr. Mary Anne Mercer, David Katz, Anne Moses, Jack and Bonnie, Martinell, Dr. Willis Weight, and Dr. David Lehnherr. |

*Panel E: 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*<br>ITEM 10 – REPORT ON NATURAL GAS PRODUCTION<br>This proposal was submitted by The Park Foundation, 311 California St., Suite 510, San Francisco, CA 94104, as lead proponent of a filing group.<br>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.<br><u>There is virtually no public disclosure of chemicals used at fracturing locations</u>. 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.<br>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.<br>Because of public concern, in September 2009, some natural gas operators and drillers began advocating greater disclosure of the chemical constituents used in fracturing.<br><u>In the proponents’ opinion, emerging technologies to track ‘chemical signatures’ from drilling activities increase the potential for reputational damage and vulnerability to litigation</u>. <u>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</u>.<br><u>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.</u><br>Supporting statement:<br><u>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.”</u><br>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 Hydraulic Fracturing 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 | |

**Table OA2: How HF Disclosures Impose Costs on HF Operators**

*Panel A: Liability risk*

The fact that disclosure may increase liability risk is illustrated indirectly. The following examples illustrate how the existence of trade secret exemptions impair the ability of disclosure rules to provide key information to the key:

| **Outlet** | **Date** | ***Title* / Quotes** |
|---|---|---|
| Great Falls Tribune | January 19, 2017 | *Fracking chemicals focus of lawsuit seeking more disclosure*<br>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.<br>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.<br>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.<br>"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*<br>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.<br>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. 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. |
| Reuters | September 26, 2017. | *Cabot Oil & Gas Co. [COG.N] has settled a lawsuit filed by two families in Dimock*<br>HARRISBURG, Pa. (Reuters) – 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. 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.<br>“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. |

*Panel B: Public shaming*

The article below discusses the reasons that led the state of New York to ban HF activities, exposing the practice as highly harmful for the ecological health of a community.

| **Outlet** | **Date** | ***Title* / Quotes** |
|---|---|---|
| The New York Post | December 18, 2014 | *A pain in the gas! NY bans fracking, but don't blame me*<br>'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 (left)<br>Get the frack outta here!<br>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.<br>"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."<br>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."<br>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. |

*Panel C: Regulatory risk*

The following example illustrates that HF disclosure could tighten and become a federal matter:

| **Outlet** | **Date** | ***Title* / Quotes** |
| --- | --- | --- |
| Congressional research on HF and disclosure requirement (Murril and Vann, 2012) | May 2012 | *Congressional research on HF and disclosure requirements*<br>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.<br>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 (…)<br>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*<br>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.<br>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.<br>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.<br>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.<br>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. |

*Panel D: Investors response*

The following example illustrates that investors are organizing and campaigning for more transparency on HF practices:

| **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<br><br>INDUSTRY SCORES "F" ON RISK DISCLOSURES TO INVESTORS<br>*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.*<br>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).<br><u>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.</u> Even the highest scoring company, Encana Corporation (<u>ECA</u>) 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.)<br><u>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</u>. "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 $CO_2$ equivalent per valve. Devon plans to replace 3,000 additional valves, recouping the cost of each within two months.

## Table OA.3 Summary of other Major Changes in the State-Level Oil and Gas Regulations

| 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 |
| **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 |
| **Pennsylvania** | *SECTION 95.10/SECTION 78.60* 1989/7/29 | | *RULE 3215* 2012/4/16 | *SECTION 78.56* 2013/12/13 (1) | | *SECTION 3211-3227* 2012/4/16(3) | | |
| **Texas** | *SECTION 3.8* 2013/4/15 | *SECTION 3.9* 2014/11/17 | | *SECTION 3.8* 2013/4/15(2) | | *SECTION 3.13* 2014/1/1(4) | | |

| State | Wastewater Disposal | | | | | HF Drilling Standards | | |
|---|---|---|---|---|---|---|---|---|
| | **Discharge Prohibited** | **Injection Well** | **Pit Siting** | **Pit Liner** | **Pit Freeboard** | **Well Casing** | **BOP (Blowout Control)** | **Mechanical Integrity Test** |
| **Utah** | *CODE 649-9-3* 2013/8/1 | *CODE 649-3-39* 2012/11/1 | *CODE 649-3-16/CODE 649-9-3* 2013/8/1 | *CODE 649-9-4* 2013/8/1[2] | | *CODE 649-3-8* 1989/3/17 | | *CODE 649-3-13* 1989/3/17 |
| **West Virginia** | | | | *SECTION 35-8-17* 2016/6/9[2] | | *SECTION 22-6-21-30* 2011/2/14 | | |
| **Wyoming** | | *CHAPTER 4 SECTION 4* 2005/1/1 | *CHAPTER 4 SECTION 1* 2015/6/4 | *CHAPTER 4 SECTION 1* 2015/6/4 | | *CHAPTER 3 SECTION 4* 2010/8/17 | *CHAPTER 3 SECTION 28* 2010/8/17 | *CHAPTER 18 SECTION 9* 2018/11/13 |

(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 to hydraulic fracturing (HF) in the O&G state legislations along with the respective adoption dates. Besides disclosure rule, 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 related regulation changes carefully and identified the most prevalent and relevant regulatory aspects among 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, an academic research database that contains the administrative codes, regulatory texts, and regulation tracking for all U.S. states. The cells in the table record the corresponding regulatory change as well as its adoption date. Using the data in this table we build the three variables used in Table 5 in the paper: *HUC10_HF×CUM_WASTEWATER* cumulates over time the number of regulations related to wastewater disposals; *HUC10_HF×CUM_HF_STANDARDS* cumulates over time the number of regulations on HF drilling standards; HUC10_HF×CUM_HF_REG cumulates over time the number of regulations related to wastewater disposal and HF drilling standards.

**Table OA.4 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 |
| **Mississippi**[4] | 1 | 1 | 0 | 0 | 0 |
| **Montana**[5] | 0 | 0 | 0 | 0 | 0 |
| **New Mexico**[6] | 0 | 0 | 0 | 0 | 0 |
| **North Dakota**[7] | 0 | 0 | 0 | 0 | 0 |
| **Ohio**[8] | 1 | 1 | 0 | 0 | 0 |
| **Oklahoma**[9] | 1 | 0 | 0 | 0 | 1 |
| **Pennsylvania**[10] | 1 | 0 | 1 | 0 | 0 |
| **Texas**[11] | 0 | 0 | 0 | 0 | 1 |
| **Utah**[12] | 0 | 0 | 0 | 0 | 0 |
| **West Virginia**[13] | 1 | 0 | 1 | 0 | 0 |
| **Wyoming**[14] | 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 *Mississippi Oil&Gas Board Rule 1.26*
5 *Mont. Admin. R. 36.22.608, 36.22.1015 & 1016*
6 *New Mexico Code R. 19.15.16.19 (b)*
7 *North Dakota Admin. Code 43-02-03-27.1 (1)(g)&(2)(i)*
8 *Senate Bill 315*
9 *Revised Oklahoma Admin. Code. 165:10-3-10*
10 *Pa. Legis. Serv. 2012-13 (HB 1950) §3222.1*
11 *Texas Admin. Code 3.29*
12 *Utah Admin. Code 649-3-39*
13 *CSR 8-5.6&8-10.1*
14 *Wyoming Oil&Gas Conservation Commission Rules, Chapter 3,45*

This table presents a summary of the trade secret legislations on O&G wells in US states. Using the NRDC report (2012) and cross-checking with states' regulations, we identify five conditions that states may require to claim a trade-secret exemption: (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 (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.

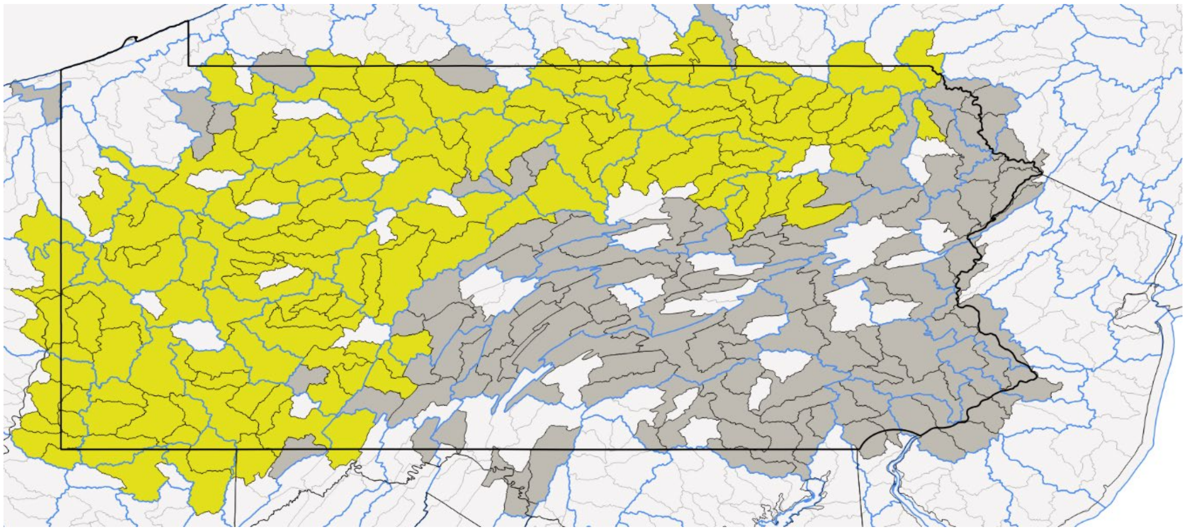
# Online Appendix B

## Contents

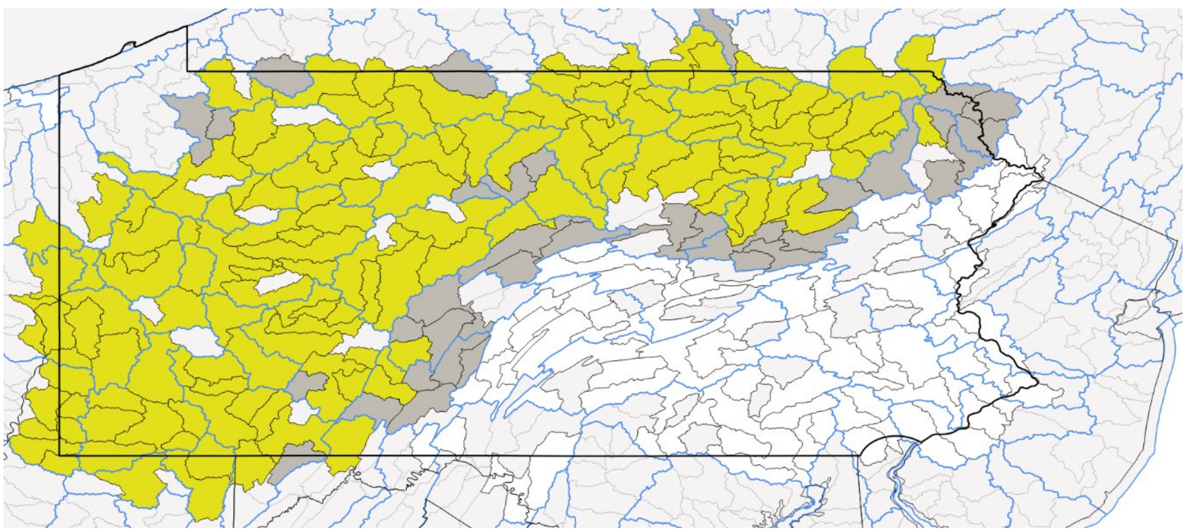
This appendix contains analyses addressing specific concerns about the inferences of the paper. These analyses are not included in the main body of the paper for the sake of brevity.

## OB1. Identification maps

*Panel A*



*Panel B*



The figure illustrates how the identification strategy exploits variation across treated and control watersheds using Pennsylvania as an example. Panel A visually shows the within-state design. Watersheds with HF in the pre-period (treatment or exposure) are in yellow. Watersheds with no HF in the pre-period (control) are in dark gray. Watersheds with no water measurements are in light gray. The black (blue) lines depict HUC10 (HUC8s) borders.
Panel B visually shows the within-HUC8 design. Watersheds with HF in the pre-period (treatment or exposure) are in yellow. Watersheds with no HF in the pre-period (control) are in dark gray. Watersheds with no water measurements are in light gray. HUC10s no longer contributing to identification are in white. The black (blue) lines depict HUC10 (HUC8s) borders.

**OB2. Sample selection choices**

We examine whether our inferences are robust to alternative sampling selection choices. Specifically, we re-estimate Eq. (1) by considering the following alternative samples: (i) HUC10s in treated states; (ii) HUC10s in HUC4s with HF activity; (iii) HUC10s in treated states or in treated HUC4s. Table B1 reports the results that confirm 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* | **-0.2406**$^{***}$ | **-0.0920**$^{**}$ | **-0.1441**$^{***}$ | **-0.0894**$^{**}$ | **-0.2311**$^{***}$ | **-0.0775**$^{**}$ |
| | **[0.0453]** | **[0.0369]** | **[0.0380]** | **[0.0358]** | **[0.0439]** | **[0.0325]** |
| Observations | 449,192 | 415,319 | 357,612 | 336,484 | 518,924 | 484,126 |
| R-squared | 0.949 | 0.962 | 0.964 | 0.973 | 0.953 | 0.965 |
| 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 from Eq. (1) of the impact of disclosure mandates on ion concentrations. In Columns (1) – (2), 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-disclosure period and located in treated states. In Columns (3) – (4), 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-disclosure period and located over Sub-Region (HUC4s). In Columns (5) – (6), 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-disclosure period and located over Sub-Region (HUC4s) or 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.

## OB3. Other robustness tests

*OB.3.1 Clustering of standard errors*

We examine whether our inferences are robust to alternative clustering options. Specifically, we re-estimate Eq. (1) by considering the following clustering strategies: (i) HUC8-state level; (ii) state-level. Table B2 reports the results that confirm the paper's main inferences.

**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* | **-0.1443*****<br>**[0.0417]** | **-0.0918****<br>**[0.0448]** | **-0.1443***<br>**[0.0704]** | **-0.0918***<br>**[0.0446]** |
| Observations | 299,978 | 279,560 | 299,978 | 279,560 |
| R-squared | 0.962 | 0.973 | 0.962 | 0.973 |
| | 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 from Eq. (1) of the impact of 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-disclosure period and located over Sub-Region (HUC4s) in treated states.
In Columns (1) – (2), standard errors (in parentheses) are clustered by Sub-Basin (HUC8)-State are reported below the coefficients. In Columns (3) – (4), standard errors (in parentheses) are clustered by State are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

*OB.3.2 Ion concentration measurements functional form*

We examine whether our inferences are robust to an alternative functional form of the ion concentration measurements. Specifically, we re-estimate Eq. (1) by considering concentration measures in levels instead of in logs. Table B3 reports the results that confirm the paper's main inferences.

**Table B3 – Disclosure Mandates and Water Quality**

| | All Ions pooled (µg/l) not logged | |
|---|---|---|
| | (1) | (2) |
| *HUC10_HF×POST* | **-3,464.55*****<br>**[1,230.36]** | -1,029.13<br>[1,119.22] |
| Observations | 299,978 | 279,560 |
| R-squared | 0.922 | 0.957 |
| Monitoring station FE | Yes | Yes |
| Weather controls | Yes | Yes |
| State×Month×Year FE | Yes | No |
| HUC8×Month | Yes | No |
| HUC8×Month×Year FE | No | Yes |

This table reports OLS estimates from Eq. (1) of the impact of disclosure mandates on ion concentrations in which ion concentration measurements are not logged. 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-disclosure period and located over Sub-Region (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 Ion concentration measurements truncation choices form*

We examine whether our inferences are robust to alternative truncation choices for the ion concentration measurements. Specifically, we re-estimate Eq. (1) by considering the following truncation options: (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. Table B4 reports the results that confirm 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* | **-0.1287**$^{***}$ | **-0.0775**$^{**}$ | **-0.1367**$^{***}$ | **-0.0911**$^{**}$ | **-0.1298**$^{***}$ | **-0.0753**$^{**}$ |
| | **[0.0359]** | **[0.0380]** | **[0.0365]** | **[0.0362]** | **[0.0366]** | **[0.0376]** |
| Observations | 285,721 | 265,553 | 298,728 | 278,386 | 291,845 | 272,119 |
| R-squared | 0.963 | 0.973 | 0.962 | 0.972 | 0.962 | 0.972 |
| 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 from Eq. (1) of the impact of disclosure mandates on different truncation versions of 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-disclosure period and located over Sub-Region (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.3.4 Ion concentration measurements*

We further examine whether our inferences are robust to alternative definitions of the 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:

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.[1]

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.

[1] 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.

We use V2 only to gauge the sensitivity of our results to different ways of dealing with BDL/LD/ND/NR measurements.

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 replicate Equation (1) using Version 2 and Version 3. Table B5 reports the results that confirm the 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* | **-0.0659**$^{***}$ **[0.0163]** | **-0.05667**$^{**}$ **[0.0280]** | **-0.1164**$^{***}$ **[0.0375]** | **-0.0417**$^{*}$ **[0.0212]** |
| Observations | 295,038 | 274,649 | 322,285 | 300,403 |
| R-squared | 0.983 | 0.987 | 0.962 | 0.973 |
| 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 from Eq. (1) of the impact of disclosure mandates on ion concentrations measured under 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-disclosure period and located over Sub-Region (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 now examine whether our results reflect trends in water pollution coming from economic activity, in general, and agricultural activity, in particular. To do so we collect data on the fraction of land devoted to agriculture from the Census of Agriculture (National Agricultural Statistics Service (NASS), and compute the HUC10 fraction of land devoted to agricultural activity in 2007. Then, we split the treatment sample of HUC10s with HF in the pre-period in two non-overlapping groups based on the sample median of the fraction of land devoted to agriculture. HUC10s with an above the median are classified in the *High_Agr* group, while HUC10s with a below the median are classified in the *Low_Agr* group. Table B6, reports OLS coefficients from the estimation of Eq. (1) in which we replace the variable, *POST×HUC10_HF*, with two non-overlapping variables marking observations in the post-disclosure period in HUC10s with an above (below) the pre-disclosure period fraction of land devoted to agricultural activity, *High_Agr* (*Low_Agr*). The table suggests that our results do not reflect pollution coming from agriculture.

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

| | Bromide (μg/l)<br>(1) | Chloride (μg/l)<br>(2) | Barium (μg/l)<br>(3) | Strontium (μg/l)<br>(4) | All (μg/l)<br>(5) |
|---|---|---|---|---|---|
| *POST×HUC10_HF×High_Agr* | 0.0104 | **-0.1838*** | **-0.1488***** | 0.0032 | **-0.1440**** |
| | [0.1017] | **[0.1023]** | **[0.0520]** | [0.0336] | **[0.0658]** |
| *POST×HUC10_HF×Low_Agr* | **-0.2104***** | **-0.1756***** | -0.0601 | **-0.0715***** | **-0.1424***** |
| | **[0.0667]** | **[0.0384]** | [0.0369] | **[0.0260]** | **[0.0285]** |
| Observations | 7,183 | 114,404 | 44,158 | 29,494 | 195,239 |
| R-squared | 0.871 | 0.855 | 0.795 | 0.964 | 0.952 |
| 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) the pre-disclosure period fraction of land devoted to agricultural activity, *High_Agr* (*Low_Agr*). *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-disclosure period and located over Sub-Region (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. Media coverage**

In this section, we examine the media coverage of HF-related environmental water consequences around the adoption of the disclosure mandates. This test aims at examining whether one channel through which disclosures can impose costs on HF operators is public shaming. Given that newspaper stories tend to rapidly spread to many other types of news outlets, the test explores whether HF disclosures are more costly for HF operators when a wider audience of stakeholders is likely to see them.

Operationally, we identify and download newspaper articles from Lexis-Nexis between January 2005 and December 2016, which contain in the headline the following keywords: "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*"). Then, we separate local from national newspapers, and assigned 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. We limit the sample to counties located over shales in the treated states only. We then regress the natural logarithm of one plus the articles-count variable on a binary variable marking the months after the disclosure regulation entry-into-force dates, *POST,* County and Year-Month FEs. Inference is based on standard errors clustered at the state-level.

Table B7 reports the estimation results. We observe an increase in the number of newspaper articles pointing to HF as a source of water pollution after the disclosure mandate. Moreover, the estimated coefficient is virtually unaffected when we control for HF activity [Column (2)] suggesting that the increase in media coverage is coming from disclosure and not only from an increase in HF activity over time. Lastly, we observe a greater increase in media coverage in counties where the population is more educated and wealthier.

**Table B7 – Media Coverage**

| Dependent Variable: | Local Media Coverage | | | |
|---|---|---|---|---|
| | | | *Splitting by:* | |
| | | | *Income* | *Education* |
| | (1) | (2) | (3) | (4) |
| *Post* | **0.07356*** | **0.0738*** | | |
| | **[0.0372]** | **[0.0366]** | | |
| *#WELLS_HF* | | **0.0272***** | | |
| | | **[0.0021]** | | |
| *Post_HIGH* | | | **0.1460**** | **0.1371**** |
| | | | **[0.0654]** | **[0.0550]** |
| *Post_LOW* | | | 0.0029 | 0.0170 |
| | | | [0.0370] | [0.0313] |
| Observations | 7,392 | 7,392 | 7,392 | 7,392 |
| R-squared | 0.346 | 0.357 | 0.359 | 0.355 |
| Sample | Counties over shales | | | |
| County FE | Yes | Yes | Yes | Yes |
| Month×Year FE | Yes | Yes | Yes | Yes |

This table reports OLS estimates of the impact of the disclosure mandates on the newspaper coverage of HF potential water pollutions consequences. The dependent variable is the logarithm of one plus the number of newspaper articles pointing to HF as a source of water pollution by County-Year-Month. In Column (2) we control for the number of newly fractured HF wells in a County-Year-Month. In Column (3) 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 of income per capita, *POST_HIGH* (*POST_LOW*). In Column (4) 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* (*POST_LOW*). Level of education is the share of the population with at least a college degree. *POST* is a binary variable marking water quality 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. Predicting water measurement**

The timing of water quality measurements is not random. One concern is that such timing is systematically related to HF activity and that such possible relation varies with the adoption of the disclosure rules. To explore this concern, we re-shape the data at the HUC10-monthly level, and code up a count 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)–(2), shows that the adoption of the disclosure regulation is not strongly related to an increase in the frequency of water measurement in HUC10s with HF relative to HUC10s without HF. Then, we control for the new wells being spudded in a given HUC10-Month-Year. Table B8, Columns (3)–(4), shows that the disclosure mandates are again not strongly associated with a change in the frequency of water measurement after controlling for trends in HF activity. Moreover, water measurement does not seem to be predicted by HF activity.

**Table B8 – Trends in Water Measurements**

| | #readings<br>(1) | #readings<br>(2) | #readings<br>(3) | #readings<br>(4) |
|---|---|---|---|---|
| *HUC10_HF×POST* | **0.0210*** | -0.0030 | **0.0200*** | -0.0036 |
| | **[0.0105]** | [0.0138] | **[0.0095]** | [0.0138] |
| *#WELLS_HF* | | | 0.0007 | 0.0021 |
| | | | [0.0013] | [0.0015] |
| Observations | 375,726 | 356,420 | 375,726 | 356,420 |
| R-squared | 0.475 | 0.653 | 0.475 | 0.653 |
| 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 water quality 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.