NBER WORKING PAPER SERIES

INTERNALIZING EXTERNALITIES THROUGH PUBLIC PRESSURE: TRANSPARENCY REGULATION FOR FRACKING, DRILLING ACTIVITY AND WATER QUALITY

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Working Paper 30842
http://www.nber.org/papers/w30842

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 2023, Revised May 2024

We would like to thank Wes Austin, Jenn Baka, Marianne Bertrand, Thomas Bourveau, Susan Brantley, Matthias Breuer, Thomas Covert, Aytekin Ertan (discussant), Michael Greenstone, Jodi Grewal, Chris Hansen, Elaine Hill (discussant), Ginger Jin, Ryan Kellogg, Sendhil Mullainathan, Max Muller (discussant), Miao Liu, Felix Oberholzer-Gee, Joseph Shapiro, Luigi Zingales and workshop participants at the AEA 2022 Annual Meeting, Bocconi, Boston College, Chicago Booth Micro Lunch, Columbia Business School, EPA, FARS, Frankfurt School of Finance & Management, Goethe University Frankfurt, HEC Paris, University of Mannheim, University of Maryland, LMU München, London Business School, University of San Diego, University of St Gallen, Stanford University, Yale University Law and Economics, the UN PRI Seminar Series, the Scandinavian Accounting Research Conference 2023, the Shale Gas Network Conference, and the Swiss Winter Accounting Conference for helpful comments. We also gratefully acknowledge the excellent research assistance of Patricia Breuer, Tom Kim, Igor Kuznetsov, Alessandro Maimone, Fabian Nagel, Christopher Nance, Claudia Serra, and Zirui Song. This work is supported by research funding from the Energy Initiative at the University of Chicago Booth School of Business, IESE Business School and University of Bristol Business School. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Internalizing Externalities through Public Pressure: Transparency Regulation for Fracking, Drilling Activity and Water Quality
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NBER Working Paper No. 30842
January 2023, Revised May 2024
JEL No. D62,G38,K22,K32,L71,L72,M41,M48,Q53

ABSTRACT

The rise of shale gas and tight oil development has triggered a major debate about hydraulic fracturing (HF). In an effort to bring light to HF practices and their potential risks to water quality, many U.S. states have mandated disclosure for HF wells and the fluids used. We employ this setting to study whether targeting corporate activities that have dispersed externalities with transparency reduces their environmental impact. Examining salt concentrations that are considered signatures for HF impact, we find significant and lasting improvements in surface water quality between 9-14% after the mandates. Most of the improvement comes from the intensive margin. We document that operators pollute less per unit of production, cause fewer spills of HF fluids and wastewater and use fewer hazardous chemicals. Turning to how transparency regulation works, we show that it increases public pressure and enables social movements, which facilitates internalization.

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A online appendix is available at http://www.nber.org/data-appendix/w30842

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

1. Introduction

In this study, we pose the question in Brandeis' famous article and ask what publicity (or transparency) can do when it comes to environmental externalities. This question is highly relevant as transparency regulation has become a key policy tool in many areas (e.g., Fung *et al.*, 2007, Dranove and Jin, 2010, Weil *et al.*, 2013, Leuz and Wysocki, 2016). In fact, disclosure requirements have been called the third wave of environmental policy for pollution control, following a wave of direct regulation and a second wave of market-based approaches (Tietenberg, 1998, Graham, 2002). Despite having a long tradition in the U.S., going back to the 1986 Emergency Planning and Community Right-to-Know Act, which created the public Toxic Release Inventory (TRI), we still have relatively little evidence as to whether mandating transparency works for behaviors with dispersed negative externalities as well as how it produces intended (or unintended) effects.

We investigate these questions in the context of unconventional oil and gas (O&G) development, which combines horizontal drilling with hydraulic fracturing (HF) to extract shale gas and tight oil in deep formations. HF is considered the most important innovation in the energy sector since the introduction of nuclear energy, which has dramatically increased U.S. energy production and lowered consumer prices (e.g., Bartik *et al.*, 2019). But the rise of HF has also been very controversial due to the associated health and environmental risks, including air and water pollution (e.g., Currie *et al.*, 2017, Hill and Ma, 2021, Hill, 2024). Chief among them are concerns about the chemicals in the HF fluids (e.g., EPA, 2016) and the large amounts of wastewater that HF generates (Vidic *et al.*, 2013, Vengosh *et al.*, 2014). In contrast, the industry maintains that environmental and health risks of HF are limited (API, 2017, 2019).

In an effort to shed light on HF practices given the lack of federal regulation, many U.S.

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

Conceptually, the effect of transparency is not obvious either. On the one hand, disclosure can enable the public to exert pressure, assign blame, or quantify damages. Doing so should impose costs (or an implicit tax) on HF operators, which in turn should incentivize them to reduce pollution or to invest in cleaner practices (Pigou, 1920, Baumol and Oates, 1988). On the other hand, whether disclosure is effective depends on the accessibility and dissemination of the information and the extent to which the publicity creates sufficient pressure, i.e., allows users to take actions that are indeed costly to firms (Tietenberg, 1998, Weil *et al*., 2013).

Our study analyzes the effectiveness of Brandeis' sunlight in targeting environmental externalities and, specifically, how transparency regulation creates public pressure. In addition, we provide a long-run assessment of the impact of HF on U.S. surface water quality as well as the first empirical analysis of state environmental disclosure rules with respect to water pollution. We focus on water pollution given its substantial environmental and social costs (Keiser and Shapiro, 2019a, Keiser and Shapiro, 2019b, Hill and Ma, 2021). Further, several recent studies document the impact of HF wells and spills on water quality (Hill and Ma, 2017, Agarwal *et al.*, 2020, Bonetti *et al.*, 2021). We exploit this recently established link between HF and surface water quality to assess changes in the environmental impact and practices of unconventional O&G development, without having to rely on information that operators are

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

required to provide (e.g., Fetter *et al.*, 2021) or having to limit the analysis to the post-disclosure period (as, e.g., studies of the U.S. TRI have to do).[2]

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

States imposed their new disclosure rules for HF wells at different points in time, allowing us to perform staggered difference-in-differences analyses. We estimate panel regressions with fixed effects for each water monitoring station to control for differences in local water quality. In addition, we use monthly fixed effects to flexibly control for within-state or alternatively within sub-basin changes in water quality. Thus, the identification comes from differences in

2 Some operators provided chemical disclosures voluntarily before the mandates. We exploit these data in one analysis similar to Fetter *et al.* (2021). However, the sample of voluntary disclosures is limited and selected.

3 Watersheds are homogenous hydrologic areas that drain or shed surface water into a common outflow point. There are roughly 22,000 watersheds in the U.S. Their average size is 230 square miles (i.e., ¼ of counties). Watersheds are also called HUC10s. The acronym stands for the 10-digit Hydrologic Unit Code that identifies the watershed. The codes come from a hierarchical land area classification system that is based on surface hydrologic features and that divides and sub-divides the U.S. into successively smaller hydrologic units consisting of regions, sub-regions (HUC4), basins, sub-basins (HUC8) and watersheds (HUC10).

the pre- and post-disclosure evolution of ion concentrations between watersheds (HUC10s) with HF activity and close-by control watersheds without HF activity, i.e., in the same subregion (HUC4) or sub-basin (HUC8) within a state. We also perform analyses restricting the sample to watersheds situated over shales to further reduce heterogeneity between treated and control watersheds.

In the main analyses, we find that salt concentrations decrease between 9 and 14%, after the state disclosure mandates become effective, pooling all four HF-related ions. The declines are statistically significant for three of the ions; Br^{-} is generally not statistically significant. These estimated decreases in ion concentration are ecologically meaningful.

Reassuringly, we do not find similar declines in three other water quality proxies (dissolved oxygen, phosphorus and fecal coliforms) that are *not* signatures for HF-related water impact but might reflect broader changes in economic activity related to local O&G development. In a similar spirit, we also perform water quality analyses for watersheds with conventional drilling activity, to which the HF disclosure rules do not apply. The results do not mimic what we find for HF transparency regulation in watersheds with HF wells. Additionally, we find that controlling for other HF regulations, such as wastewater management rules and drilling standards, does not alter our inferences with respect to HF transparency regulation. We also perform extensive tests with respect to the timing of the states' adoption dates to gauge whether it poses a threat to identification.

Next, we analyze the margins along which HF operators adjust their practices after the disclosure mandate. We examine whether the documented improvements in water quality come from less HF drilling activity or production (extensive margin) or from changes in operator practices (intensive margin). We find that the entry rate of new HF wells declines by almost 7%, but the quantitative effect of this decline is small and most of the improvement in water quality comes from HF operator adjustments along the intensive margin.

To illustrate changes along the intensive margin, we analyze the environmental performance of wells and show that O&G production per unit of pollution increases relative to the pre-disclosure levels. Next, we perform a per-well analysis and present evidence on changes in ion concentration *patterns* after the start of the drilling process (i.e., the well spud date). Bonetti *et al.* (2021) document spikes in all four HF-related ion concentrations between 91 and 180 days after well spudding. These spikes occur precisely when HF wells generate large amounts of wastewater. When we examine these concentration spikes after mandatory disclosure, we find that they decline by 22%. This finding is particularly relevant from the perspective of identification as it ties ion concentration patterns to the timeline of the drilling process. To further illustrate changes in operator practices, we study HF-related incidents (e.g., spills, leaks and accidents) as they are likely a key pathway by which HF wells affect surface waters (Agarwal *et al.*, 2020). We detect a decline in the likelihood of HF-related incidents, especially those related to fracking pits and wastewater handling. We also examine changes in the HF fluid composition after the introduction of transparency regulation. We document a decrease in the use of hazardous chemicals and chloride-related chemicals in HF fluids after the disclosure mandate, albeit relative to voluntary disclosures in the pre-period (Fetter, 2022). Taken together, our evidence suggests that targeted transparency materially improved HF practices, reducing the surface water impact from new HF wells.

Having established water quality effects and explored the margins of adjustment, we turn to the question of what targeted transparency meant in this setting and how it created public pressure. Transparency could create pressure in many ways. It could enable social movements led by the media, environmental groups, and local communities that exert pressure on HF operators.[4] For instance, social movements could lead to protests or shame operators for their use of toxic chemicals (see Online Appendix OA2). These movements could also put pressure on regulators with respect to monitoring and enforcement (Buntaine *et al.* 2022; Colmer *et al.*,

[4] For related work on the role of these institutional actors in creating pressure on firms, see, e.g., Pargal and Wheeler (1996), Dyck *et al*. (2008), and Johnson (2020).

2023). In addition, HF disclosures can stimulate public debate about stricter regulations, including bans, which in turn create incentives for operators to improve their practices. Moreover, the disclosures could make it easier for local NGOs to monitor surface waters for chemical signatures of HF-related contamination (Shale Network, 2020, Watson, 2022).

Consistent with the idea that transparency creates public pressure, we document post-mandate increases in local news coverage of HF-related environmental impacts, in the number of volunteers at local anti-fracking NGOs, and in the occurrence of local anti-fracking protests. Moreover, we find that the water quality improvements due to the transparency mandates are greater in areas where public pressure is higher. Specifically, we document larger decreases in HF-related ion concentrations in counties where a local newspaper or a local environmental NGO are present. We also show that the water quality improvements after the mandates are more pronounced in counties with more news articles covering HF concerns and protests as well as in areas that see larger increases in volunteers at local anti-fracking NGOs. Furthermore, ion declines are larger in areas where more wells are owned by publicly listed O&G firms, consistent with the idea that public firms face more scrutiny than private ones. We also find incremental water quality improvements as the public dissemination of the HF disclosures further improves after the state mandates are in place. All these results underscore the role of public pressure created or galvanized by transparency (or sunlight) regulation, just as Justice Brandeis predicted.

Our study makes two primary contributions. First, we contribute to a burgeoning literature studying the use of disclosure regulation in public policy and to change in firm behavior (e.g., Dranove and Jin, 2010, Weil *et al.*, 2013, Christensen *et al.*, 2021).[5] Much of this literature examines the dissemination or spotlighting of information about "negative" firm behaviors, such as violations of standards or rules, mining accidents, tax avoidance or citizen complaints

[5] There is also an accounting literature on the real effects of financial reporting regulation. See Leuz and Wysocki (2016) and Roychowdhury *et al*. (2019) for reviews. In addition, there are studies on CSR disclosure mandates documenting subsequent increases in CSR activities (e.g., Chen *et al.*, 2018, Fiechter *et al.*, 2022).

(e.g., Bennear and Olmstead, 2008, Dyreng *et al.*, 2016, Christensen *et al.*, 2017, Johnson, 2020, Rauter, 2020, Buntaine *et al.*, 2022), documenting improvements in firm behavior. In our setting, the information is new and provides transparency about corporate actions before they have (negative) impact, which is closer in spirit to the seminal study by Jin and Leslie (2003) on restaurant hygiene disclosure. Moreover, it is not obvious that transparency works when it targets corporate actions with dispersed externalities, for which Coasian bargaining is difficult. In other contexts, disclosure rules did not work as intended (e.g., Dranove *et al.*, 2003, Weil *et al.*, 2013), which is why understanding *how* transparency works is important.

By focusing on environmental disclosure, our paper is related to the large literature on the Toxic Release Inventory (TRI). The evidence on real effects in these studies is mixed with some documenting a decrease in pollution after negative stock market reactions to the information release (e.g., Konar and Cohen, 1997, Khanna *et al*., 1998) or for the post-TRI period (e.g., Khanna and Damon, 1999, Graham and Miller, 2001) and others questioning these effects and the use of the complex information by the public (e.g., Bui and Mayer, 2003, Bui, 2005; Oberholzer-Gee and Mitsunari, 2006, Bae *et al*., 2010). As the HF disclosure forms are also technical, we dig deeper into the mechanism and show how the mandates create public pressure by various institutional actors. Moreover, and in contrast to the TRI studies, we can observe environmental impacts before and after the mandate and hence we can pinpoint transparency and public pressure as the drivers of the decrease in water pollution from HF.

Our paper is also related to recent studies on mandated disclosure of greenhouse gas emissions (GHG). Downar *et al.* (2021), Yang *et al.* (2021) and Tomar (2023) examine mandatory reporting of corporate emissions in the UK and in the U.S., documenting reductions in GHG emissions between 7 and 15 percent. Tomar (2023) attributes the effects primarily to inter-firm benchmarking and learning. In our setting, the HF disclosure form does not reveal pollution per se. Instead, it provides transparency about local business activity with potentially harmful effects and the question is whether mandating this information can alter firm behavior.

We provide evidence on NGO volunteers and anti-fracking protests illustrating that the transparency mandates serve as a catalyst locally, galvanizing public pressure from social movements and the media, and ultimately changing operator practices.

Our second major contribution is to present new evidence on the environmental impact of HF on U.S. surface waters for an extended time period covering much of the HF boom. Such evidence is not only important in light of the public controversy about HF, but also when considering its role for U.S. energy supply. Our evidence on the transparency mandates complements other work in environmental economics showing that major regulatory initiatives, like the Clean Air Act or the Clean Water Act, have been effective at limiting environmental pollution (Greenstone, 2002, Greenstone, 2004, Keiser and Shapiro, 2019a, Keiser and Shapiro, 2019b). Our results are different because, unlike the aforementioned acts, mandating HF disclosure does not directly regulate environmental pollution.

In terms of its setting, our paper is closely related to contemporaneous studies by Fetter (2022) and Fetter *et al.* (2021). The former shows that, after the state HF disclosure rules, operators report using fewer hazardous chemicals in their HF fluids, relative to prior voluntary disclosures. Fetter *et al.* (2021) examine whether the mandates facilitate learning and imitation across operators for the HF fluid mixes. They find evidence that firms' chemical choices converge to the mix of more productive wells. These findings as well as Tomar (2023) highlight a firm learning channel, whereas we study public pressure. Moreover, convergence of operator practices does not necessarily imply lower environmental impact. Our study in turn provides evidence on water pollution, HF-related incidents and drilling activity.

2. Empirical Setting and Institutional Details

2.1 Hydraulic Fracturing and Water Quality

Unconventional development has tapped into large O&G reserves that sit in low-permeability formations and require HF for extraction. In the U.S., the production of shale gas and tight oil is projected to expand to 29.0 trillion cubic feet (tcf) by 2040, up from 13.6 tcf produced in 2015 (EIA, 2018). However, despite its importance for energy production, unconventional development has been controversial due to its potential negative effects on human and ecological health (Currie *et al.*, 2017, Hill and Ma, 2022, Hill, 2024). Among the environmental risks, water pollution is a key concern for at least two reasons (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. The latter is naturally occurring water from the deep formations with very high salt concentrations and also potentially harmful (Rosenblum *et al.*, 2017).

In light of these concerns, the Environmental Protection Agency (EPA) 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, p. ES-3). 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, Darrah *et al*., 2014, Llewellyin *et al*., 2015). In Pennsylvania, Hill and Ma (2017, 2022) document increases in shale gas-related contaminants at ground-water intake locations of community water systems that are in close proximity and downstream to gas wells. For surface water, there are a number of studies documenting contaminations after spills and leaks (e.g., Lauer *et al.*, 2016, Agarwal *et al.*, 2020) and two studies linking unconventional O&G development and water quality. Olmstead *et al*. (2013) find higher Cl^{-} concentrations in surface water downstream from wastewater treatment facilities and that higher HF well density within a watershed is associated with increased concentrations of total suspended solids. Using a large geo-coded database of water measurements and HF wells covering several U.S. shales, Bonetti *et al*. (2021) find elevated surface water concentrations of ions that are signatures of HF-related impact (Ba, Br^{-}, Cl^{-} and Sr) in watersheds with new HF wells, suggesting widespread impact, albeit well below respective toxicity limits. The results are stronger for wells with large amounts of produced water, for wells located in areas with high-salinity formations, and for wells located upstream and in proximity of water monitoring stations.

Potential pathways for surface water contamination are accidents, leaks and spills of HF fluids, flowback or produced water (on-site, from HF pits or brine trucking), and the direct (unauthorized or permitted) disposal of untreated wastewater from HF operations (e.g., Vidic *et al.*, 2013, Vengosh *et al.*, 2014, EPA, 2016, Agarwal *et al.*, 2020, Bonetti *et al.*, 2021). Furthermore, there is significant scientific evidence that the chemical concentrations in HF fluids, flowback and produced water would pose significant risks to human health and the environment, in particular aquatic ecosystems, if released into surface waters (Harkness *et al.* 2015, Kaushal *et al.* 2018, Folkerts *et al.* 2020).

2.2 Targeted Transparency Regulation for HF

Although HF is subject to the Clean Water Act, it is exempted from the SDWA provision on underground injections (except for diesel fuel), which regulates monitoring, recordkeeping and reporting requirements for any injection of chemicals endangering drinking water sources. Due to this exemption, granted by Section 322 of Energy Policy Act (2005), HF operators had no obligation to disclose the components used in 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 HF activity and disclosure laws for the HF fluids (Konschnik and Dayalu, 2016).[6] These rules were adopted at different points between 2010 and 2015 (Table 1, Panel A and Figure 1).[7]

The HF forms require information on the operator, well identification number, exact location (state, county, latitude, longitude), job start and end dates, some drilling information, such as the vertical well depth and the volume of water used, as well as details on HF fluids. The required fluid information varies only slightly across states. Typical disclosures are the ingredient name (plus trade name if applicable), the chemical abstract service number, the concentration in the fluid (typically the maximum concentration in any fracturing stage), and the supplier name (see Appendix for an example). All states allow operators to obtain trade secrets exemptions for chemicals that are considered confidential business information under the Uniform Trade Secrets Act. The prerequisites and procedures to obtain such exemptions vary across states (McFeeley, 2012, Jiang, 2022).[8] If granted, the form still discloses the chemical concentration, but the name and chemical abstract service number are omitted.

The disclosure forms have to be filed with a state agency or, predominantly, with the FracFocus registry,[9] which is a web-based database created by the Groundwater Protection Council and the Interstate Oil and Gas Conservation Commission. State rules stipulate when the disclosure must be made, typically between 30 and 120 days after the spudding or the

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

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

8 In Online Appendix OA4, we provide more details on the states' requirements to obtain an exemption. We also exploit this variation in our analysis (see Table 9).

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

completion of the HF well. In addition, all states require HF operators to submit completion reports to their respective state agencies. These reports include the well identification number, location, completion date, and basic information on the drilling process. Many states introduced this requirement prior to the HF disclosure mandate, but initially the filings were difficult to access (e.g., only as hard copies at the state agencies) and it was not until later that they moved to online portals.[10]

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

2.3 Transparency Regulation and Public Pressure

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

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

However, for disclosure rules to work in this way, they need to provide relevant information about environmental risks, they need to disseminate or publicize the information widely and finally users need to be able to act on this information (Tietenberg, 1998; Weil *et al*., 2013). As discussed in Section 2.2, the HF disclosure rules likely satisfy the first two criteria. But it is not obvious that the HF disclosures lead to enough pressure for HF operators to change their practices. Conceptually, public pressure can arise in numerous ways and from various institutional actors.

First, given the contentious public debate, HF operators could expect the public to react negatively to the disclosure of hazardous chemicals in the fluids. As the disclosures are well-specific, they could facilitate pressure and protests at HF wells by local communities or NGOs (e.g., Green, 2014, on use of diesel in HF fluids). Such social movements can impose reputational costs on HF operators, e.g., through shaming (see also Johnson, 2020). In addition, the disclosures could be useful to NGOs that monitor surface waters for the chemical signatures of HF fluids, flowback or produced water (e.g., Shale Network, 2020). The disclosures and the composition of HF fluids also received considerable attention from the scientific community (e.g., Tollefson, 2013), which can further increase public pressure (e.g., media coverage). Transparency about the HF fluids could also increase regulatory enforcement and liability risks for HF activity, for example, by facilitating citizen complaints or private litigation (Olmstead and Richardson, 2014, Colmer et al. 2023).[11]

Second, public debate about HF spurred by the increase in transparency could eventually lead to stricter regulation (Maxwell *et al*., 2000), including bans (e.g., Dokshin, 2021, for the public discourse in New York). This regulatory threat could motivate firms to operate in a cleaner or more careful fashion. Third, investors in O&G companies could use the disclosures to pressure firms to change their practices (e.g., use fewer toxic chemicals), especially if the

[11] However, identifying the operator responsible for contamination is very difficult, even when the HF fluids are known. For one, the produced water composition is not publicly available. Moreover, the burden of proof in litigation is high, which often leads to the dismissal of tort cases (Tsekerides and Lowney, 2015).

practices entail regulatory or litigation risks that are ultimately borne by investors.[12]

In the Online Appendix OA1, we provide anecdotal evidence illustrating the demand for information on HF activity and the HF fluids by local communities, environmental groups, policymakers and regulators, investors, the media as well as plaintiffs in HF-related lawsuits. In Online Appendix OA2, we furnish anecdotes illustrating public pressure from NGOs and social movements arising after the state transparency mandates.

In addition to the public pressure channel, it is also possible that disclosure facilitates peer learning, i.e., HF operators learn from the other operators' disclosures and imitate high-productivity practices and fluid mixes (e.g., Fetter *et al.*, 2021, Tomar, 2023). However, it is not clear that higher productivity practices have less environmental impact. Moreover, the competitive costs from the disclosures (e.g., the imitation of practices) can reduce HF operators' incentives to innovate (e.g., Fetter *et al.*, 2021, Breuer *et al.*, 2022). Thus, at least in the long run, the direction of the learning effect on pollution is unclear.

3. Data

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

[12] In 2013, a coalition of investors started a campaign called "Disclosing the Facts", aimed at assessing companies' HF disclosure practices, including their chemical use and efforts to reduce toxicity of the fluids. The 2013 "Transparency and Risks in HF" report states: "Institutional investors have expressed concern about how companies manage toxic chemicals because of their potential to pollute water and affect public health. (…) Using the least toxic chemicals functionally effective in hydraulic fracturing operations reduces risks, which helps protect a company's bottom line and preserve its social license to operate. Therefore, best practice is to provide comprehensive disclosure on chemicals used and efforts to reduce toxicity of fracturing fluids." The 2014 report re-emphasizes these points in its summary and goes on to highlight that best practices and transparency about these practices reduce operators' regulatory, reputational, and liability risks as well as increase access to capital. (http://disclosingthefacts.org/)

over a long period in public data, allowing us to estimate reliable baseline concentrations.

Water quality data come from the EPA (STORET), USGS (NWIS), the Shale Network (2020), Susquehanna River Basin Commission, and from the Pennsylvania Department of Environmental Protection (PADEP). STORET and NWIS data contribute by far the most observations to our sample. Surface water observations include rivers, lakes, streams, and ponds. More than 90% of them come from rivers and streams. We have information on the latitude and longitude of each water monitoring station, the ion, the type of surface water (e.g., rivers, lakes), the sampling method, and the agency in charge of the monitoring station.[13]

We obtain data on the location and spud date of HF wells from three sources: (1) the WellDatabase; (2) Enverus (formerly Drillinginfo); and (3) PADEP. WellDatabase and Enverus collect relevant information for each well from various state agencies; they are widely used in empirical studies on the O&G industry. For Pennsylvania, PADEP provides comprehensive information, which we use to complement WellDatabase and Enverus information. We use information on the latitude and longitude of each well, the type of each well (horizontal vs. vertical), the production type of each well, and the spud date. By combining the three databases we make our sample of wells as comprehensive as possible. If a well appears in only one of the three databases, we use the spud date from the respective database. If a well appears in more than one database but is recorded with different spud dates in the databases, we first rely on the spud date from PADEP, then use the date in the WellDatabase, and finally use the Enverus spud date if a well exists only in the latter.[14]

We obtain the adoption dates of the state disclosure mandates from state websites. We carefully review the text of the laws introducing the disclosure requirements and cross-validate these dates with those reported in the FracFocus repository. We also search for other

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

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

(potentially concurrent) regulations related to HF drilling and wastewater disposal. Specifically, we consider regulations regarding wastewater discharge, injection wells for wastewater, design of wastewater pits as well as standards for well casing, blowout control and mechanical integrity testing. These rules and their adoption dates are reported in the Online Appendix OA3. We use these dates to construct controls for these regulations.

The literature shows that surface water impacts of HF wells are detectable at the watershed level (Agarwal *et al.*, 2020, Bonetti *et al.*, 2021). For this reason, our analysis is at the watershed level. We assign each monitoring station and HF well to a watershed (HUC10) through the QGIS geographical software.[15]

We retain water readings from monitoring stations that are located in states that have adopted HF disclosure mandates and in sub-regions (HUC4) within the state that have at least one new HF well during the sample period. With these restrictions, we focus on sub-regions for which unconventional O&G development is relevant, but we do not impose HF activity in all watersheds within these sub-regions. We require non-missing information on the latitude/longitude of each monitoring station, the measurement date, the unit of measurement, the type of surface water, the ion sampled, and the amount of the ion measured. Furthermore, we require at least two water measurements per ion×sub-basin×month×year to estimate the ion concentration baselines in our models and remove HUC10s that have water measurements in the post-disclosure period only. These requirements yield a sample of 325,351 surface water quality measurements from January 2006 to September 2019, in 2,209 watersheds and 16 states with HF disclosure mandates. To our knowledge, this is the longest panel for which the impact of HF on U.S. water quality has been analyzed.

Table 1 reports the distribution of water quality observations and HF activity across states with HF disclosure mandates. Figure 1 plots the time trend in HF activity in our sample, along

[15] Data on the watershed boundaries come in *shapefile* formats from the Watershed Boundary Dataset (WBD) provided by the Natural Resources Conservation Service (NRCS) at the Geospatial Data Gateway (GDG). A watershed is uniquely identified by a 10-digit hydrologic unit code (HUC10). See also footnote 3.

with the staggered adoption of the state disclosure mandates. Figure 2 shows HUC10s with and without HF activity and the locations of water monitoring stations. We use the daily average temperature and precipitation data from Schlenker (2020) for the 2.5×2.5 mile grid in which a particular monitoring station is located.[16]

Our final estimation sample consists of (i) treatment HUC10s with at least one HF well in the pre-disclosure period and (ii) control HUC10s without HF activity in the pre- and post-disclosure period, located in sub-regions (HUC4) of treated states that have some HF activity.[17] We provide descriptive statistics for the ion concentrations in the two groups in Table 2. All ion concentrations are reported in microgram per liter (μg/L). To limit the influence of outliers due to measurement or recording errors, we truncate the sample at the 99th percentile, computed by ion and HUC4 to account for regional variation in ion concentrations. We take the natural logarithm of the ion concentrations to account for their highly skewed distributions (Bonetti *et al.*, 2021, Hill and Ma, 2019).[18] We provide descriptive statistics for the distribution of monitoring stations and water measurements per ion and HUC10 in Table 2, Panel C. This illustrates that measurements can be sparsely distributed, except for Cl^{-}. On average, there are 15 monitoring stations per HUC10, ranging from 8 for Br^{-} to 17 for Sr. The average number of measurements per ion in a HUC10 ranges from 37 for Br^{-} to 85 for Cl^{-}.

4. Research Design for the Water Quality Analysis

In our primary analysis, we examine changes in the concentrations of Br^{-}, Cl^{-}, Ba, and Sr around the introduction of targeted transparency. Our tests exploit variation in the timing of the state disclosure mandates as well as within-state (or alternatively within-sub-basin)

[16] The raw data files give daily minimum and maximum temperature as well as total precipitation on a 2.5 x 2.5-mile grid for the contiguous United States from 1900-2019. The data are based on the PRISM weather dataset.

[17] The assignment of watersheds is based on the pre-disclosure period only. Thus, it is possible that, in some control watersheds, HF activity starts in the post-disclosure period. In fact, we have 85 watersheds (with 12,758 water measurements) without HF activity in the pre-period but some HF activity in the post-disclosure period. Keeping these watersheds in the control group could overstate improvements in water quality. Thus, we exclude them from the main analyses. As a robustness, we re-run our analyses including these 85 watersheds and obtain results that are indistinguishable from those reported in the paper.

[18] We gauge the role of truncating and taking logs of ion concentrations for the results in Online Appendix OB2.

variation in HF activity across watersheds. There are pros and cons to either specification, which we discuss below. We estimate the following model:

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

where C_{idk} is the natural logarithm of the ion concentration, measured at monitor i on day d located in HUC10 k, $station_i$ is the monitoring station fixed effect, $State_s(HUC8_h)$×month$_m$× year$_t$ is a monthly state [or alternatively monthly sub-basin] fixed effect, $HUC8_h$×month$_m$ is a calendar-month fixed effect for each sub-basin to account for seasonal effects in the within-state specification, p_{idk} is the cumulative precipitation over three days ending on the day an ion measurement is drawn, t_{idk} are binary indicators for the average temperature range on the day of ion measurement,[19] and ε_{idk} is the error term. $HUC10\_HF_k$ is a binary, time-invariant indicator variable marking watersheds with at least one HF well in the pre-disclosure period (treated HUC10s). $POST_{sd}$ is a binary indicator marking water measurements taken after the state disclosure regulation has come into force. The coefficient α on $HUC10\_HF$×$POST$ is the key parameter of interest. It estimates the impact of the state transparency mandates on ion concentrations in treated HUC10s relative to concentration changes in control HUC10s. Our inferences are based on standard errors that are clustered at the HUC10 level.

The model in Eq. (1) controls for: (i) arbitrary cross-sectional and monthly heterogeneity in background ion concentrations at the state or sub-basin level, including seasonal changes, the effects of road de-icing, agriculture, economic development associated with the rise of HF in particular areas, and changes in the O&G prices; (ii) local time-invariant heterogeneity in ion concentrations at the water monitoring stations, including the way of measurement, the type of monitor or water body, the location of the monitor, and natural brine migration at the

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

monitoring station; and (iii) local weather conditions at the time of the water measurement. The model essentially estimates the impact of the state disclosure mandates comparing the pre- and post-disclosure evolution of ion concentrations in treated and control watersheds within the same state or the same sub-basin (see identification maps in Online Appendix OB1). The estimated coefficient for *HUC10_HF×POST* is the average over all state mandates.

This identification strategy assumes that watersheds within a state or within a sub-basin are good counterfactuals for each other, i.e., they exhibit parallel trends in water quality but for the disclosure mandates. It also assumes that the state adoption dates are not selected in response to trends in water quality or changes in operator practices. We later gauge these two assumptions. We also address recent econometric concerns about staggered difference-in-differences analyses (de Chaisemartin and D'Haultfoeuille, 2020, Goodman-Bacon, 2021).

5. Results: Effects on Water Quality, Drilling and HF Practices

5.1 Water Quality Changes after the Introduction of Transparency Regulation

We present results from estimating Eq. (1) in Table 3, Panel A. The R^2 of the regressions is very high, suggesting that our model explains most of the background variation in ion concentrations across watersheds and time. We first estimate the effect of the HF disclosure mandates, *HUC10_HF×POST*, for each ion separately. We find significant reductions in the concentrations for three ions in the within-state model (Columns 3, 5 and 7) and for two ions in the within-HUC8 model (Columns 4 and 6). For Br^-, the coefficients are not statistically significant. For Br^-, in particular, but also Ba and Sr, water measurements can be sparse in some locations (see Table 2, Panel C). We therefore pool the water measurements for all ions in one regression to harness statistical power.[20] In these models, the coefficients on

[20] See also Hill and Ma (2017) for such pooling. We estimate one regression for all ions and include a fixed effect for each ion as well as interactions of this ion indicator with the controls and other fixed effects, so that the coefficients are specific to each ion. This model is akin to running a seemingly unrelated regression model. The model produces an estimate for the average concentration change over all ions. Alternatively, we could focus on Cl^-, which is the best measured ion, and obtain the same inferences.

HUC10_HF×POST are negative (9 to 14%) and statistically significant, irrespective of the fixed effects structure (Columns 9 and 10). We also estimate models restricting control watersheds to those located directly over shales to further reduce potential differences between treated and control watersheds. The findings in Columns 11 and 12 are essentially the same as those in Columns 9 and 10. Taken together, the results in Table 3, Panel A, suggest that the state disclosure mandates are followed by significant improvements in water quality.

To illustrate the timing of the ion reductions and gauge the parallel-trends assumption, we plot estimates around the introduction of transparency regulation. We estimate Eq. (1) replacing *POST* with separate indicator variables, D_t, for each year, coded relative to the entry-into-force date of the disclosure regulation in the respective state. That is, D_1 is equal to one for any water measurement taken within 365 days of the date the state disclosure rule becomes effective (and zero otherwise), D_2 marks water measurements taken in the second year, and so on. We omit D_{-1} (i.e., the indicator for measurements taken within 365 days before the effective date). We use the all-ions, within-HUC8 model shown in Column 12 of Table 3 and plot the coefficients together with their 95% confidence intervals. Figure 3 does not indicate differences in the pre-trends for treated and control HUC10s. It shows a decrease in ion concentrations starting after the HF disclosure mandates come into force and a further decline in the following year; thereafter the effect on ion concentrations stays fairly constant. This timing seems plausible. Well operators typically have between 30 and 120 days from the spud date or well completion to provide the HF disclosures. Moreover, prior evidence shows that the water impact of new HF wells does not occur until roughly 90 days after well spudding (Bonetti *et al.*, 2021; see also Section 5.3 below). Thus, we would not expect to see the full effect until roughly a year after the mandates become effective.[21]

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

The estimated reductions in ion concentrations are meaningful in terms of water quality. Pooling all ions, the effect amounts to a decline in ion concentrations of 14% (within state) and 9% (within sub-basin). In interpreting the two specifications and the estimated magnitudes, it is important to consider the following tradeoff. The within-sub-basin specification uses only nearby HUC10s, which are likely better counterfactuals. However, the number of control HUC10s within a sub-basin is small (Table 2, Panel C). Some of these control HUC10s are downstream from treated HUC10s and hence could be affected by contamination spillovers, which would reduce the treatment effects. The within-state specification has many more control HUC10s and is less likely to be affected by spillovers.[22]

To gauge the role of downstream spillovers, we compute the minimum elevation of the treatment and control HUC10s within a sub-region (HUC4) and use as controls only HUC10s that have a minimum elevation above the median elevation of *treated* HUC10s within a HUC4 (in the within-state model) or within a HUC8 (in the within-HUC8 model). Two important results emerge (Table 3, Panel B). First, the estimated declines in ion concentrations increase in magnitude across all ions in the within-sub-basin specification, suggesting pollution spillovers into the control HUC10s. Second, the estimated effects are now more consistent across the within-state and the within-sub-basin specifications. As expected, the results for the within-state specification are not as much affected. They still show significant declines and the estimated decline within state using all ions is around 16 to 18%.

Based on these results, we use the within-sub-basin specifications adjusted for spillovers to gauge the concentration declines. We find declines of 17% for Cl^-, 8% for Ba, and 12% for Sr. Translating these percentages into ion concentration changes measured in μg/l, we obtain concentration declines in treated HUC10s of 7,896.9 μg/l for Cl^-, 6.78 μg/l for Ba, and 56.55 μg/l for Sr. These declines are ecologically meaningful, considering that even relatively small

[22] Note, however, that the within-state analysis does not use all watersheds in a state because we require control watersheds to be in a sub-region where there is some HF activity (Section 3). See OB3 for robustness.

increases in the concentrations of these ions can be damaging to aquatic ecosystems (e.g., Folkerts *et al.* 2020). Moreover, surface waters serve as intake for community water systems and all four ions are tied to human health concerns (Vidic et al., 2013).[23]

We gauge the robustness of the results with respect to: (i) clustering of standard errors; (ii) truncation of large ion concentrations; (iii) ion measurements that are zero or reported as below detection levels; (iv) changes in the frequency of water measurement and (v) control sample composition. These sensitivity analyses are presented in the Online Appendix (Sections OB2, OB3, and OB4). They show that our findings and estimated magnitudes are robust to a range of alternative design choices. Given recent studies in econometrics showing that staggered difference-in-differences analyses and two-way fixed effect structures can produce biased estimates in the presence of heterogeneous treatment (de Chaisemartin and D'Haultfoeuille, 2020, Goodman-Bacon, 2021), we also use a "stacked" regression approach and draw the same inferences (Cengiz *et al.*, 2019, see Section OB5 for details).

5.2 Addressing Alternative Explanations for the Changes in Water Quality

In this section, we summarize several analyses to address standard concerns with regulatory analyses, primarily related to the timing of regulation as well as concurrent events. A concern in our context is that states choose to adopt the disclosure mandates in response to local shocks to water quality (e.g., due to spills or accidents). It is conceivable that these events or local shocks would have led to changes in operator practices that reduced HF water impact, even in the absence of state transparency mandates. We perform a series of tests to gauge this alternative explanation and report the results in the Online Appendix (Section OB6). We do

[23] Small increases in Br^{-} in source water of treatment plants raise disinfectant by-product formation, such as brominated trihalomethanes (THMs), in drinking water, which in turn has been linked to increased bladder cancer rates (Regli et al., 2015; see also Brantley *et al.*, 2014). Cl^{-} increases the corrosivity of water and the leaching of lead from pipes (Stets *et al.*, 2018). High concentrations of Ba can have health effects such as increased blood pressure (WHO, 2016). Although Sr is not currently regulated under the SDWA and hence there are no EPA limits, high concentrations may cause harm for skeletal health, especially in children and adolescents (Health Canada, 2018).

not find evidence supporting this concern.[24]

Next, we conduct two "placebo" tests (reported in Section OB7). First, we examine concentration changes in analytes that are not specific to HF, meaning their concentrations are unlikely to change due to HF water impact. However, they can reflect other economic activities with potential water impact that grow because of local HF activity or its economic benefits (e.g., agriculture, housing). Thus, in using these analytes, we gauge how well our models control for these other potentially confounding effects on water quality. Specifically, we use: (i) Dissolved oxygen (DO), (ii) Fecal Coliforms, (iii) Phosphorus. The concentrations of these three analytes do not exhibit consistent patterns around the introduction of the state mandates and all the estimated coefficients except for one are statistically insignificant.[25]

Second, we examine changes in the four HF-specific ion concentrations around the transparency mandates, but in watersheds with conventional drilling. Given that the disclosure mandates apply only to HF wells, watersheds with conventional drilling should not exhibit the same patterns. To check this, we re-estimate the analyses in Table 3, but define treatment HUC10s as watersheds with *conventional* (i.e., vertically drilled) wells in the pre-disclosure period but without HF activity. The control sample comprises HUC10s in treated states without conventional or HF wells in the pre-period. In these analyses, we do not find significant water quality effects around the disclosure mandates.

A common concern for regulatory studies is that there could be other concurrent events that also affect the relevant outcome variables. The staggering of the transparency mandates in our setting alleviates this concern with respect to broad changes in water quality due to federal

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[24] We first add lagged changes in the ion concentrations to the model to control for states responding to local water quality shocks (Table B6). Second, we show that public pressure, economic or political differences and HF drilling intensity do not predict the relative timing of state disclosure rules (Table B7). Third, we run tests based on Altonji *et al*. (2005) and Oster (2019) using proxies for local factors that could prompt states to pass the disclosure rules and find that these factors are unlikely to explain our results (Table B8). A related concern is that the state mandates respond to public pressure, rather than lead to more pressure. We explicitly analyze this dynamic in Section 6.

[25] The results are tabulated in Section OB7 of the Online Appendix. In Section OB7.2, we also test whether our results are influenced by changes in water pollution due to agricultural activity.

regulation or common trends in HF technology or drilling practices. However, states have other regulations for HF activity, in particular, wastewater management rules and HF drilling standards. Although these regulations were often introduced well before the sample period, states could update them or add new ones. To the extent that states introduce new or amend existing other HF regulations around the same time as they introduce the transparency mandates, these regulatory changes could contribute to the water quality effects documented in Table 3. To explore this possibility, we identify relevant regulatory changes to wastewater rules and HF drilling standards for each state in our sample and create indicator variables marking such changes over time. We introduce these variables into the main analysis as additional controls.[26] We find that the key variable of interest, *HUC10_HF×POST*, is still negative and significant in all specifications. More importantly, we see little attenuation in the coefficient magnitudes relative to the estimates reported in Table 3. This evidence makes it unlikely that the improvements in water quality are mainly driven by other regulatory changes that happen to be concurrent or close in time to the disclosure mandates.

5.3 Margins of Adjustment

In this section, we examine which margins HF operators adjust. The decline in water impact after the mandates could come both from less HF activity (wells or production), i.e., the extensive margin, or from less water impact of each HF well, i.e., intensive margin.

We expect drilling activity to be driven primarily by market factors, e.g., energy prices and demand, as well as existing supply and new drilling opportunities in an area. It is important to control for these first-order forces when teasing out the impact of transparency regulation on the extensive margin (i.e., on new HF wells). Thus, we restrict the analysis to watersheds over shales, i.e., to areas where HF is feasible. In another specification, we restrict the analysis to watersheds in sub-basins that cross state borders and hence are located in two neighboring

[26] In Section OA3 of the Online Appendix, we provide more details on these other regulatory changes and list their respective adoption dates. In Section OB7, we explain the coding of the indicator variables and present the results controlling for other HF regulatory changes.

states, so that we can compare the rate of well entry in watersheds of a state that introduced disclosure with the rate of entry in watersheds of the neighboring state, which has not yet introduced or already has a disclosure mandate.

We measure well entry as the number of new HF wells spudded in a HUC10-month-year. We include HUC10 fixed effects to account for location-specific factors to well entry (e.g., O&G reserves), and either region×month×year or shale×month×year fixed effects to account for regional or shale-specific trends in unconventional O&G development as well as output price variation.[27] Table 4, Columns 1–4, documents a decrease in the well entry rate after the state disclosure mandates are introduced across all specifications. To further tighten identification, we add a control for other HF regulations, *CUM_HF_REG*, following Section 5.2, and measure HF well entry *relative* to the entry rate of conventional wells (Table 4, Columns 5–6). Since the latter wells are not subject to the HF disclosure rules, but reflect broader changes in the O&G industry, the conventional well entry rate serves as a benchmark. Thus, the dependent variable is the difference between the number of new HF wells and the number of new conventional wells in a given HUC10-month-year. In this specification, we still observe a significant decrease in HF wells entry. Figure 4 plots coefficients from the model in Column 6 of Table 4, mapping out the effect by quarter relative to the disclosure mandate. Figure 4 exhibits parallel trends in the pre-disclosure period and a decline afterwards. The estimated coefficient in Column 6 implies 0.051 fewer new HF wells per HUC10-month-year, relative to the pre-disclosure period and the entry rate for conventional wells. Comparing this decline to an average HF well entry rate of 0.74 per HUC10-month-year, the percentage change (almost 7%) is meaningful but smaller than the overall percentage reduction in ion concentrations. This result is plausible considering that drilling less, or producing less for that matter, are likely expensive margins for the HF operators.

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

To estimate intensive margin adjustments following transparency regulation, we examine changes in the environmental performance of HF wells, which we define as the ratio of O&G production volume, in barrels, and the local ion concentrations, in µg/l at the HUC10-month-year level. This ratio abstracts from adjustments in drilling and computes O&G production per unit of pollution.[28] Table 5 reports OLS estimates for the impact of transparency regulation on environmental performance. We provide results defining the treatment sample as in Table 3, i.e., HUC10s with HF activity in the pre-disclosure period (Columns 1-2) and, alternatively, as HUC10s with HF activity in the pre- and post-disclosure periods (Columns 3-4). For all specifications, we find significant increases in environmental performance after mandatory disclosure (4-7%), which essentially implies that operators produce with less water impact.[29]

5.4 Linking Water Quality Changes to the HF Process and At-Risk Water Measurements

In this section, we tighten identification further by linking the ion concentration declines to the HF process and at-risk water measurements. Prior research suggests that mishandling of flowback and produced waters is likely a key mechanism by which HF could pollute surface water (Vidic *et al.,* 2013, Vengosh *et al.,* 2014). Consistent with this mechanism, Bonetti *et al.* (2021) document significant spikes in the four ion concentrations occurring between 90 and 180 days after new wells are spudded, which is roughly when production starts, and HF wells generate large amounts of flowback and produced water that need to be collected. Thus, the ion increases are directly tied to critical phases of HF process.

Based on these findings, we explore changes in the concentration patterns around well spud dates after the transparency regime is introduced. Specifically, we plot the coefficients estimated for HF well counts calculated over fixed time windows defined relative to the well spud dates, both for the pre- and the post-period, respectively (Figure 5). The idea is to visualize

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[28] One could also consider the inverse, pollution per unit of production, but as O&G production is zero for some watersheds in some months, this ratio would have missing values in these instances.

[29] A simple quantitative decomposition (untabulated) suggests that more than 90% of the overall reduction in ion concentrations comes from the intensive margin.

changes in HF-related water impact after the introduction of the transparency regime. To further tighten the link and to increase the power of the test, we focus on at-risk water measurements. These measurements are more likely to detect HF-related water impact because they stem from water monitoring stations that sit closer to wells and are more likely downstream (for details see Figure 5). Consistent with Bonetti *et al*. (2021), we find concentration spikes in the [91, 180]-day window. More importantly for our analysis, the spike in this window is significantly smaller (22%) after mandatory disclosure ($p<0.05$; F-statistic of 4.05). This per-well result not only illustrates improvements along the intensive margin, but also shows that the changes in water impact that we see after the transparency regime are directly linked to the drilling of HF wells and stem from at-risk water measurements.

5.5 Specific Changes in HF Operators' Practices

In this section, we study specific changes in HF operator practices to further link the improvements in water quality to the introduction of the transparency regulation. First, transparency and the ensuing public scrutiny could incentivize operators to improve the safety of the drilling process, e.g., to exercise more care in managing HF wastewater. As discussed in Section 5.4, spills, leaks and accidents related to the handling of HF fluids and wastewater are likely a key pathway for surface water contamination, especially early in the production process. Thus, we examine changes in the likelihood of such HF-related incidents before and after the staggered introduction of the disclosure mandates. We use data on major HF-related spills from Brantley *et al*. (2014) and Patterson *et al.* (2017). As these data extend only to 2015 and are confined to Colorado, New Mexico, North Dakota, and Pennsylvania, we restrict the sample accordingly. We code the occurrence of an incident by HUC10-month-year using either all HF-related incidents or HF incidents specifically related to the handling of wastewater for all watersheds over shales. Table C1 provides descriptive statistics for these incidents. We estimate changes in these incidents after disclosure regulation using both HUC10 and month×year fixed effects. Table 6 reports the results. Consistent with the water quality results in Table 3, we find significant declines in the (monthly) occurrence of all HF-related incidents (5-6%) as well as those related to the handling of HF wastewater (around 6%).

Second, we examine whether HF operators reduce the use of hazardous chemicals after the HF fluid disclosures become mandatory. We rely on data from Konschnik and Dayalu (2016) for the use of chemicals in HF fluids and create a variable for the combined percentage share of all hazardous chemicals in the HF fluids. We first compute the ratio of the total amount of hazardous chemicals to total fluids injected for each well, and then average over all wells at the HUC10-month-year level. Hazardous chemicals are those (i) regulated as primary contaminants by the SDWA; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on fracturing operations (EPA, 2014). For the pre-disclosure period, we have to use voluntary disclosures for the share of hazardous chemicals to calculate the HUC10-month-year averages.[30] Assuming that operators using a larger share of hazardous chemicals were more reluctant to provide this information prior to the mandates, the use of voluntary disclosures in the pre-period is likely to bias against finding a reduction in the share of hazardous chemicals. In addition, we compute the hazardous share in HF fluids using only chemicals related to Cl^-, considering that the earlier water quality analyses are based on salt and in particular Cl^- concentrations in surface waters. Table C2 lists the most common hazardous chemicals in HF fluids and highlights those related to Cl^-. Table C3 provides descriptive statistics for the two variables used in the fluid analysis. We estimate changes in the use of hazardous chemicals after the HF disclosure mandates using HUC10 and month×year fixed effects to flexibly control for broader changes in the composition of HF fluids (e.g., due to technological advances). The results presented in Table 7 show that operators disclose using a lower share of all and Cl^--related hazardous

[30] Not all watersheds have HF wells, for which voluntary disclosures are available in the pre-period. Thus, we first compute pre-disclosure averages at the HUC8 level using voluntary disclosures and then use these averages as baselines for watersheds without voluntary disclosures in the pre-period.

chemicals in the HF fluids after the introduction of disclosure regulation. These results are similar to Fetter (2022) and consistent with the water quality results in Table 3.

6. Targeted Transparency and Public Pressure

In this final section, we turn to the questions of how targeted transparency creates public pressure, what public pressure actually means in this setting as well as what role it plays for the documented improvements in water quality. As discussed in Section 2.3, disclosure regulation can enable social movements, environmental groups, local communities, and the media to exert pressure on HF operators (see Online Appendix OA2 for anecdotal evidence from various sources). Here, we explore several of these channels and sources of public pressure more formally.[31]

We measure the public pressure faced by HF operators in the areas of O&G development in three different ways: (i) local HF-related newspaper coverage; (ii) local anti-fracking activity by NGOs and watershed groups and (iii) local anti-fracking protests (see Online Appendix OB8 for more details on the construction of these variables). We examine changes in these variables around the introduction of the state transparency mandates. We restrict the analysis to counties located over shales in treated states. The model regresses the three variables on a binary indicator variable for the time period after transparency regulation has come into force, *POST,* controlling for county and year-month (or year) fixed effects as well as local HF activity. The inferences are based on standard errors clustered at the state-level.

Table 8 presents the results of this analysis. We find a significant increase in the number of local newspaper articles discussing HF-related environmental and water impacts after the state mandates. Similarly, we observe that local anti-fracking NGOs and watershed groups report a

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[31] We recognize that public pressure could be a confounding factor if state legislators adopt the transparency regimes in response to public pressure. Our analyses in Table 8 and, in particular, the pre-trends in Figure 6 address this concern empirically, showing that the introduction of state regulation leads to more public pressure, rather than the other way around. See also Section OB6 in the Online Appendix for other tests examining the potential endogeneity of the state adoption dates.

significant increase in their number of volunteers after the transparency mandate. Lastly, we find a significant increase in the occurrence of anti-fracking protests reported in local newspapers. For all three variables, the coefficients are essentially unaffected when we control for local HF activity, suggesting that the increases in public pressure are not driven by HF activity itself. Moreover, when we map out the changes in the three public pressure variables in event time, the increases in public pressure occur after states introduce transparency regulation (Figure 6). Taken together, our analyses suggest that targeted transparency enables social movements and increases public pressure on HF operators locally.[32]

Having established that targeted transparency leads to increases in public pressure, we examine whether differences in these public pressure changes are associated with differences in the water quality effects around the mandates. Such evidence would be reassuring and provide further support for the proposed mechanism, i.e., the notion that targeted transparency operates through public pressure. Towards this end, we first examine differences in the effects of the state mandates based on two public pressure variables: the presence of a local newspaper and the presence of a local NGO or watershed group. Both of these variables are assigned ex ante, rather than based on post-disclosure responses. We code counties with at least one (versus no) local newspaper that is active in the year leading up to the state's transparency mandate (which assumes that media pressure is stronger in the county where the newspaper is published). Similarly, we code Census core-based statistical areas (or counties) with at least one (versus no) local anti-fracking NGO or watershed group that has been active in the year before the adoption of the state mandate. In Table 9, Columns 1 and 2, we report results estimating differences in the treatment effects of the mandates, splitting by the two (ex-ante) public pressure variables. We find that the effects are (statistically) larger in areas where public pressure is likely stronger.

[32] In un-tabulated analyses, we find that the coefficient for the effect of the disclosure mandates on the public pressure variables is larger in magnitude and more significant in counties with more educated and wealthier households, further corroborating our interpretation of the link between transparency and public pressure.

Second, we explore whether the impact of transparency regulation is more pronounced in areas that experience larger increases in public pressure after the state mandates are introduced. We rely on our results in Table 8 and create two split variables for areas with higher (lower) changes in public pressure using: (i) increases (vs. no change) in media coverage discussing the environmental or water impacts of HF activity in the year after the mandates (relative to the year before adoption); (ii) increases in the average number of volunteers helping local anti-fracking NGOs (versus no change, using three years before and after the state mandate). In Table 9, Columns 3 and 4, we report results estimating differences in the treatment effects of the mandates. We find that the transparency effects on water quality are (significantly) more pronounced in areas where public pressure increases more.

Third, we explore heterogeneity in the effects with respect to ownership. HF operators owned by publicly traded O&G firms are likely to face greater public pressure and more scrutiny than HF operators owned by private firms (see OA1 for anecdotal evidence). Thus, we estimate separate treatment coefficients for watersheds where the percentage of HF wells owned by publicly traded owners is above (versus below) the median. The results presented in Table 9, Column 5, indicate that the effect of transparency regulation is greater in watersheds where the fraction of HF operators owned by publicly traded firms is higher.

In sum, we obtain consistently stronger treatment effects for the HF disclosure mandates for firms or areas for which public pressure is expected to be ex ante higher or when the mandates increase pressure in the respective area.

The three final tests in Table 9 explore specific features of the transparency regime (e.g., dissemination and strictness) and how they relate to heterogeneity in the treatment effects. First, we examine whether improvements in the accessibility and dissemination of the HF disclosure forms have a discernible incremental effect after the introduction of the transparency mandates. As discussed in Section 2, FracFocus is the primary repository for the HF disclosure forms. Since its launch in 2011, the FracFocus website was revamped several times to improve the accessibility and dissemination of the HF well disclosure forms.[33] We identify three major changes during our sample period (see Section OB9 for more details). To exploit these shifts, we introduce an interaction variable into Eq. (1) using *HUC10_HF×POST* and a variable, *CUM_FF_CHANGES,* that increases by one for each website changes implemented by FracFocus (i.e., the variable goes from 0 to 3). The results in Table 9, Column 6, indicate that improvements in the accessibility and dissemination of the HF disclosure forms on FracFocus are associated with incremental ion concentration decreases in HF watersheds. Furthermore, in untabulated analyses, we find that the FracFocus changes are associated with significant increases of public pressure locally for each of the three variables presented in Table 8, further linking the transparency mandates, the HF disclosures and public pressure.

Second, we consider the ease with which HF operators can obtain trade secret exemptions for specific chemical disclosures, as such exemptions could make the forms less effective (McFeeley, 2012). Given that the composition of HF fluids is potentially proprietary, all states allow trade secret exemptions. If granted, operators can withhold the identifying name of the respective chemical, but they still have to report the amount and percentage of this masked chemical in the HF fluid. To measure how easy it is for an operator to obtain a trade secret exemption, we consider the following five conditions that states may require when claiming a trade-secret exemption (McFeeley, 2012, listed in OA4). The more conditions a state requires, the more difficult it is for operators to obtain the trade secret exemption. In the Online Appendix (OA4), we summarize the trade secret regulations for each state in our sample. In Table 9, Column 7, we report separate coefficient estimates for two state groups, splitting on whether a state has two or more (fewer) conditions for obtaining trade secret exemptions. The

[33] The following anecdote highlights the importance of the FracFocus website and its functionality for NGOs using the HF disclosure forms. Skytruth, an environmental NGO, posted on May 8, 2015: "If you've been a faithful reader of this blog, you've seen a relentless series of posts from us criticizing the functional failures of FracFocus as a tool for the effective public disclosure of chemicals used for fracking at oil and gas drilling sites nationwide. Well, today we got some good news: FracFocus has finally stepped up to fix one of those problems, and is now making the chemical data available in an aggregated, machine-readable database." [https://skytruth.org/2015/05/at-last-fracfocus-now-publishing/]

coefficient is larger in magnitude in states making it more difficult to obtain a trade secret exemption, though the difference between the high and low group is not statistically significant.

Finally, we consider differences in how much time HF operators are given to file the disclosure forms as an alternative indicator for the strictness of the state's transparency regime. As water impact from HF wells is most likely to occur in the early phases of production (Bonetti *et al*., 2021), timelier disclosures could be important for local communities and watershed groups. The filing deadlines vary substantially across states and we split states into two groups depending on how quickly they require operators to file, using the median number of days for filing in the sample. In Table 9, Column 8, we find larger increases in water quality for states where the transparency mandates require timelier disclosure.

7. Conclusion

We study to what extent and how mandating transparency for corporate practices facilitates the internalization of dispersed environmental externalities using targeted transparency for HF wells in the U.S. as a setting. The rise of unconventional O&G development in many U.S. states triggered a major public debate about its environmental and health risks. Given these concerns, U.S. states with unconventional O&G development passed disclosure rules for HF wells in an effort to shed light on HF practices, in particular, the composition of the HF fluids.

We estimate the effects of this regulation with respect to the environmental impact of HF wells on surface waters as well as the practices of HF operators. Examining four salts that are considered signatures for HF impact, we find significant concentration declines between 9-14% in surface waters after the state mandates are introduced. We examine the source of these improvements in water quality and find that, aside from a minor decline in HF drilling activity, most changes are attributable to adjustments along the intensive margin. Specifically, we document better environmental performance of HF wells, smaller water impact of HF wells in the early phases of production, fewer spills and accidents related to wastewater handling, and a decline in the use of hazardous chemicals in HF fluids. These results provide detailed evidence that targeted transparency significantly improved HF practices.

The core idea of targeted transparency for corporate activities with environmental externalities is to enlist social movements and enable public pressure. To illustrate that this mechanism is at play in our setting, we first document post-mandate increases in local news coverage about HF environmental impact, in the number of volunteers joining local anti-fracking NGOs, and in the occurrence of anti-fracking protests. We then show that water quality improvements after the disclosure mandates are greater in areas where public pressure is ex ante expected to be higher. Specifically, we find larger decreases in HF-related ion concentrations in areas with local newspapers and local environmental NGOs. We also show that the water quality effects are more pronounced in counties that see larger increases in public pressure, as measured by increases in the number of newspaper articles or number of volunteers joining local anti-fracking NGOs and watershed groups. All this evidence is consistent with Brandeis' notion that sunlight can be a "remedy for social and industrial diseases."

Finally, our study provides the most extensive longitudinal evidence on the surface water impact of HF on U.S. surface waters. HF has dramatically increased U.S. energy production and is considered to be the most important change in the energy sector since the introduction of nuclear energy. Thus, understanding its environmental impact is important. As our period of analysis covers much of the U.S. HF boom, it provides novel evidence on the evolution of the industry's impact as well as the role of HF disclosure regulation and the dissemination of this information through FracFocus in mitigating it. Our analysis suggests that the documented improvements in water impact are driven by changes in operators' practices, including the handling of wastewaters and prevention of spills, which are the most likely pathways for negative water impacts.

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

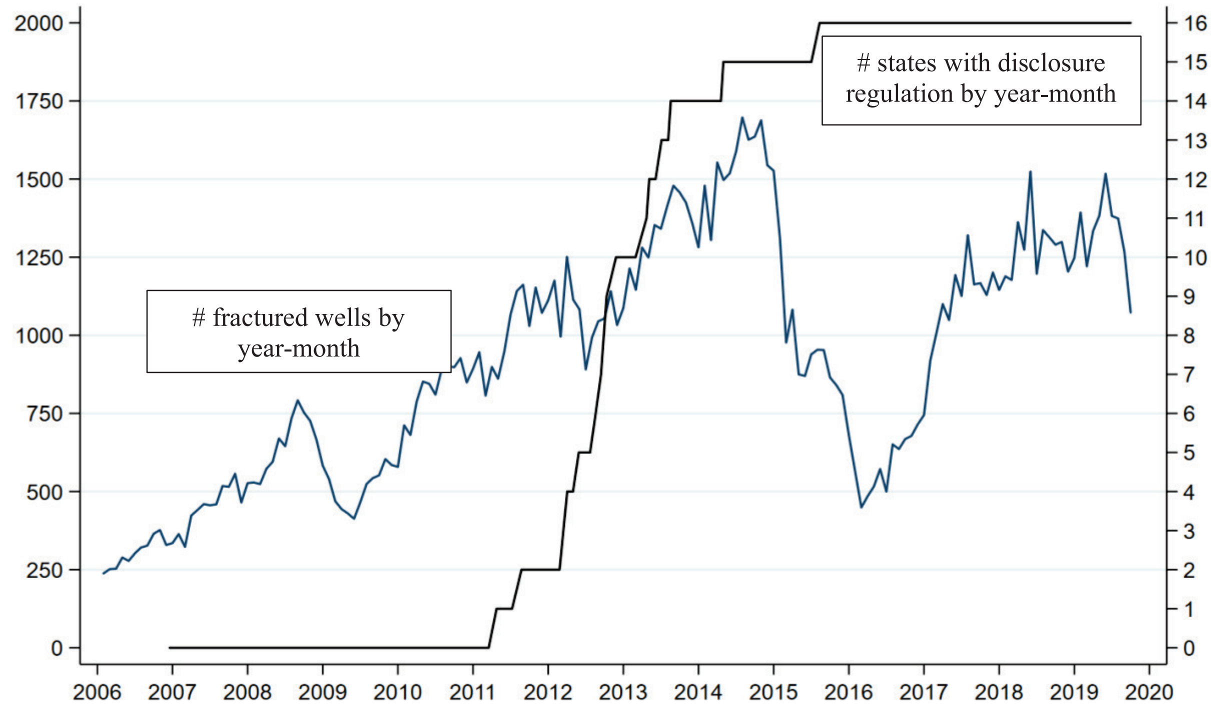
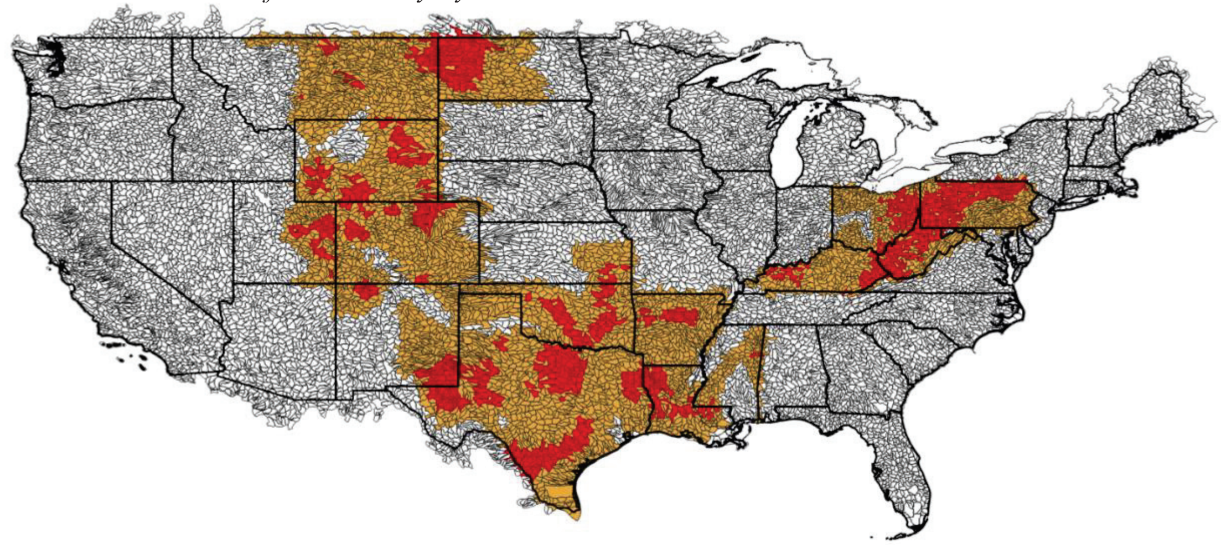


Figure 1 plots the time trend in HF activity in the U.S. along with the adoption timing of the HF disclosure regulation by the U.S. states with HF activity. The *x* axis shows the year. The *left-y* axis shows the number of new HF wells by spud year-month. The *right-y* axis shows the cumulative number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

Figure 2 – Location of HF Wells and Water Monitoring Stations

Panel A – Location of HF Activity by Watershed



Panel B – Location of Water Monitoring Stations by Watershed

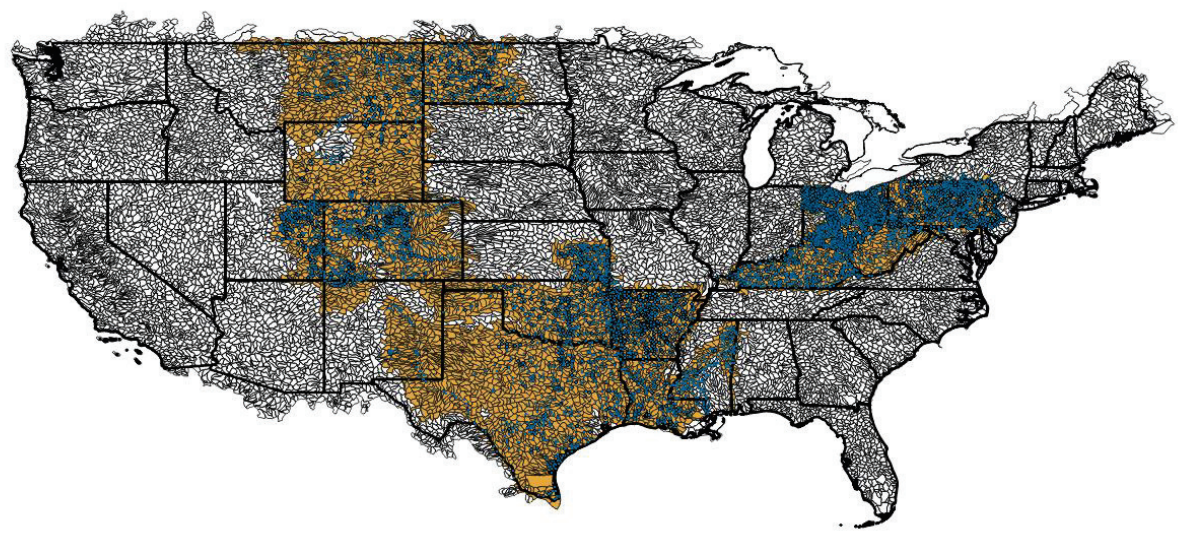


Figure 2 shows the location of HF activity (Panel A) and the location of water monitoring stations (Panel B) across watersheds (HUC10s). Watersheds in the treatment sample are colored in red. Watersheds in the control sample are colored in ocher. Blue dots mark the location of monitoring stations. Data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

Figure 3 – Mapping Out the Effect of HF Disclosure Regulation

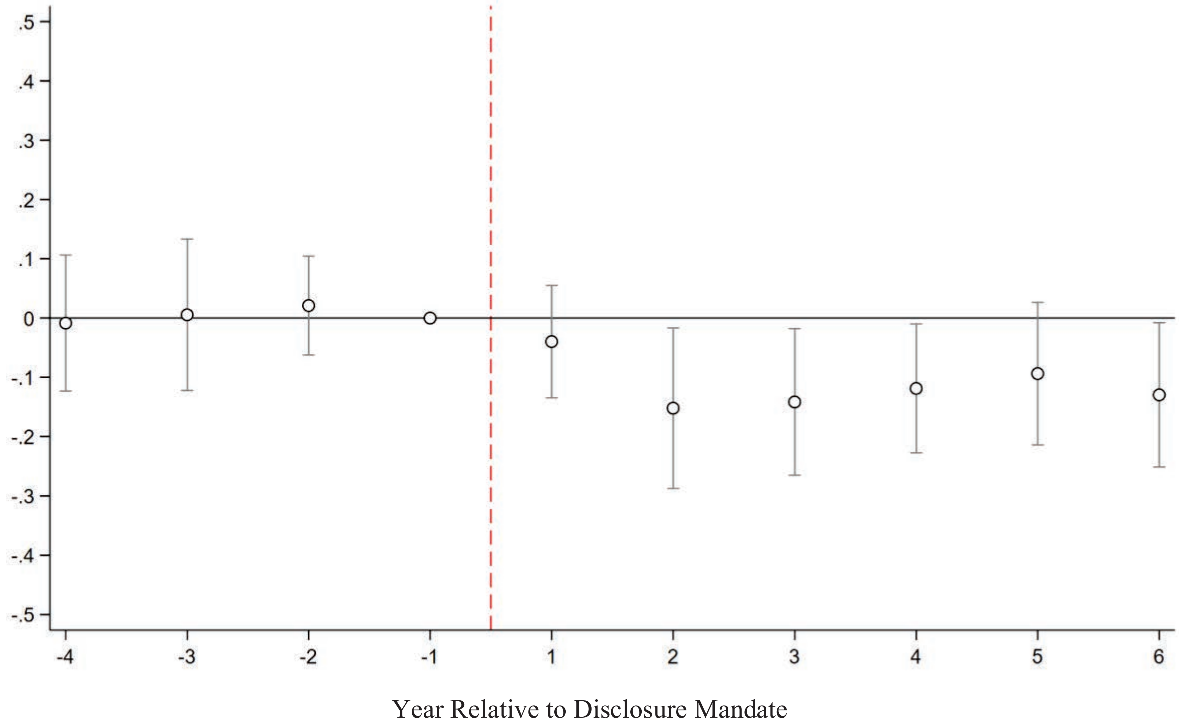
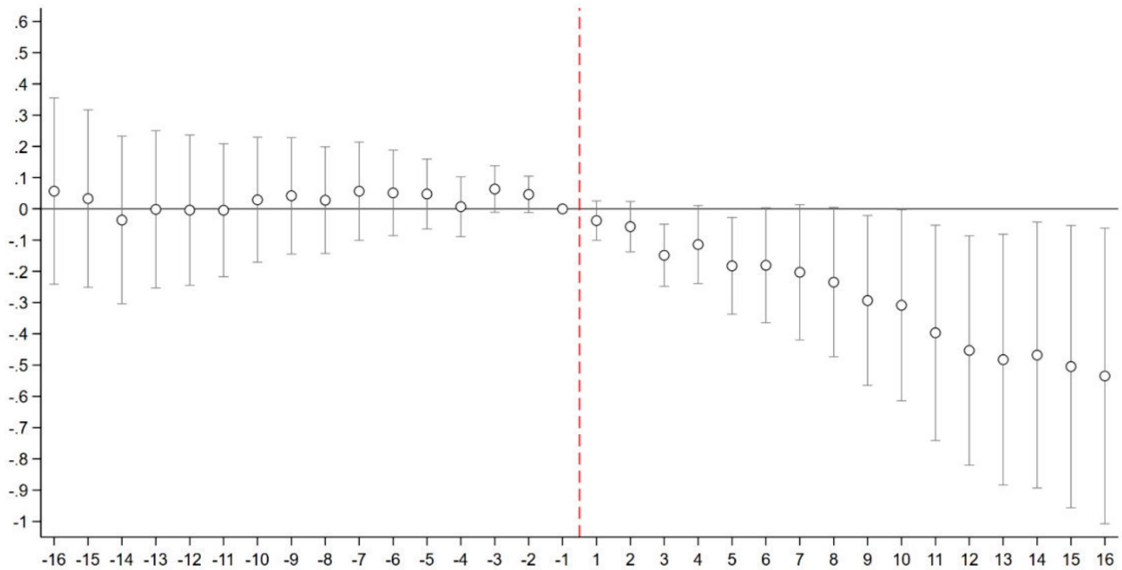


Figure 3 plots coefficients from the estimation of Eq. (1), together with the respective 95% confidence intervals, adding indicators for the years relative to the introduction of the disclosure mandate. Year 1 comprises all water measurements that take place within the first 365 days from the state-specific entry-into-force date. Year -1 comprises measurements in the 365 days before the entry-into-force date. The coefficient for the year before the disclosure mandate (-1) is omitted from the regression and therefore serves as benchmark. We use the within-HUC8 model shown in Column (12) of Table 3.

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



Quarter Relative to Disclosure Mandate

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

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

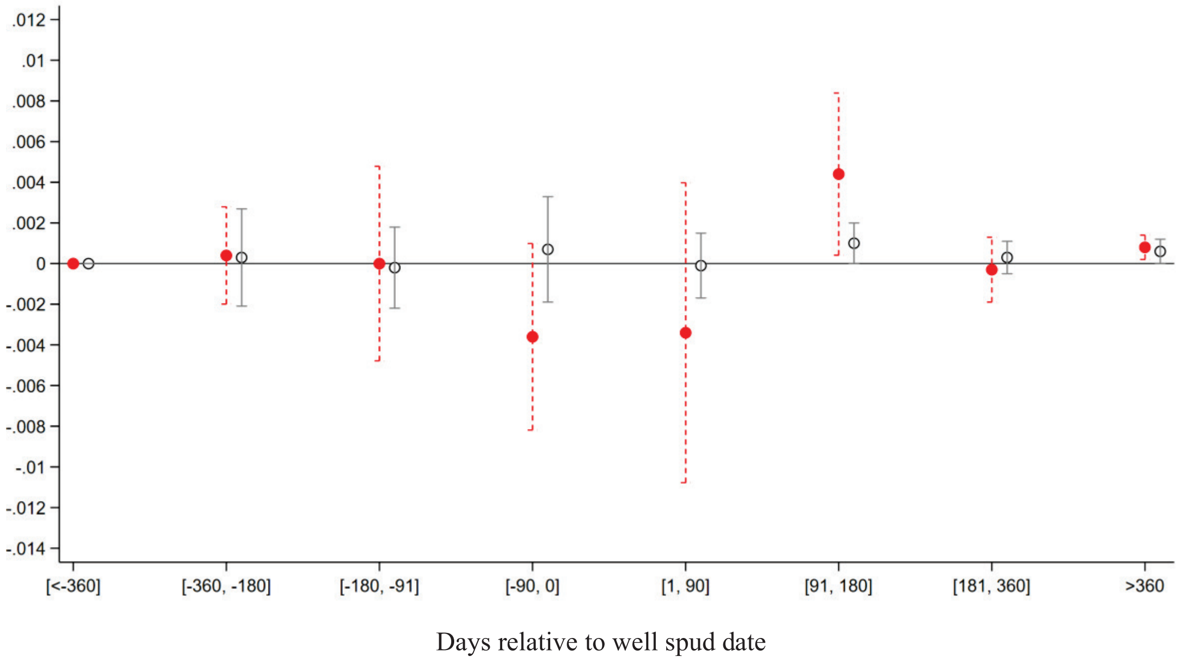


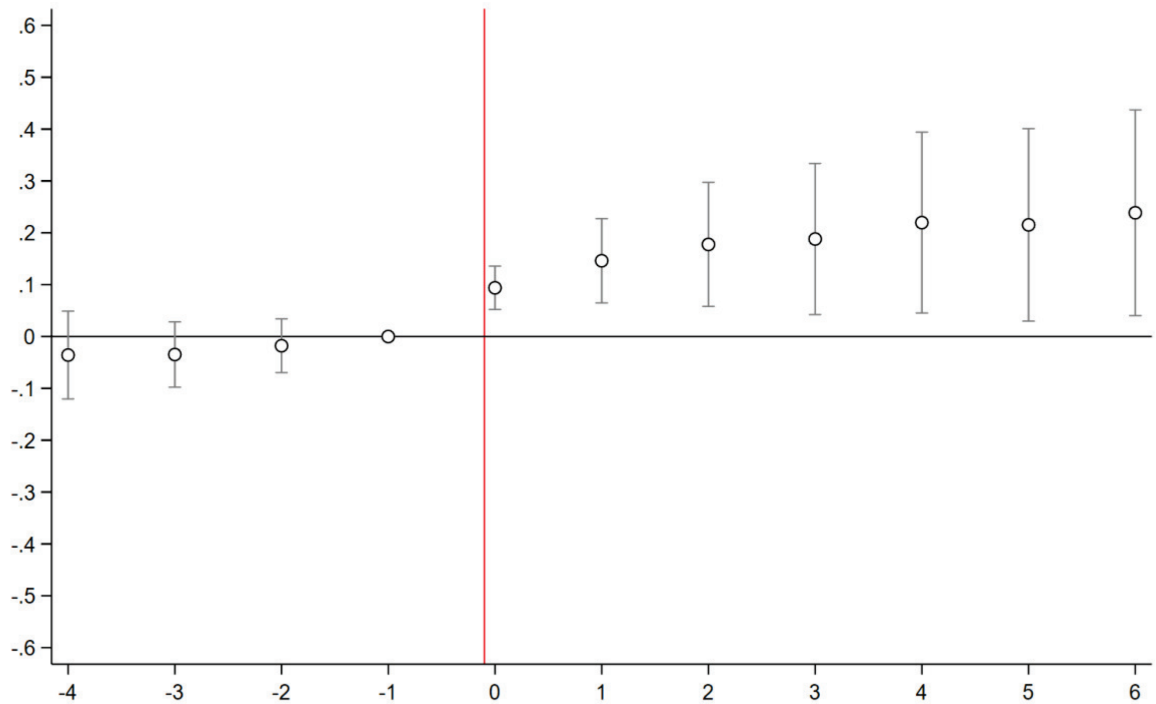
Figure 5 plots coefficients from the estimation of the model shown below, together with the respective 95% confidence intervals, using separate HF well counts calculated over fixed time windows relative to the well spud date. We estimate the coefficients on the well count variables for the pre- and post-disclosure period separately. The red (gray) dots are the coefficients for HF wells spudded in the pre-disclosure (post-disclosure) period. The analysis is restricted to at-risk water measurements from HUC10s with HF activity that stem from monitoring stations that are more likely to detect a HF-related water impact. In particular, we restrict the sample to water measurements that satisfy the following conditions: (ii) the measurement is from a monitoring station that is within 15 km of a well in a given watershed; (ii) the measurement is from a monitor that is likely downstream from a well in a given watershed. The distance between a well and a monitoring station (in km) is computed using Vincenty's formula for calculating the distance between two points on a sphere. To assign wells as (likely) up- or downstream from a monitor within the respective watershed, we sub-divide each watershed into cells of constant size (1 km^2) and first identify flow direction and flow accumulation by computing flow direction codes (1 to 255) and flow accumulation values for each cell. We then apply the flow-length routine in ArcGIS to these square-km cells to assign monitors to be likely upstream or downstream from a well. Furthermore, we require at least two measurements before and after well spudding for each well-monitoring station pair. After imposing these sample restrictions, we estimate the following OLS model, separately for the pre- and post-disclosure periods (see Section 4 for a description of the base model):

$$
\begin{aligned}
C_{ikd} = station_i + HUC_{kmy} + \alpha\, p_{ikd} + t_{ikd} + \beta_1\, \#wellsHUC10[-180;-91] \\
+ \beta_2\, \#wellsHUC10[-90;0]_{kd} + \beta_3\, \#wellsHUC10[1;90]_{kd} \\
+ \beta_4\, \#wellsHUC10[91;180]_{kd} + \beta_5\, \#wellsHUC10[181;360]_{kd} \\
+ \beta_6\, \#wellsHUC10[>360]_{kd} + \varepsilon_{ikd}
\end{aligned}
$$

To illustrate the well count variables, *#wellsHUC10 [91, 180]* counts all wells in the respective HUC10 that were spudded between 91 and 180 days ago, relative to the date of the respective ion concentration measurement, in either the pre- or post-disclosure periods. The [<−180] window is the omitted category and serves as a benchmark. See Section 5.4 for details and Section 4 for other variable definitions. We conduct a formal *F*-test to compare the pre- and post-coefficients for the [91;180]-day window. The *F*-test indicates that the concentration spike observed in this window is statistically smaller in the post-disclosure period (p-value<0.05; F-statistic = 4.05).

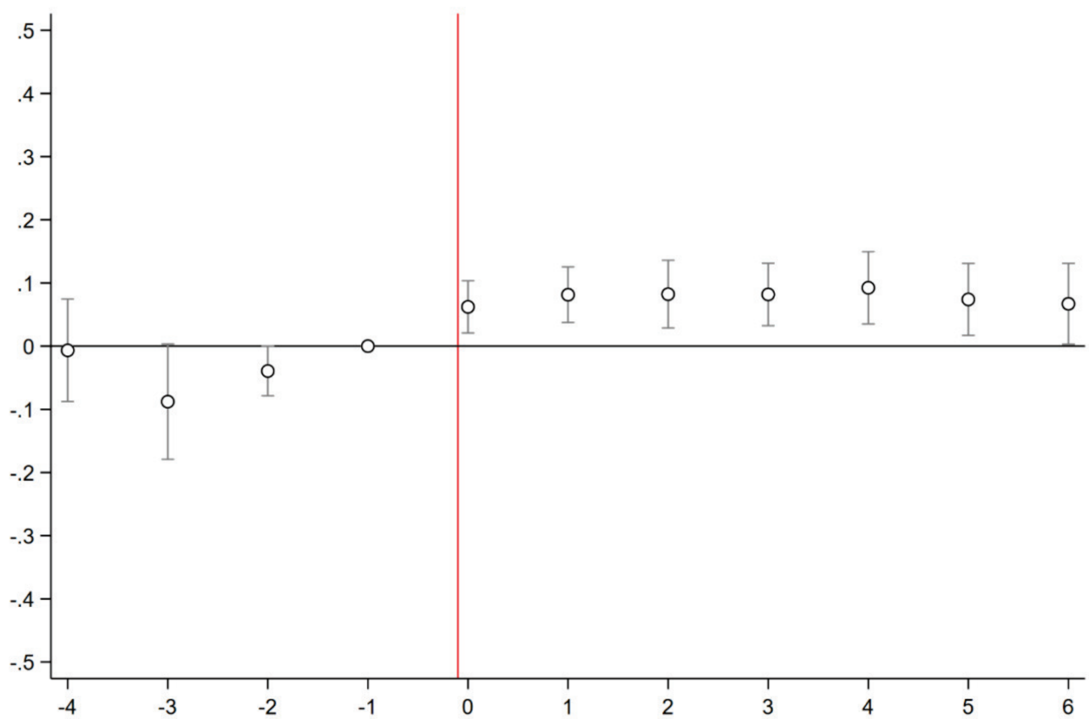
Figure 6 –Changes in Public Pressure after the State Transparency Mandates

Panel A – Changes in HF-Related Newspaper Coverage



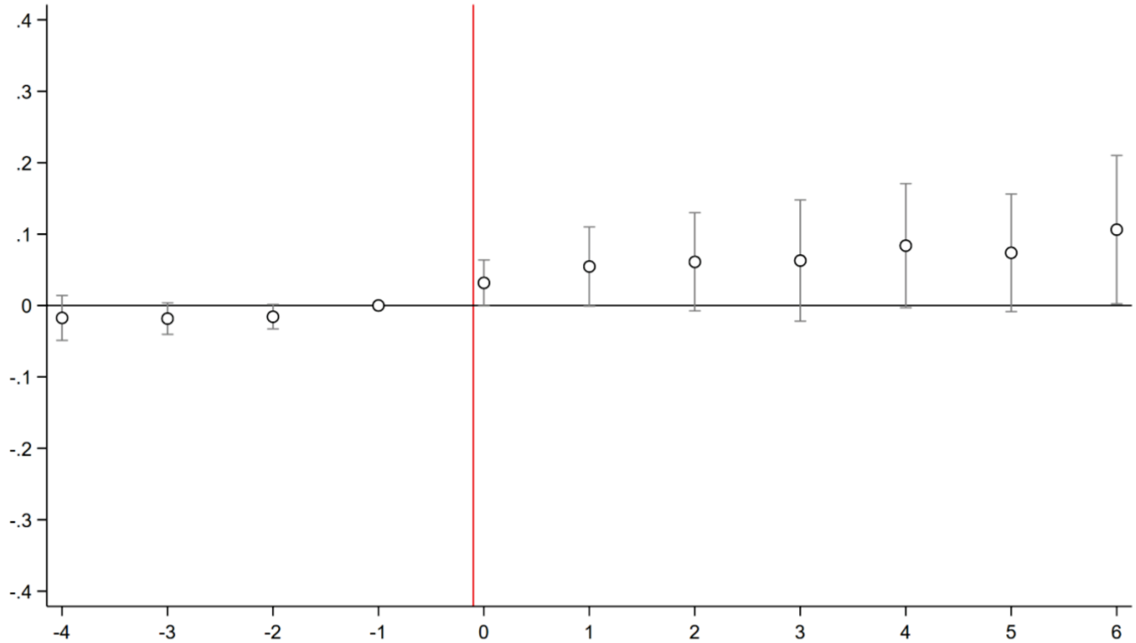
Year Relative to Disclosure Mandate

Panel B – Changes in the Number of Volunteers at local NGOs and Watershed Groups



Year Relative to Disclosure Mandate

Panel C – Changes in the Occurrence of Anti-Fracking Protests



Year Relative to Disclosure Mandate

Figure 6, Panels A, B, and C, plots coefficients from estimating the models shown in Column (2), Column (4), and Column (6) of Table 8 together with the respective 95% confidence, respectively. To clarify, the alignment of the public pressure variables relative to the introduction of the state transparency mandates: In Panel A, Year 0 comprises all HF-related newspaper articles published in the first 12 months after the state-specific entry-into-force date. Year -1 pertains to all newspaper articles published in the 12 months before the entry-into-force date. In Panel B, Year 0 comprises the number of volunteers helping local anti-fracking NGOs and watershed groups in the year of adoption of the disclosure mandate. Year -1 pertains to the year before the adoption of the disclosure mandate. In Panel C, Year 0 comprises anti-fracking protests reported in local newspapers in the first 12 months after the state-specific entry-into-force date. Year -1 pertains to anti-fracking protests that occurred in the 12 months before the entry-into-force date. In all three panels, the coefficients for the year before the disclosure mandate (-1) are omitted from the regression and hence this year serves as benchmark.

Table 1 – Sample Composition and Descriptive Statistics

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

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

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

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

Table 1, Panel A, provides the number of water monitoring stations, HF wells and water quality measurements per state as well as the date when the state transparency mandate came into force. Panel B shows the number of watersheds (HUC10s) in the treatment and control samples for the respective ion. HUC10s are assigned to treatment and control depending on the existence of HF activity in the respective watershed in the pre-disclosure period. See Section 4 and also footnote 18.

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

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

Bromide	N	Mean	p25	p50	p75	SD
Concentration	6,216	121.326	31.490	60.000	100.000	333.842
Ln(Concentration)	6,216	4.139	3.481	4.111	4.615	1.090
Chloride						
Concentration	46,269	49,130.850	5,620.000	15,000.000	39,680.000	177,371.300
Ln(Concentration)	46,269	9.588	8.634	9.616	10.589	1.691
Barium						
Concentration	26,001	53.147	31.000	43.800	63.000	75.472
Ln(Concentration)	26,001	3.696	3.466	3.802	4.159	0.895
Strontium						
Concentration	21,484	296.759	49.000	146.000	290.000	523.933
Ln(Concentration)	21,484	4.895	3.912	4.990	5.673	1.250

Panel B – Control HUC10s without HF in the pre- and post-disclosure periods

Bromide						
Concentration	9,567	221.782	20.321	43.700	101.371	1,799.72
Ln(Concentration)	9,567	3.962	3.060	3.800	4.629	1.165
Chloride						
Concentration	142,060	103,213.10	4,680.00	14,165.63	35,800.00	980,708.70
Ln(Concentration)	142,060	9.298	8.451	9.559	10.486	2.114
Barium						
Concentration	46,702	64.121	30.000	47.000	71.000	524.401
Ln(Concentration)	46,702	3.700	3.434	3.871	4.277	1.059
Strontium						
Concentration	27,052	705.277	81.000	251.000	654.000	1,360.458
Ln(Concentration)	27,052	5.366	4.407	5.529	6.485	1.734

Table 2 presents descriptive statistics for surface water ion concentrations. Panel A reports statistics for the ion concentrations in treatment watersheds with HF activity in the pre-disclosure period. Panel B reports statistics for the ion concentrations in control watersheds without HF activity in the pre- and post-disclosure periods, that are located in sub-regions (HUC4) of treated states that have some HF activity. The panels report statistics for the raw ion concentrations and after applying the natural logarithm (ln).

Panel C – Distribution of surface water measurements

Unique # of HUC10s by state	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
	2,209	182	136	192	242	67
Unique # of HUC10s by HUC8	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
	2,209	7	4	5	8	4
Unique # of HUC10s by state/ion	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
Bromide	431	77	36	70	149	55
Chloride	2,209	179	135	171	242	71
Barium	1,247	141	101	134	199	64
Strontium	628	147	29	183	230	88
Unique # of monitoring stations by HUC10	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
	12,950	15	5	12	22	13
Unique # of monitoring stations by HUC10/ion	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
Bromide	1,453	8	3	5	8	8
Chloride	12,577	15	6	11	21	13
Barium	6,995	14	5	11	20	12
Strontium	4,829	17	7	14	22	13
Water quality observations by HUC10/ion	**N**	**Mean**	**p25**	**p50**	**p75**	**SD**
Bromide	15,783	37	4	12	37	62
Chloride	188,329	85	12	34	107	152
Barium	72,703	58	11	34	81	72
Strontium	48,536	77	15	49	107	91

Panel C presents distributional information for the number of HUC10s by state, sub-basin (HUC8) and by state and ion, the number of water quality monitoring stations by HUC10 and by HUC10 and ion as well as the number of surface water measurements quality by HUC10 and ion.

Table 3 – Transparency Mandates and Water Quality

Panel A – Estimated Effect of the Transparency Mandates on Ion Concentrations

	Bromide (µg/l)		Chloride (µg/l)		Barium (µg/l)		Strontium (µg/l)		All Ions pooled (µg/l)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HUC10_HF×POST	-0.1108	0.0449	**-0.1955*****	**-0.1183****	**-0.0969*****	**-0.0589****	**-0.0448****	-0.0382	**-0.1509*****	**-0.0928****	**-0.1476*****	**-0.0925****
	[0.0714]	[0.1232]	**[0.0557]**	**[0.0520]**	**[0.0352]**	**[0.0346]**	**[0.0223]**	[0.0290]	**[0.0386]**	**[0.0363]**	**[0.0418]**	**[0.0365]**
Observations	15,783	14,538	188,329	176,729	72,703	65,812	48,536	46,308	325,351	303,387	220,208	206,389
R-squared	0.860	0.915	0.865	0.903	0.834	0.867	0.968	0.976	0.961	0.971	0.961	0.971
Treatment Sample	HUC10s with HF activity in the pre-disclosure period											
Control Sample	All HUC10s without HF but located in sub-regions (HUC4s) with some HF activity in treated states										HUC10s w/o HF over shales in treated states	

Panel B – Estimated Effect of the Transparency Mandates Addressing Potential Downstream Pollution Spillovers

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HUC10_HF×POST	**-0.1336***	0.0305	**-0.2319*****	**-0.1810****	**-0.0844****	**-0.1156****	0.0034	**-0.1282***	**-0.1753*****	**-0.1626*****	**-0.2012*****	**-0.1626*****
	[0.0680]	[0.0951]	**[0.0578]**	**[0.0724]**	**[0.0395]**	**[0.0542]**	[0.0251]	**[0.0706]**	**[0.0436]**	**[0.0587]**	**[0.0550]**	**[0.0592]**
Observations	13,354	12,465	167,004	157,629	63,642	57,375	42,120	39,768	286,120	267,237	180,938	170,239
R-squared	0.872	0.911	0.869	0.904	0.842	0.866	0.969	0.977	0.961	0.970	0.961	0.970
Treatment Sample	HUC10s with HF activity in the pre-disclosure period											
Control Sample	As above but excluding control HUC10s more likely affected by spillovers										As above but excluding those likely affected	

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
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 FE	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, Panel A reports OLS coefficients estimating Eq. (1) to assess the impact of the state disclosure mandates on the respective ion concentrations. The models in Columns (9)-(12) pool all four ion concentrations in one model, as described in Section 4. In Columns (1)-(10), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre-and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. In Columns (11)-(12), the sample consists of the same treatment sample, but the control HUC10s without HF activity are restricted to those located over shales in treated states. Panel B presents results for the same analysis after excluding control HUC10s that are more likely to be affected by downstream spillovers, i.e. we use as controls only HUC10s that have a minimum elevation above the median elevation of treated HUC10s within a HUC4 (in the within-state model) or within a HUC8 (in the within-HUC8 model). *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 4 – Transparency Mandates and 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	**-0.0554*****	**-0.0629*****	**-0.0559*****	**-0.0506***	**-0.0505****	**-0.0692***
	[0.0162]	**[0.0213]**	**[0.0196]**	**[0.0285]**	**[0.0257]**	**[0.0372]**
Observations	199,962	112,644	199,773	112,455	199,773	112,455
R-squared	0.383	0.408	0.468	0.461	0.480	0.492
Sample	HUC10s over shales	HUC8s across two or more states	HUC10s over shales	HUC8s across two or more states	HUC10s over shales	HUC8s across two or more states
Control other HF regulation	No	No	No	No	Yes	Yes
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 4 reports OLS estimates for the impact of the state disclosure mandates on the rate of HF well entry. The sample comprises HUC10s in treatment states that are located over shales. In Columns (1)-(4), the dependent variable is the natural logarithm of one plus the number of new HF wells spudded in a given HUC10-month-year. In Columns (5)–(6), the dependent variable is the (unlogged) number of new HF wells minus the (unlogged) number of new conventional (or vertical) wells. In these models, we also control for changes in other HF regulations (see OA3 and OB4). In Columns (2), (4) and (6), the sample is restricted to HUC10s within HUC8s that are partially located in at least two states (i.e., are crossing state lines). *POST* is a binary variable equal to one in the post-disclosure period. In Columns (1) and (2), we include region×month×year fixed effects in the model. In Columns (3)–(6), we include shale×month×year fixed effects. There are 30 shales in our sample that can be classified into five regions: North-East, South-Mid-West, South-West, Mountain, North-West. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 5 – Transparency and Environmental Performance (Production per Unit of Pollution)

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

Table 5 reports OLS coefficients estimating Eq. (1) for an alternative dependent variable: the ratio of the average O&G production (bbl) in a given HUC10-month-year and the sum of the four ion concentrations (μg/l). In Columns (1)-(2), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period (and non-missing O&G production data) and control HUC10s without HF in the pre- and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. In Columns (3)-(4), the sample consists of treatment HUC10s with HF activity in the pre- and post-disclosure periods (and non-missing O&G production data) and control HUC10s without HF in the pre- and post-disclosure periods that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking treated watersheds (HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 6 – Transparency and HF-Related Spills and Wastewater Incidents

	All Incidents		Wastewater Incidents	
	(1)	(2)	(3)	(4)
POST	**-0.0661****	**-0.0561***	**-0.0613*****	**-0.0609*****
	[0.0259]	**[0.0304]**	**[0.0147]**	**[0.0196]**
Observations	22,682	15,001	19,320	12,840
R-squared	0.167	0.187	0.088	0.100
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 6 reports OLS estimates for the impact of the state disclosure mandates on HF-related incidents such as spills, leaks and accidents using data from Brantley *et al*. (2014) and Patterson *et al.* (2017). The sample comprises HUC10s over shales in four states from 2005 to 2015 (see Section OC1). In Columns (1)-(2), the dependent variable is a binary variable equal to one if there is at least one HF-related incident in a given HUC10-month-year, zero otherwise. In Columns (3)-(4), the dependent variable is a binary variable equal to one if there is at least one incident related to the handling of HF wastewater, including HF fluid, flowback, produced water, or brine spills, zero otherwise. In Columns (2) and (4), the sample is further restricted to HUC10s within HUC8s that are partially located in at least two neighboring states, i.e., are crossing state lines. *POST* is a binary variable equal to one in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 7 – Transparency and Hazardous Chemical Use in HF Fluids

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

Table 7 reports OLS estimates for the impact of the state disclosure mandates on the use of hazardous chemicals in HF fluids. Data on the chemicals disclosed by well operators are from Konschnik and Dayalu (2016). See Section OC2 for descriptive statistics. The dependent variable is constructed at the HUC10-month-year level, as described in Section 5.5. We compute averages for the share of all hazardous chemicals and for the share of chloride-related hazardous chemicals, respectively, relative to the total amount of fluids injected. Hazardous chemicals are those (i) regulated as primary contaminants by the Safe Drinking Water Act; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on HF operations (EPA, 2014). For the pre-period, we use voluntary disclosures to calculate HUC10-month-year averages, following Fetter (2022). *POST* is a binary variable equal to one in the post-disclosure period. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table 8 – Targeted Transparency and Increases in Public Pressure

	HF Newspaper Coverage		*Local NGO Volunteers*		*Anti-HF Protests*	
	(1)	(2)	(3)	(4)	(5)	(6)
POST	**0.0951***** **[0.0210]**	**0.0951***** **[0.0209]**	**0.0560**** **[0.0249]**	**0.0576**** **[0.0253]**	**0.0339*** **[0.0167]**	**0.0338*** **[0.0165]**
#WELLS_HF		0.0013*** [0.0004]		0.0002** [0.0001]		0.0008*** [0.0002]
Observations	8,844	8,844	600	600	7,788	7,788
R-squared	0.333	0.334	0.619	0.620	0.139	0.141
	Counties over shales					
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Month×Year FE	Yes	Yes	No	No	Yes	Yes
Year FE	No	No	Yes	Yes	No	No

Table 8 reports OLS estimates for the impact of the state disclosure mandates on three public pressure variables. The dependent variable in Columns (1)–(2) is the logarithm of one plus the number of newspaper articles covering HF and its potential environmental or water impact by county- month -year. The dependent variable in Columns (3)–(4) is the logarithm of one plus the number of volunteers reported by local anti-fracking NGOs and watershed groups by county and year. The dependent variable in Columns (5)–(6) is a binary variable equal to one if there is an anti-fracking protest in a given county-year-month, zero otherwise. *#WELLS_HF* is the number of new wells 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.

Table 9 – Targeted Transparency and Water Quality: Role of Public Pressure

	All Ions Pooled (μg/l)							
	Partitioning on:						*Features of the disclosure regime – partitioning on:*	
	Local Media Presence (1)	*Local NGO Presence* (2)	*Increase in Media Coverage* (3)	*Increase in Local NGO Volunteers* (4)	*Publicly Traded Operators* (5)	*FracFocus Dissemination* (6)	*Trade Secret Exemptions* (7)	*Disclosure Timeliness* (8)
POST×HUC10_HF×High Group	**-0.1908***** **[0.0686]**	**-0.1386***** **[0.0398]**	**-0.2224***** **[0.0604]**	**-0.3619***** **[0.1032]**	**-0.1419***** **[0.0426]**		**-0.1275**** **[0.0508]**	**-0.1536***** **[0.0586]**
POST×HUC10_HF×Low Group	**-0.0906**** **[0.0365]**	**-0.0894**** **[0.0370]**	**-0.0639*** **[0.0342]**	**-0.0928**** **[0.0363]**	**-0.0592*** **[0.0350]**		-0.0582 [0.0446]	-0.0161 [0.0269]
POST×HUC10_HF						**-0.0774**** **[0.0378]**		
POST×HUC10_HF×CUM_FF_CHANGES						**-0.0255*** **[0.0152]**		
Observations	303,387	303,387	303,387	303,387	303,387	303,387	303,387	303,387
R-squared	0.972	0.971	0.971	0.971	0.971	0.971	0.971	0.971
Treatment Sample	HUC10s with HF activity in the pre-disclosure period							
F-Test	**0.0998**	**0.0912**	**0.0115**	**0.0054**	**0.0133**	NA	0.2881	**0.0364**
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HUC8×Month×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 9 reports coefficients estimating an alternative version of Eq. (1). In all columns, except (6), we split *POST×HUC10_HF* by two non-overlapping binary variables marking observations in the post-disclosure period as falling either into a *High Group* or a *Low Group*. The high (low) partitions are as follows: (1) counties with an *at least one* (*no*) local newspapers that has been active in the 360 days leading up to the adoption of the state's disclosure mandate; (2) Census core-based statistical areas or counties with *at least one* (*no*) local anti-fracking NGO that has been active in the year before the adoption of the state mandate; (3) counties with an *increase* (*no change*) in the number of newspapers articles about HF-related environmental and water impacts between the pre- and post-disclosure period; (4) counties with an *increase* (*no change*) in the number of volunteers in local anti-fracking NGOs between the pre- and post-disclosure period; (5) HUC10s with an *above* (*below*) median number of wells owned by publicly traded operators; (7) states where it is *more difficult* (*easier*) to obtain trade secret exemptions for the disclosure of HF fluids. The high (low) group includes states with two or more (none or one) conditions for trade secret exemptions; (8) states where the required disclosures need to be timelier, based on a *below* (*above*) the sample median split on the #days between the spud date and the required regulatory filing date. In Column (6), we estimate an interaction between the cumulative number of major changes to FracFocus website improving accessibility and dissemination, *CUM_FF_CHANGES*, and *HUC10_HF×POST*. The sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre-and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. *HUC10_HF* and *POST* are defined as in Table 3. We report results for the within-sub-basin specification using HUC8×Month×Year FE. The results using the within-state specification are very similar. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Appendix

Example of HF Well and Fluid Disclosure

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

GROUNDWATER PROTECTION COUNCIL

Interstate Oil & Gas Compact Commission

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 of HF well and fluid disclosure. It is taken from a well drilled in Texas after the state adopted its transparency mandate. The disclosure provides the start date of the on-site operations, the well ID, the operator name, the geo-coordinates of the well, and the total water used. It also provides detailed information on the composition of the HF fluids, including the chemicals used. Operators can omit some information because of trade secret exemptions (see Section OA4). In this example, the operator omitted the chemical (CAS#) identifier but still had to report the trade name, the purpose of the chemical and the quantity used.

For Online Publication

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

Section OA – Descriptive or anecdotal evidence and background information

Section OB – Supplemental analysis

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

OA1 – Examples of the Demand for HF Transparency

Societal calls for more transparency about HF generally

Outlet	Date	*Title* / Quotes
Pennlive	September 5, 2010	***'Gasland,' a documentary about the natural gas industry in Pennsylvania, is a national hit*** The movie "Gasland" — about the environmental hazards of drilling and fracking shale for natural gas — has become a national sensation. The documentary has aired repeatedly on HBO in recent months. Critics, including some Pennsylvania government officials, say it's a shameless piece of propaganda riddled with inaccuracies. Fans say it opened their eyes to what really happens when drillers come to town. Either way, it has become a force to be reckoned with in the ongoing political debate over Marcellus Shale in Pennsylvania. (…) Q: The film focuses on the secrecy surrounding the chemicals used in fracking. Range Resources and several other companies have since begun publicly posting the fracking recipe for each of their wells in Pennsylvania. Your thoughts on that? A: They're clearly afraid of federal regulation. 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. That Wyoming law requires the industry to disclose the chemicals to the state, but not to the people. 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.
Science	August 11, 2012	***Federal Committee: Shale Gas Needs More Openness, Better Data*** (…) The subcommittee to the secretary's Energy Advisory Board was not asked who should be regulating shale gas, Zoback says. Regulation now lies primarily with the states. But "we're pointing out what can and should be done." To regain public trust, the report says, much information about shale gas should become readily available to the public, starting with the chemical recipes for the fluids pumped at high pressure into shale to free up the gas. Those fluids sometimes spill onto the surface and into waterways. And much more information should be gathered on the environment before, during, and after drilling. The debate over whether and how drilling and fracking contaminate groundwater with gas—the infamous flaming water faucet of the documentary Gasland—would benefit especially. "We feel very strongly that having good data will advance a lot of the issues," Zoback says. Some sort of national organization focused on shale gas should also be formed, the report says. It could create a national database of all public information as well as disseminate best practices to industry as they evolve. Added support for existing mechanisms that aid communication among state and federal regulators would also help.
Huffington Post	November 21, 2012	***Fracking's Toxic Secret: Lack of Transparency Over Natural Gas Drilling Endangers Public Health, Advocates Say*** (…) The disclosing of chemicals used by the industry remains seriously incomplete. 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. David Headley, of Smithfield, Penn, is one of those that's been getting incomplete information about contaminates in his water. 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*** (…) 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. 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, the loophole exempts the oil and gas industry from the requirements of the Safe Drinking Water Act. What's more, manufacturers and operators are not required to disclose all their ingredients, on the principle that trade secrets might be revealed. Even George P. Mitchell, the Texas wildcatter who pioneered the use of fracking, has called for more transparency and tighter regulation. In the absence of well-defined federal oversight, states are starting to assert control. In 2011 the North Dakota legislature passed a bill that said, in effect, fracking is safe, end of discussion. (…)

Demand from local communities, NGOs, and environmental activists for information about the HF fluids

Outlet	Date	*Title* / Quotes
Earth Justice	December 11, 2011	***Colorado Adopts New Fracking Disclosure Rule - Victory — Earthjustice instrumental in positive outcome*** The Colorado Oil and Gas Conservation Commission has announced a new state rule on hydraulic fracturing that requires full disclosure of the substances used in the fracking process. The rule is one of the strongest in the country and Earthjustice's Denver office was actively involved in shaping the decision. "This rule is an important step forward that will provide Coloradans with information they need to ensure the safety of their drinking water, air and health, said Earthjustice staff attorney Michael Freeman. "While the conservation community did not get everything it wanted, Colorado's disclosure rule provides a good foundation for ensuring that hydraulic fracturing is done safely in this state." (…) "We are pleased we could reach a reasonable compromise on protecting legitimate trade secrets while ensuring that all types of fracking chemicals and their concentrations are reported to the public," said Charlie Montgomery, Energy Organizer at Colorado Environmental Coalition. "Colorado has taken a strong first step to addressing public health and environmental concerns from fracking," said Matt Reed, public lands director of the High Country Citizens Alliance. "The new disclosure rule, while not perfect, adds transparency to what has been a secretive process. The result will be a better-informed public, recourse for citizens to pursue violations of the rule, and ultimately a better understanding of what chemicals are going into the ground and where."
The Bismarck Tribune	April 1, 2012	***Environmentalists sue over fracking fluids*** CHEYENNE, Wyo. (AP) – Environmentalists are suing the Wyoming Oil and Gas Conservation Commission, saying the regulatory agency hasn't done enough to justify honoring requests by companies to keep the public from reviewing ingredients in hydraulic fracturing fluids. The groups Powder River Basin Resource Council, Wyoming Outdoor Council, Earthworks and OMB Watch sued in Natrona County District Court on Monday. They allege the commission denied their state open records requests to review fracking fluid ingredients. Hydraulic fracturing involves pumping water, sand and chemicals into oil and gas wells to crack open fissures. Wyoming has required oilfield service companies to disclose to state officials the ingredients in their fracking fluids since 2010. Environmentalists have raised alarm for years that fracking could contaminate groundwater. Few if any such cases are confirmed although last year the U.S. Environmental Protection Agency theorized that fracking may have contaminated the groundwater near Pavillion, a small community in central Fremont County. Testing groundwater for fracking-related pollution gets complicated because what goes into fracking fluids isn't generally known outside the companies that make it. Wyoming's open records law provides an exception for public disclosure of trade secrets. The groups say the commission has repeatedly allowed companies to invoke the exception - on flimsy grounds - to keep fracking fluid ingredients out of the public realm. He pointed out that companies must also track fracking fluids after they've been used and account for their reuse, storage or disposal. Wyoming led the nation in its fracking disclosure regulations and other states are following suit, Gov. Matt Mead said in a statement. "Wyoming and the additional states requiring disclosure believe it is the states rather than the federal government that should regulate hydraulic fracturing," said Mead, who as governor is chairman of the commission. "We will watch this case closely to determine if either the rules or the administration of the rules need work. If improvements need to be made we will make them."

Efforts by policy makers and regulators

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

Outlet	Date	*Title* / Quotes
Gas Daily	May 4, 2011	***Maryland to sue Chesapeake over Pa. fluid spill*** The state of Maryland intends to sue Chesapeake Energy for allegedly violating federal environmental laws when hydraulic fracturing fluids from one of its Marcellus Shale gas wells spilled into a north-eastern Pennsylvania creek. "Companies cannot expose citizens to dangerous chemicals that pose serious health risks to the environment and to public health," Maryland Attorney General Douglas Gansler said late Monday. "We are using all resources available to hold Chesapeake Energy accountable for its actions." Gansler said in a letter to Oklahoma City-based Chesapeake that he plans to sue the company and its affiliates for violating the federal Resource Conservation and Recovery Act and the Clean Water Act. Federal law mandates that Gansler give the company 90 days notice of his intent. On April 19, thousands of gallons of fracking fluid were released from the Bradford County well into Towanda Creek, a tributary of the Susquehanna River, which supplies drinking water to about 6.2 million people in Pennsylvania, Delaware and Maryland (GD 4/20). "Exposure to toxic and carcinogenic chemicals in unknown quantities creates a risk of imminent and substantial endangerment to humans using Maryland waterways for recreation and to the environment," Gansler said. "Although the precise mixture of these fracking fluids is not known, a recent congressional study found that they contain 750 chemicals and other components, including several extremely toxic compounds. High levels of these contaminants remain in the fracking fluid that returns to the surface as wastewater after a well has been hydrofracked." He said radioactivity levels in Pennsylvania's fracking wastewater "have sometimes been thousands of times above the maximum allowed by federal standards for drinking water."
Reuters	January 25, 2012	***Obama backs shale gas drilling*** Improvements in drilling techniques have transformed the U.S. energy landscape in recent years by unlocking the country's immense shale oil and gas reserves. But the drilling boom has raised concerns about the safety of natural gas extraction techniques like hydraulic fracturing, or fracking, which environmentalists say could pollute water supplies. 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. 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*** 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. A rule to take effect in June also updates requirements for well construction and disposal of water and other fluids used in fracking, as the drilling method is more commonly known. The rule has been under consideration for more than three years, drawing criticism from the oil and gas industry and environmental groups alike. The industry fears federal regulation could duplicate efforts by states and hinder the drilling boom, while some environmental groups worry that lenient rules could allow unsafe drilling techniques to pollute groundwater.

	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. Jewell, who worked on fracking operations in Oklahoma long before joining the government in 2013, said decades-old federal regulations have failed to keep pace with modern technological advances. The League of Conservation Voters called the bill an important step forward to regulate fracking.

Demand from shareholders for information about HF fluids

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

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

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

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

Demand from potential plaintiffs for information about HF disclosures

HF fluid information can help plaintiffs to prove contamination and establish causation. The following excerpts are from a local newspaper article explaining how landowners (in the proximity of HF wells) can use HF disclosures.

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

OA2 – Examples of Public Pressure following the HF Transparency Mandates

The examples illustrate how HF information is used to create public pressure after the transparency mandates come into effect.

Outlet	Date	*Title* / Quotes
Environment (Wyoming adopted the disclosure rule on August 17, 2010)	March 27, 2012	***Groups seek fuller disclosure of fracking in Wyoming*** SALMON, Idaho (Reuters) - Environmental groups are asking a state court to force Wyoming to provide a more complete list of chemicals used in hydraulic fracturing, or fracking, a drilling technique vital to natural gas and oil production in the state. Wyoming in 2010 became the first state to require disclosure of chemicals that energy companies inject - along with sand and water - deep underground to free gas or oil from rock. But the state exempted products and chemicals that qualified as confidential commercial information, or trade secrets. The Wyoming Outdoor Council and others contend in a legal petition in state court that the Wyoming Oil and Gas Conservation Commission has illegally allowed energy drillers to claim exemptions where they were not warranted. The groups claim such secrecy is impeding efforts to protect public health and water quality. There are 150 chemicals in Wyoming that these companies have asked to be protected under trade secret status," said Steve Jones, watershed program protection attorney for the Wyoming Outdoor Council. Since these chemicals pose a potential threat to ground water and to people's heath, we need to know what they are." The court challenge in Wyoming may have broader implications as other states, including Pennsylvania and Texas, have adopted similar standards for disclosure. Fracking and other drilling advancements have unlocked vast supplies of domestic natural gas, but health and environmental groups worry fracking operations near homes and schools can pollute air and water. The effort to force disclosure comes after the U.S. Environmental Protection Agency agreed earlier this month to work with Wyoming to retest water supplies in Pavillion, the Wyoming town where a 2011 EPA draft study linked natural gas fracking to pollution of a nearby aquifer. Industry representatives said disclosure of so-called "recipes" will hamper market place driven efforts to develop more benign - or greener - fracking chemistry. If companies can't get the benefit of their intellectual capital, we don't get the benefit of their innovation," said energy company advisor Jason Hutt of Bracewell & Giuliani LLP, an international law firm headquartered in Texas. The outdoor council, Powder River Basin Resource Council and others are asking a Wyoming judge to find that the state Oil and Gas Conservation Commission's actions in granting trade secret exemptions in certain cases were "arbitrary, capricious, an abuse of discretion" or otherwise illegal
Skytruth (Pennsylvania adopted disclosure rule on April 16, 2012)	May 12, 2012	***What's In My Frack Fluid?*** Let's consider a typical hydraulic fracturing (fracking) operation at a natural-gas well in Beaver County, Pennsylvania. This particular frack site is right in the middle of Marcellus Shale country and lies along the state's western border, in a rural community similar to many throughout the mid-Atlantic region. The nearest house is approximately 300 feet away and the nearest neighborhood is 1200 feet away. Within 3000 feet of the site lies a sprawling golf course and a small community of 20 houses. The frack site itself is in the center of a farm field in an agricultural setting, and is operated by Chesapeake Energy Appalachia LLC. With such close proximity to a small community, the chemicals used in the fracking procedure certainly raise concerns. So…what exactly is in "fracking fluid" anyway? FracFocus.org is the website used by the drilling

		industry to voluntarily publish their frack site information (i.e. location, ingredients in frack fluid) for the public to see, and a quick look at its ingredients list should help to answer our question. The ingredients list for this specific frack reveals a seemingly innocuous mixture (for a fluid that, y'know, breaks open rock thousands of feet below the ground). The fracking fluid consists mostly of water (89% by weight) and sand (10.38%). These ingredients amount to 25,025 tons of fluid. The remaining 0.52% of the mixture is made up of an additional 133 tons of chemicals that must be trucked onto the site.
Doddridge County Watershed Association (West Virgina adopted the disclosure rule on August 29, 2011)	August 2, 2013	***[From Facebook page]*** Here is a list of those "commonly used chemicals" in frack fluid the industry would like you to think is harmless because they are used in everyday products - the effects on the humans are horrible - also, think about wildlife too: Toxic chemicals in fracking fluid FracFocus, a chemical disclosure registry, lists many of the chemicals currently being used in hydraulic fracturing operations in Colorado. Gas and oil companies do not always disclose their specific fracking recipe, but FracFocus reports that the average "frack job" in shale gas plays in the United States is 99.2 percent water. The other .8 percent can be made up of a wide variety of substances – some of them toxic.
Great Falls Tribune (Montana adopted the disclosure rule on 26 August 2011)	January 19, 2017	***Fracking chemicals focus of lawsuit seeking more disclosure*** A lawsuit against the Board of Oil and Gas seeks to require more disclosure of chemicals used in hydraulic fracturing jobs in Montana, arguing the state's own records fail to provide key information to landowners, but a state official says current rules are sufficient. The lawsuit seeks to reform rules requiring disclosure of the types of chemicals used during "fracking," the process of pumping large volumes of water, sand and chemicals at high pressure to free oil and gas trapped in porous rock. "In Montana there's no ability for the public to scrutinize these trade secret claims," said Katherine O'Brien, an Earthjustice attorney, who is representing the plaintiffs, Montana Environmental Information Center, Natural Resources Defense Council and seven individuals. Operators currently can cite trade secrets to avoid disclosing specific chemicals, she said. In Wyoming, by contrast, oil and gas operators must explain in an affidavit why the chemicals involved are a trade secret, and then the state's oil and gas supervisor makes a ruling whether a trade secret exists, O'Brien said. In Montana, oil and gas operators don't have to prove that the chemical mixture is in fact a trade secret, O'Brien said. "The board's fracking chemical rules in contrast just create an honor system" O'Brien said. In an effort to provide more transparency, the Montana Board of Oil and Gas passed new rules in 2011 that required companies to publicly disclose the generic names of chemicals they pump into the ground to remove oil and gas from rock. "The board feels that the disclosure requirements adopted in 2011 are adequate," said Jim Halvorson, administrator for Montana Board of Oil and Gas. The plaintiffs in the lawsuit petitioned the board in July 2016 to close what they call gaps in the disclosure rules and require operators to disclose specific chemical information before fracking occurs and justify trade secret claims. "The framework for exempting trade secrets under the Board's current disclosure rules contravenes the fundamental purpose of the constitutional right-to-know provision and violates the specific requirements established by the Supreme Court to implement that right when alleged trade secret information is at issue," the

	lawsuit says. Under current rules, oil and gas operators are not required to share specific ingredients of a fracking operation until after the job is completed, O'Brien said. That's a problem for landowners with property near the operation if they want to educate themselves about the risk, O'Brien said. Also, under a trade secret provision, some chemicals are exempt from disclosure, even to board members, and even after the job is completed, O'Brien said. "The board's longstanding position is we need to know as much information as we can about the well location at the time a well is permitted," said Halvorson of the Board of Oil and Gas. "Because an aquifer at risk from hydraulic fracturing could also be at risk from any number of activities related to drilling and production operations. Isolating a requirement to hydraulic fracturing activities doesn't allow the board the opportunity to review potential risks from any other activities.

OA3 – Summary of other Changes in State-Level Regulations related to HF

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

<table>
<tr><th>State</th><th colspan="5">Wastewater Disposal Rules</th><th colspan="3">HF Drilling Standards</th></tr>
<tr><th></th><th>Discharge Prohibited</th><th>Injection Wells</th><th>Pit Siting</th><th>Pit Lining</th><th>Pit Freeboard</th><th>Well Casing</th><th>BOP (Blowout Control)</th><th>Mechanical Integrity Test</th></tr>
<tr><td>Pennsylvania</td><td>SECTION 95.10/SECTION 78.60
1989/7/29</td><td></td><td>RULE 3215
2012/4/16</td><td colspan="2">SECTION 78.56
2013/12/13 (1)</td><td></td><td>SECTION 3211-3227
2012/4/16(3)</td><td></td></tr>
<tr><td>Texas</td><td>SECTION 3.8
2013/4/15</td><td>SECTION 3.9
2014/11/17</td><td></td><td colspan="2">SECTION 3.8
2013/4/15(2)</td><td></td><td>SECTION 3.13
2014/1/1(4)</td><td></td></tr>
<tr><td>Utah</td><td>CODE 649-9-3
2013/8/1</td><td>CODE 649-3-39
2012/11/1</td><td>CODE 649-3-16/CODE 649-9-3
2013/8/1</td><td colspan="2">CODE 649-9-4
2013/8/1(2)</td><td colspan="2">CODE 649-3-8
1989/3/17</td><td>CODE 649-3-13
1989/3/17</td></tr>
<tr><td>West Virginia</td><td></td><td></td><td></td><td>SECTION 35-8-17
2016/6/9(2)</td><td></td><td colspan="2">SECTION 22-6-21-30
2011/2/14</td><td></td></tr>
<tr><td>Wyoming</td><td></td><td>CHAPTER 4 SECTION 4
2005/1/1</td><td>CHAPTER 4 SECTION 1
2015/6/4</td><td>CHAPTER 4 SECTION 1
2015/6/4</td><td></td><td>CHAPTER 3 SECTION 4
2010/8/17</td><td>CHAPTER 3 SECTION 28
2010/8/17</td><td>CHAPTER 18 SECTION 9
2018/11/13</td></tr>
</table>

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

This table presents a summary of changes in other state regulations related to HF along with the respective adoption dates. We focus on two types of HF regulations that are particularly relevant for the water impact of HF: wastewater disposal rules and HF construction and operating standards. To identify relevant regulatory changes, we read the respective administrative codes and laws adopted by the 16 sample states. We further divide them into sub-categories. With respect to wastewater disposal rules, we identified changes in rules pertaining to discharge (whether discharge is prohibited or land-spread is allowed with a permit), injection wells (regulating injection well usage for wastewater disposal), pit siting (restrictions to the location of wastewater pits), pit lining (whether pits must be lined), pit freeboard (whether pits must have freeboard). With respect to HF drilling standards, we identified changes in the standards for well casings, blow control and mechanical integrity tests. We hand-collected the effective dates of the corresponding regulatory changes in these sub-categories from the regulatory texts either from the official state legislation website or Nexis Uni, a research database that contains the administrative codes, regulatory texts, and regulatory tracking for all U.S. states. The cells in the table record the corresponding regulatory change as well as its effective date. Based on the data in this table, we build three additional control variables and use them in the analysis presented (see Section OB7): *HUC10_HF×CUM_WASTEWATER* counts the cumulative number of regulations related to wastewater disposals at a point in time; *HUC10_HF×CUM_HF_STANDARDS* counts the cumulative number of regulations on HF drilling standards; HUC10_HF×CUM_HF_REG combines the two previous counts for regulations related to wastewater disposal and HF drilling standards.

OA4 – Summary of the Trade Secret Regulations

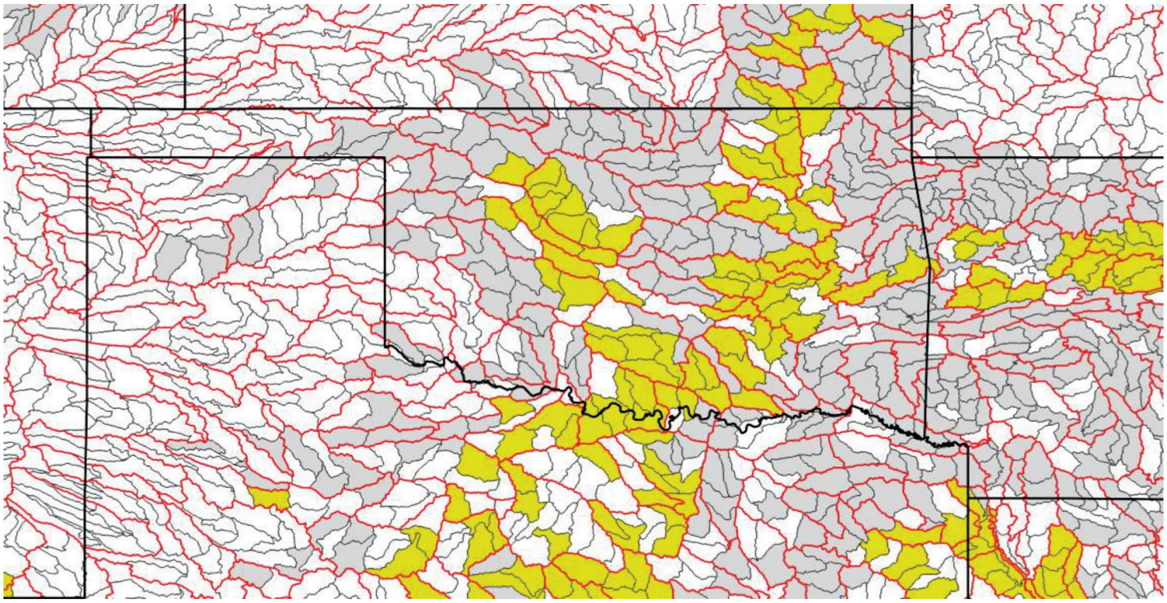
	(1) Submission to claim trade secret	(2) Factual justification	(3) Obligation to provide trade secret information	(4) Process for evaluating trade secret claim	(5) Standards for showing trade secret protection is justified
Arkansas[1]	1	1	1	0	1
Colorado[2]	1	1	0	0	1
Kansas[3]	1	1	0	0	0
Kentucky[4]	1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

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

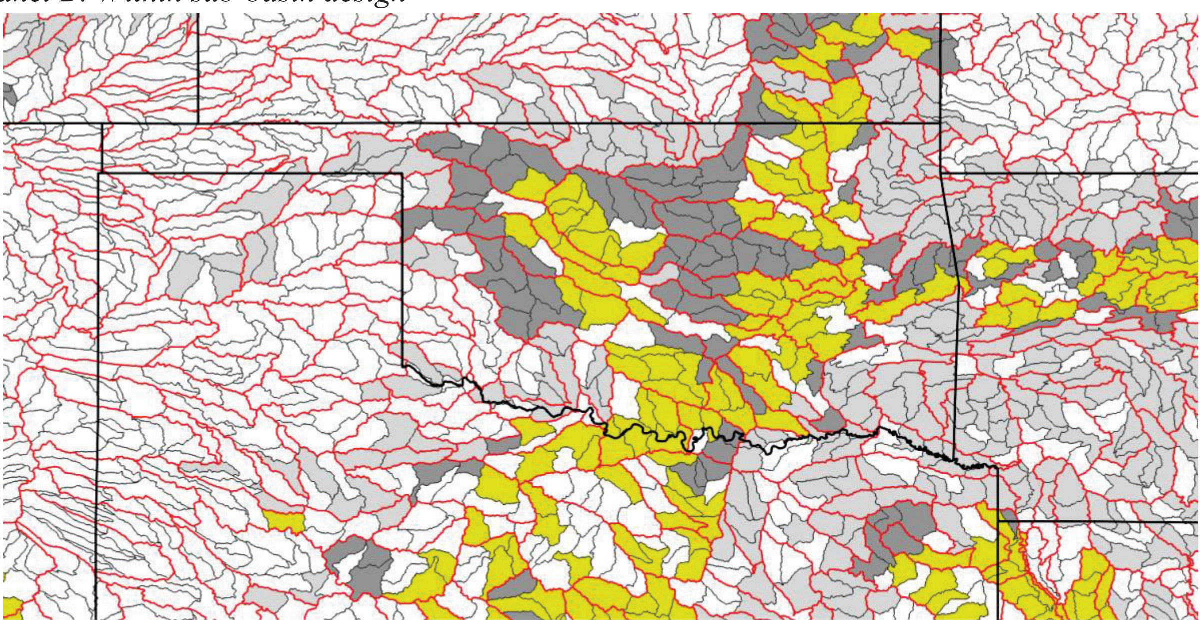
States differ in what they require to grant trade secret exemption. This table presents a summary of these requirements by state. Using McFeeley (2012) and cross-checking the respective state regulations, we identify five conditions that a state may impose when operators submit the claim for a trade-secret exemption: (1) the trade secret exemption requires the submission of a formal claim request; (2) the submission requires a factual justification; (3) operators have to provide supporting information (for example from suppliers and manufacturers who claim the trade secret); (4) there is a process for evaluating the trade secret claim; (5) operators must follow specific standards to prove that the trade secret exemption is justified. As the table shows, states differ in the conditions that they require. States with more requirements make obtaining a trade secret exemption more difficult.

OB1. Identification Maps

Panel A: Within state design



Panel B: Within sub-basin design



The figure illustrates for Oklahoma which variation across watersheds the two alternative designs use for identification. Panel A visualizes the within-state design. Black lines depict watershed (HUC10) borders. Treatment watersheds with HF in the pre-disclosure period are shown in yellow. Control watersheds without HF in the pre- and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity are shown in light gray. The within-state design uses only watersheds within the treated state, even if the sub-region extends beyond state borders. Watersheds without water measurements are shown in white. Panel B visualizes the within-sub-basin design. The red lines depict sub-basin (HUC8) borders. In this design, control watersheds have to be within the same HUC8 as the treatment watersheds. Control watersheds are shown in dark gray. To highlight the difference between the designs, we also mark HUC10s that do not contribute to identification in light gray.

OB2. Robustness Tests for Standard Errors and Ion Measurements

OB.2.1 Alternative clustering of standard errors

We examine whether our inferences are robust to alternative clustering choices for the standard errors. Specifically, we re-estimate Eq. (1) clustering at: (i) the HUC8-state level and (ii) the state-level. We use HUC8-state because HUC8s can cross state lines. The results presented in Table B1 remain statistically significant even when conservatively clustering by state.

Table B1 – Transparency 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	**-0.1509*** [0.0423]**	**-0.0928** [0.0441]**	**-0.1509* [0.0719]**	**-0.0928* [0.0438]**
Observations	325,351	303,387	325,351	303,387
R-squared	0.961	0.971	0.961	0.971
	HUC10s with HF 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 FE	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes

This table reports OLS estimates for the impact of the disclosure mandates on ion concentrations The sample includes a treatment sample of HUC10s with HF in the pre-disclosure period and a control sample of HUC10s without HF in the pre- and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. In Columns (1) – (2), standard errors (in parentheses) clustered by sub-basin (HUC8)-state are reported below the coefficients. In Columns (3) – (4), standard errors (in parentheses) clustered by state are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB.2.2 Truncation of ion concentration measurements

We examine whether our inferences are robust to alternative truncation choices for large ion concentration measurements (outliers). The main analysis truncates concentration measurements at the 99th percentile by ion and HUC4 to account for regional variation in ion concentrations. Here, we re-estimate Eq. (1) for alternative choices: (i) we truncate measurements above the 95th percentile by ion and HUC4; (ii) we truncate measurements above the 99th percentile by ion; (iii) we truncate measurements above the 95th percentile by ion. The results in Table B2 show that the inferences from Table 3 are robust to alternative truncations.

Table B2 – Transparency Mandates and Water Quality

	All Ions pooled (μg/l) truncation at p95 by ion and HUC4		All Ions pooled (μg/l) truncation at p99 by ion over the full sample		All Ions pooled (μg/l) truncation at p95 by ion over the full sample	
	(1)	(2)	(3)	(4)	(5)	(6)
HUC10_HF×POST	**-0.1346***** **[0.0365]**	**-0.0821**** **[0.0373]**	**-0.1433***** **[0.0371]**	**-0.0921**** **[0.0358]**	**-0.1367***** **[0.0371]**	**-0.0767**** **[0.0371]**
Observations	309,748	288,073	324,055	302,164	316,928	295,673
R-squared	0.961	0.972	0.961	0.971	0.960	0.971
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No
HUC8×Month FE	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes

This table reports OLS estimates for the impact of the disclosure mandates on ion concentrations. The sample includes a treatment sample of HUC10s with HF in the pre-period and a control sample of HUC10s without HF in the pre- and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. 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.2.3 Alternative ways of dealing with zero or missing ion concentration measurements

Although the four ions used in our analysis are specific signatures of HF water impact, if and when it occurs, they naturally occur in surface waters. Thus, the baseline concentrations even without HF impact are non-zero. However, there are instances (less than 0.2% of our sample), in which the measured concentration level is explicitly reported as zero. As we take the natural logarithm of the ion measurements,[34] we add the value of one to all zero measurements. This addition is unlikely to have a large effect on our estimates because one is a very small increment relative to average or median ion concentration levels (see Table 2). Moreover, changes in ion concentrations from zero to a non-zero value do not have the usual extensive margin interpretation in our setting, mitigating concerns discussed in Chen and Roth (2024).

Nevertheless, we examine whether our inferences are robust to alternative ways of dealing with zero ion concentration measurements. In particular, we gauge how sensitive the magnitudes of the estimated percentage treatment effects are given the concerns raised in Chen and Roth (2024). We estimate alternative versions of Eq. (1) using three different "log-like" transformations. First, we explicitly calibrate the value assigned to the "extensive margin" by dividing each ion concentration

[34] There is no consensus in the literature on how to model water concentrations in regressions. Keiser and Shapiro (2019a) use raw concentrations and provide robustness in logs. Hill and Ma (2017) model concentrations in logs. We obtain very similar inferences using raw concentrations truncated at the 95th percentile to account for extreme outliers.

by its minimum non-zero value (i.e., 2.0 for Bromide, 0.21 for Chloride, 0.009 for Barium, and 0.1 for Strontium), which sets the minimum concentration for each ion equal to one. We then take the natural log of this transformed ion concentration variable, which returns a zero for the minimum concentrations. We also assign a value of zero to the zero measurements, so that they have the same value as the minimum concentrations, essentially shutting off "the extensive margin." Second, we transform ion concentration as natural log(0.1+µg/l). Third, we transform ion concentration as natural log(10+µg/l). The latter two transformations essentially alter the constant that is added by an order of magnitude in both directions. The results using these three alternative transformations are reported in Table B3 below.

We find that our estimated percentage effects do not change dramatically when we estimate Eq. (1) with an explicit calibration that shuts down the "extensive margin" as suggested in Chen and Roth (2024) (Columns 1–4). The percentage treatment effects range between 10.2% and 15.5%. Similarly, we find that our percentage effects remain within a 10-16% range when we assign different (ad-hoc) values to each observation prior to the natural log transformation (Columns 5–12). Thus, the estimated treatment effects do not appear overly sensitive.

Finally, we note that a small number of water measurements in the NWIS and STORET databases have a flag indicating that a measurement was taken, but that the concentration was *below the detection level (BDL)*, *not detected (ND)* or *not reported (NR)*. These measurements are reported as missing in the databases but could also be treated as zero concentrations. We follow Bonetti et al. (2021) in the treatment of these missing values. Specifically:

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" (6,263 observations);
c) We assign a missing value, if the "Result Detection Condition Text" equals "NA", "Not Reported" or "Present Below Quantification Limit" (227 observations), but only if condition a) does not apply.

As b) increases the number of zero measurements, we perform these steps prior to gauging the role and treatment of zero measurements reported in Table B3.

Table B3 – Transparency Mandates and Water Quality: Alternative Log Transformations

	All Ions pooled (µg/l)											
	Recalibration of ln(*k*+µg/l) in the spirit of Chen and Roth (2024)				Y = ln(0.1+µg/l)				Y = ln(10+µg/l)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
HUC10_HF×POST	**-0.1689***** **[0.0442]**	**-0.1084***** **[0.0405]**	**-0.1685***** **[0.0479]**	**-0.1081***** **[0.0408]**	**-0.1744***** **[0.0465]**	**-0.1060**** **[0.0417]**	**-0.1732***** **[0.0507]**	**-0.1057**** **[0.0419]**	**-0.1256***** **[0.0307]**	**-0.0788**** **[0.0313]**	**-0.1200***** **[0.0329]**	**-0.0784**** **[0.0315]**
Observations	325,351	303,387	220,208	206,389	325,351	303,387	220,208	206,389	325,351	303,387	220,208	206,389
R-squared	0.930	0.948	0.929	0.947	0.947	0.961	0.947	0.960	0.971	0.979	0.972	0.980
Treatment Sample	HUC10s with HF activity in the pre-disclosure period											
Control Sample	All HUC10s without HF but located in sub-regions (HUC4s) with some HF activity in treated states		HUC10s w/o HF over shales in treated states		All HUC10s without HF but located in sub-regions (HUC4s) with some HF activity in treated states		HUC10s w/o HF over shales in treated state		All HUC10s without HF but located in sub-regions (HUC4s) with some HF activity in treated states		HUC10s w/o HF 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 FE	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

This table reports OLS coefficients estimating Eq. (1) to assess the impact of the state disclosure mandates on ion concentrations. The reported models pool all four ion concentrations in one model, as described in Section 4 and in Table 3. In Columns (1)-(2), (5)-(6), and (9)-(10) the sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre-and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. In Columns (3)-(4), (7)-(8), and (11)-(12) (11)-(12), the sample consists of the same treatment sample, but the control HUC10s without HF activity are restricted to those located over shales in treated states. The two samples essentially correspond to the samples used in Table 3. In Columns (1)-(4), we use an explicit calibration for zero and minimum concentrations that essentially shuts down the "extensive margin" of going from a zero to a minimum concentration level. See description in Section OB.2.3 for more details. In Columns (5)-(8), we transform ion concentrations with ln(0.1+µg/l). In Columns (9)-(12), we transform ion concentrations with ln(10+µg/l). The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB3. Robustness Tests for Sample Selection

We examine whether our inferences are robust to alternative control sample choices. In Table 3, Columns 11 and 12, we narrow the set of control HUC10s to those over shales. Here, we enlarge the set by re-estimating Eq. (1) for the following alternative control samples: (i) using *all* HUC10s in treated states without HF in pre-period (i.e., not restricting to HUC10s in sub-regions with some HF activity in the pre-period); (ii) using *all* HUC10s in sub-regions with some HF activity in the pre-period (i.e., not requiring that the HUC10s of the sub-regions are in the treated state); (iii) all HUC10s in treated states or in treated sub-regions (i.e., combining control HUC10s from (i) and (ii)). A sub-region (HUC4) is treated if it is located at least partially in a state that adopts a disclosure mandate and some of its HUC10s have HF activity. In our main analysis, we exclude control HUC10s from treated HUC4s that are not in a treated state. The results in Table B4 show similar results (and if anything stronger findings in the within-state specification) and essentially the same inferences as the main analysis presented in Table 3 (Columns 9-12).

Table B4 – Transparency Mandates and Water Quality

	All Ions pooled (µg/l)					
	Sample: *All HUC10s in treated states*		Sample: *All HUC10s in treated HUC4s*		Sample: *HUC10s in treated HUC4s or in treated states*	
	(1)	(2)	(3)	(4)	(5)	(6)
HUC10_HF×POST	**-0.2499***** **[0.0459]**	**-0.0932**** **[0.0364]**	**-0.1509***** **[0.0386]**	**-0.0904**** **[0.0354]**	**-0.2397***** **[0.0444]**	**-0.0792**** **[0.0321]**
Observations	450,957	417,159	384,150	361,518	522,616	487,810
R-squared	0.949	0.962	0.963	0.972	0.952	0.964
Treatment Sample	HUC10s with HF 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 FE	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes

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

OB4. Changes in Water Measurement

A potential concern for our analysis is that the transparency regime leads to changes in water measurement (e.g., frequency), which in turn influences the estimates for the changes in water quality. In this section, we explore such changes in water measurement. We re-shape the data at the HUC10-month level and create a variable that counts the number of water measurements (for any of the four chemicals) in a given watershed and month. We assign a value of zero to the HUC10-months with no water readings. Then, we regress the number of water measurements on the main variable of interest, *HUC10_HF×POST*, using the same fixed effect structures as in Table 3.[35] We also add the number of new wells in a given HUC10-month-year (*#WELLS_HF*) as additional controls in some specifications. As shown in Table B5, Columns (1) and (3), there is a significant increase in the frequency of water measurement in treated watersheds with HF relative to control watersheds without HF using the within-state design. However, as shown in Columns (2) and (4), this association is no longer present in the tighter within-sub-basin design. Based on these results and considering the consistency of the findings in Table 3, it is unlikely that changes in water measurement play into our main results in a major way.

Table B5 – Changes in Water Measurement

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

This table reports OLS coefficients estimating changes in the frequency of water measurement around the introduction of transparency. The analysis is conducted at the HUC10-month-year level following Eq. (1). *#readings* is a variable that counts the number of water measurements (for any of the four chemicals) in a given watershed and month. *HUC10_HF* marks treated HUC10s, defined as watersheds with HF in the pre-disclosure period. *POST* is a binary variable marking observations in the post-disclosure period. *#WELLS_HF* is the number of new wells 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.

[35] We also estimate Poisson regressions or alternatively use the logarithm of the number of readings plus one as dependent variable. All specifications yield inferences similar to those reported in Table B5.

OB5. Robustness Tests for Staggered Diff-in-Diff Analyses with Heterogeneous Effects

A recent literature in econometrics (D'Chaisemartin and D'Haultfoeuille, 2020) highlights that difference-in-differences (DiD) analyses with two-way fixed effects (one for time and one for group) can produce biased estimates in the presence of heterogeneous treatment effects. With staggered treatments, the problem arises because DiD estimates based on two-way fixed effects are essentially weighted averages of many comparisons, including those that use post-treatment observations from earlier treatments as controls for later-treated observations, and vice versa. Heterogeneity in treatment effects can lead to negative weights attached to specific group-period estimates. We thus assess whether our inferences are affected by these potential issues.

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

To further explore the issue, we execute the diagnostic test proposed by de Chaisemartin and D'Haultfoeuille (2020). When estimating the weights of the group-period clusters for model 9 (10) in Table 3, we find that, in the within-state model, 792 out of the 2,709 Average Treatment Effects (ATTs) receive a negative weight, and 1,447 out of 15,210 ATTs in the within-HUC8 model. We investigate the source of the negative weights and find that they are particularly frequent after 2016. We therefore perform two additional analyses to gauge the severity of the negative weights for our inference. First, we find that the weights are uncorrelated with the passage of time (e.g., using weights from Model 10, Table 3: coefficient = 0.000, *t*-statistic = –0.87). Second, if we remove the years after 2016 from the sample, we find 305 ATTs out of 2,790 receive negative weights in the within-state model, which sum to only –0.027. For the within-HUC8 model, the number drops to 456 out of 15,210, which sum to –0.011. As all states adopted their mandates before 2016, we could also remove years after 2016 from the analysis. Reassuringly, our main results in Table 3 and inferences do not change when excluding years after 2016.

OB6. Endogeneity of State Adoption Dates

In this section, we explore the potential endogeneity of the adoption dates or the timing of the state disclosure mandates. We propose four different tests.

First, we examine whether our results are robust to lagged changes in ion concentrations since states might choose to adopt the disclosure requirements in response to trends or shocks to local water quality. We augment Eq. (1) by including lagged changes of the ion concentrations at the HUC10 level as additional controls (i.e., % change in the average ion concentration in a given HUC10 between year $t-1$ and year $t-2$). Table B6 shows that our results continue to hold when we control for lagged changes in ion concentrations.

Second, we examine whether we can predict the relative timing of states' disclosure rules based on variables that reflect pre-adoption differences in public pressure, economics, politics, or HF activity intensity in one state versus another. Such correlations could indicate that the relative timing of the disclosure mandates is not plausibly exogenous. To test this, we compute the difference (in months) between each state's disclosure implementation date and the start date of our sample, January 2010. We then regress this adoption timing variable on a series of variables capturing the above state-level differences. Specifically, we use the timing of the peak in Google searches for HF (expressed in months relative to January 2010 or relative to the within-state minimum between January 2010 and December 2020), the state's income per capita as of 2010, the fraction of people with a college degree as of 2010, the employment rate as of 2010, the total number of HF wells drilled up to 2010, and an indicator variable marking whether the state was leaning democratic in the 2010 house election. The results in Table B7 do not show significant associations for the relative adoption timing, suggesting that it is difficult to predict when states adopt the disclosure rules based on ex-ante state characteristics, consistent with the identifying assumption that states' relative timing is plausibly exogenous.

Third, we run a test in the spirit of Altonji, Elder, and Taber (2005). We first identify variables that capture local factors to which state lawmakers might respond when introducing the disclosure mandates. We propose the following candidate variables: the monthly number of newspaper articles covering HF and its potential environmental or water impact by county; the yearly number of volunteers reported by local anti-fracking NGOs and watershed groups by county; a dummy marking anti-fracking protests in a given county-year-month; the monthly cumulative number of HF wells in a state; and the number of water readings in a state-year-month. These variables should broadly capture HF-related pressures that state lawmakers might experience due to HF activity in their state.

Next, we exclude the variable of interest (i.e., *HUC10_HF×POST*) from Eq. (1) and instead add these candidate variables. We estimate and store the predicted values for the ion concentrations from these regressions and then re-estimate Eq. (1) by replacing actual ion concentrations with the predicted values. If our results were largely driven by local factors to which state lawmakers respond, we should see that using the predicted values produces very similar results. However, the results in Table B8 show, especially for the tighter within-HUC8 model (reported in columns 4 and 8), that the predicted values generated with these local factors explain only a very small fraction of the treatment effect estimated in Table 3 (i.e., roughly 6.3% in the within-HUC8 models 10 and 12). In un-tabulated analyses, we also include the controls for other HF regulations (from Section OA3 and Table B11) that were adopted within 360 days before or after the respective state's disclosure mandate in the estimation of the predicted values. We obtain similar results.

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

To implement this statistic, we estimate an alternative version of Eq. (1) in which we include the potential confounders considered in Table B8. This regression yields an $R^2_{controlled}$ of 0.9548 and a coefficient on *HUC10_HF×POST* (i.e., $\beta_{controlled}$) of –0.1086 (*t*-stat -3.04). We then use these estimates to compute the δ (i.e., relative degree of selection) using the following formula: $\delta = \beta_{controlled} \times (R^2_{controlled} - R^2_{uncontrolled}) / [(\beta_{uncontrolled} - \beta_{controlled}) \times (R^2_{MAX} - R^2_{controlled})]$, where $\beta_{uncontrolled}$ and $R^2_{uncontrolled}$ are the coefficient on *HUC10_HF×POST* and the R^2 from Table 3, Column 9. For an assumed R^2_{MAX} equal to 0.96, we obtain a δ of 1.75. According to Oster (2019), this value suggests that there would have to be a relatively large degree of selection on unobservables to explain our results in Table 3, which is reassuring.

Based on all four tests, we conclude that the adoption dates or the timing of the disclosure regulation across states is plausibly exogenous for our analysis.

Table B6– Disclosure Mandates and Water Quality – Controlling for Lagged Changes in Water Quality

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

This table reports OLS coefficients estimating Eq. (1) controlling for lagged changes in ion concentration. The models in Columns (9)-(10) pool all four ion concentrations in one model, as described in Section 4. In Columns (1)-(10), the sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure periods that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. *Δ Ion Concentrations[t-1]* is the % change in the average ion concentration in a given HUC10 between year $t-1$ and year $t-2$. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table B7 – Analysis of the Relative Timing of the Adoption Dates

	Disclosure Timing (1)	Disclosure Timing (2)	Disclosure Timing (3)	Disclosure Timing (4)
GS_Peak_relative_2010	16.8006		17.2458	
	[28.1740]		[28.9772]	
GS_Peak_relative_Min	-0.4326	-0.4326	-0.0173	-0.0173
	[1.5930]	[1.5930]	[1.7491]	[1.7491]
Income_per_Capita_2010	-0.3806	-0.3806	-0.2045	-0.2045
	[1.5787]	[1.5787]	[1.6440]	[1.6440]
College_2010	-6.4669	-6.4669	-8.4237	-8.4237
	[18.3246]	[18.3246]	[19.0625]	[19.0625]
Democratic_House_2010	8.3311	8.3311	-23.6840	-23.6840
	[161.3519]	[161.3519]	[172.5181]	[172.5180]
Employment_Rate_2010		0.5600		0.5749
		[0.9391]		[0.9659]
HF_Total_Count_2010			-0.0008	-0.0008
			[0.0012]	[0.0012]
Observations	16	16	16	16
R-squared	0.065	0.065	0.110	0.110

This table reports OLS estimates from models predicting timing of the disclosure rules (relative to Jan 2010). *Disclosure Timing* is the difference (in months) between each state disclosure implementation date and January 2010; *GS_Peak_relative_2010* is state-level difference in months between the peak in Google searches (GS) for HF-related terms and January 2010; *GS_Peak_relative_Min* is state-level difference in months between the peak in GS for HF-related terms relative to the month of the within-state minimum of GS between January 2010 and December 2020; *Income_per_Capita_2010* is the state-level income per capita as of 2010; *College_2010* is the state-level fraction of people with a college degree as of 2010; *Democratic_House_2010* is dummy marking whether the state was leaning democratic in the 2010 house election; *Employment_Rate_2010* is the state-level employment rate as of 2010; *HF_Total_Count_2010* is total number of HF wells drilled until the January 2010. Standard errors (in parentheses) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Table B8 – Gauging the Endogeneity of the State Adoption Dates (in the spirit of Altonji et al., 2005)

	All Ions pooled (μg/l) (1)	$\widehat{\text{All Ions}}$ pooled (mg/l) (2)	All Ions pooled (μg/l) (3)	$\widehat{\text{All Ions}}$ pooled (mg/l) (4)	All Ions pooled (μg/l) (5)	$\widehat{\text{All Ions}}$ pooled (mg/l) (6)	All Ions pooled (μg/l) (7)	$\widehat{\text{All Ions}}$ pooled (mg/l) (8)
HUC10_HF×HF Newspaper Coverage	0.0052		0.0057		0.0171		0.0068	
	[0.0300]		[0.0571]		[0.0335]		[0.0581]	
HUC10_HF×Local NGO Volunteers	-0.1654***		0.1291		-0.1365**		0.1298	
	[0.0619]		[0.0792]		[0.0618]		[0.0796]	
HUC10_HF×Anti-HF Protests	-0.0252		-0.0171		-0.0232		-0.0160	
	[0.0210]		[0.0215]		[0.0203]		[0.0209]	
HUC10_HF×CUM_WELLS_HF	-0.0002*		0.0002		-0.0002		0.0002	
	[0.0001]		[0.0001]		[0.0001]		[0.0001]	
HUC10_HF×#Readings	0.0004**		0.0004		0.0004**		0.0004	
	[0.0002]		[0.0002]		[0.0002]		[0.0002]	
HUC10_HF×POST		**-0.0119*****		**0.0059*****		**-0.0078*****		**0.0058*****
		[0.0018]		**[0.0016]**		**[0.0014]**		**[0.0016]**
Observations	325,351	325,351	303,387	303,387	211,273	211,273	198,258	198,258
R-squared	0.961	0.997	0.971	0.999	0.962	0.996	0.972	0.998
Coef. *HUC10_HF×POST* (Table 3)		**-0.1509*****		**-0.0928****		**-0.1476*****		**-0.0925****
Treatment Sample	HUC10s with HF activity in the pre-disclosure period							
Full Sample	All HUC10s in sub-regions (HUC4s) in treated states with some HF activity				HUC10s over shales in treated states			
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	Yes	No	No	Yes	Yes	No	No
HUC8×Month FE	Yes	Yes	No	No	Yes	Yes	No	No
HUC8×Month×Year FE	No	No	Yes	Yes	No	No	Yes	Yes

This table reports OLS estimates from a test in the spirit of Altonji et al. (2005). In Columns (1), (3), (5), (7) we estimate an alternative version of Eq. (1) adding the following variables: the monthly number of newspaper articles covering HF and its potential environmental or water impact by county (*HF Newspaper Coverage*); the yearly number of volunteers reported by local anti-fracking NGOs and watershed groups by county (*Local NGO Volunteers*); a dummy marking anti-fracking protests in a given county-year-month (*Anti-HF Protests*); the monthly cumulative number of HF wells in a state (*CUM_WELLS_HF*); the number of water readings in a state-year-month (*#Readings*). In Columns (2), (4), (6), (8) we re-estimate Eq. (1) replacing actual ions concentrations with the predicted values from Columns (1), (3), (5), (7) regressing them on variable of interest, *HUC10_HF× POST*. Although the coefficients of interest are significant, they are very small compared to the actual treatment effects reported in Table 3. 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.

OB7. "Placebo" Tests, Controlling for Agricultural Activity and for Concurrent Regulatory Events

OB7.1 Placebo Tests

To consider whether alternative explanations for the changes in water quality affect our results, we conduct two "placebo" tests. First, we examine concentration changes in analytes that are not specific to HF but reflect water impacts of other economic activities that grow because of local HF activity or its economic benefits (e.g., agriculture). We use: (i) Dissolved oxygen (DO), (ii) Fecal Coliforms, (iii) Phosphorus (Table B9 Panel A). Second, we examine changes in the four HF-specific ion concentrations around the transparency mandates, but in watersheds with conventional drilling, to which the disclosure mandates do not apply (Table B9 Panel B).

Table B9 – Transparency Mandates and Water Quality: Non-HF Specific Analytes and Vertical Wells

Panel A – Analytes that are not specific to HF impact

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

This table reports OLS coefficients estimating Eq. (1) for three water quality proxies that are not specific to HF impact. The models in Columns (7) and (8) pool all analytes in one model, as described in Section 4. The sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

Panel B – Water quality changes in watersheds with conventional drilling (vertical wells)

	Bromide (µg/l)		Chloride (µg/l)		Barium (µg/l)		Strontium (µg/l)		All Ions pooled (µg/l)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
HUC10_CONV×POST	0.0110	0.0107	-0.0499	-0.0593	-0.0260	-0.0504	-0.0157	-0.0587	-0.0409	-0.0567
	[0.1461]	[0.0170]	[0.0379]	[0.0570]	[0.0170]	[0.0275]	[0.0401]	[0.0528]	[0.0289]	[0.0394]
Observations	9,637	8,686	141,131	130,536	45,915	40,027	26,631	24,627	223,314	203,876
R-squared	0.879	0.929	0.870	0.905	0.838	0.864	0.968	0.975	0.956	0.967
Treatment Sample	HUC10s with conventional drilling activity in the pre-disclosure period									
Monitoring station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State×Month×Year FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

This table reports OLS coefficients estimating Eq. (1) for HUC10s with conventional, i.e., vertically drilled, wells around the introduction of the disclosure mandates. The sample consists of treatment HUC10s with conventional drilling in the pre-disclosure period (and not HF) and control HUC10s without conventional drilling (and not HF activity) in the pre- and post-disclosure periods that are located in sub-regions (HUC4) of treated states that have some conventional drilling activity. *HUC10_CONV* is a binary indicator marking watersheds with conventional drilling activity (treated HUC10s). *POST* is a binary variable marking water quality observations in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB7.2 Agricultural Activity

Further, we provide a test checking for the influence of agricultural activity, which is another source of water pollution. We collect data on the fraction of land devoted to agriculture from the Census of Agriculture (National Agricultural Statistics Service) and compute the fraction of land in a HUC10 devoted to agricultural activity in 2007. Then, we split the treatment sample of HUC10s with HF in the pre-period into two non-overlapping groups based on the sample median of this variable. HUC10s with above (below) the median level of agriculture are classified in the *High_Agr* group (*Low_Agr* group). Table B10 reports OLS coefficients estimating Eq. (1) and replacing the variable, *POST×HUC10_HF*, with two non-overlapping variables marking observations in the post-disclosure period in the respective group, *High_Agr* (*Low_Agr*). Table B10 suggests that the level of agricultural activity has little influence on our main results, if anything we find stronger results in areas with low levels of agriculture activity, with all four ions being significant.

Table B10 – Transparency Mandates and Water Quality – Influence of Agricultural Activity

	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)
POST×HUC10_HF×High_Agr	0.0389	0.1202	**-0.2111****	-0.0798	**-0.1149****	-0.0334	-0.0054	-0.0382	**-0.1419****	**-0.0634***
	[0.1050]	[0.1576]	**[0.1034]**	[0.0566]	**[0.0466]**	[0.0330]	[0.0299]	[0.0366]	**[0.0635]**	**[0.0380]**
POST×HUC10_HF×Low_Agr	**-0.1883*****	-0.0038	**-0.1829*****	**-0.1397****	**-0.0736***	**-0.0899****	**-0.0738*****	-0.0363	**-0.1591*****	**-0.1143*****
	[0.0670]	[0.1465]	**[0.0394]**	**[0.0563]**	**[0.0391]**	**[0.0451]**	**[0.0275]**	[0.0322]	**[0.0295]**	**[0.0408]**
Observations	12,578	11,445	154,675	144,640	57,916	52,064	38,312	36,639	263,481	244,788
R-squared	0.876	0.915	0.862	0.901	0.819	0.851	0.968	0.977	0.957	0.968
Treatment Sample	HUC10s with HF at least 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 FE	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
HUC8×Month×Year FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes

This table reports OLS estimates from an alternative version of Eq. (1). 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) median level of land devoted to agriculture, *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 sample of control HUC10s without HF in the pre- and post-disclosure periods and located in sub-regions (HUC4) of treated states with HF activity. Standard errors (in parentheses) clustered by watershed (HUC10) are reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB7.3 Concurrent Regulatory Changes

In OA3, we list relevant other regulatory changes for each state in our sample. To identify relevant regulatory changes for the O&G industry, we read the respective administrative codes and laws adopted by the states in our sample. Relevant regulations include provisions prohibiting the discharge of wastewater, regulating injection wells, imposing pit siting, liners, freeboard and overflow requirements, leak detection and blowout prevention systems, as well as well casing requirements. Some of these provisions have been adopted well before the start of our sample period and others were introduced only very recently, and hence long after the transparency regimes were introduced. These changes pose little threat to our analysis. Moreover, we examine the proximity of the state transparency mandates and the changes to other HF regulations listed in Section OA3. We find that they are fairly "distant" in that the mean (median) absolute difference between the adoption dates of the state disclosure mandates and the respective state's changes to other HF regulations is 52 months (27 months). However, some of the regulations have been adopted around the time of the disclosure mandates and five states (Ohio, Pennsylvania, Montana, North Dakota, and Utah) have introduced their HF disclosure requirements along with other regulatory amendments. We therefore examine whether our results reported in Table 3 are robust to controlling for other regulatory changes.

Towards this end, we create indicator variables marking relevant changes to wastewater rules and HF drilling standards in a given state over time. The coding is state and time specific. Specifically, we create three interaction variables for these other regulations: (i) *HUC10_HF×CUM_WASTEWATER* represents the number of regulations related to wastewater handling at a given point of time in watersheds with HF wells (i.e., the variable starts at the respective number of regulations we found by the beginning of our sample period and then increases by one when a new regulation or amendment for wastewater handling is introduced in the respective state); (ii) *HUC10_HF×CUM_HF_STANDARDS* represents the number of HF drilling standards at a point in time in watersheds with HF wells (i.e., the variable starts at the respective number of regulations we found by the beginning of our sample period and then increases by one when a new drilling standard or amendment is introduced in a state); (iii) *HUC10_HF×CUM_HF_REG* represents the joint number of wastewater handling rules and drilling standards at a given point in time (i.e., the variable is the sum of the previous to two variables). We introduce these variables into the main analysis as additional controls. If the documented changes in water quality primarily reflect these other regulatory changes, rather than the transparency mandates, then the estimated coefficient of interest, *HUC10_HF×POST*, should be attenuated when we also include the control variables for the other regulations.

In Table B11, we find that the coefficients on *HUC10_HF×POST* are still negative and significant in all specifications. More importantly, we see little attenuation in the coefficient magnitudes relative to the estimates reported in Table 3. This evidence makes it unlikely that the improvements in water quality are mainly driven by other regulatory changes that are concurrent or close in time to the disclosure mandates. Consistent with this interpretation, the coefficients on the other HF regulations are insignificant and relatively close to zero. These results could reflect that some of the other HF rule changes during our sample period are fairly minor, e.g., amendments to existing rules put in place much earlier.

Table B11 – Transparency Mandates and Water Quality: Controlling for other HF Regulations

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

This table reports OLS coefficients estimating Eq. (1), but adding controls for other HF regulations using three alternative variables: (i) *HUC10_HF×CUM_WASTEWATER* represents the number of regulations related to wastewater handling at a given point of time in watersheds with HF wells (i.e., the variable starts at the respective number of regulations we found by the beginning of our sample period and then increases by one when a new regulation or amendment for wastewater handling is introduced in the respective state); (ii) *HUC10_HF×CUM_HF_STANDARDS* represents the number of HF drilling standards at a point in time in watersheds with HF wells (i.e., the variable starts at the respective number of regulations we found by the beginning of our sample period and then increases by one when a new drilling standard or amendment is introduced in a state); (iii) *HUC10_HF×CUM_HF_REG* represents the joint number of wastewater handling rules and drilling standards at a given point in time (i.e., the variable is the sum of the previous to two variables). The sample consists of treatment HUC10s with HF activity in the pre-disclosure period and control HUC10s without HF activity in the pre- and post-disclosure periods that are located in treated states and within sub-regions (HUC4s) with some HF activity. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. We report the respective coefficient of interest from Table 3, Panel A, Columns 9 and 10 for comparison. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB8. Variable Measurement for Public Pressure

A core idea of the paper is that targeted transparency creates public pressure, which in turn incentivizes HF operators to change their behaviors. In this section, we provide details on the measurement of the three public pressure variables used in the analysis: (i) local media coverage of HF-related environmental and water impacts, (ii) local anti-fracking activity by NGOs and watershed groups, and (iii) the number of anti-fracking protests.

For the first variable, we identify and download newspaper articles from Lexis-Nexis between January 2005 and December 2016 that contain the following keywords in the headline: "*Hydraulic fracturing*" or "*Fracturing*" or "*Fracking*" or "*Fracing*". Next, we separate local and national newspapers and assign local newspapers to the counties in which each newspaper circulates following Gentzkow and Shapiro (2010). Within the set of local newspapers, we count the number of articles by county-month-year containing the following keywords: ("*pollut*" or "*health*" or "*contaminat*" or "*environment*" or "*water*") in conjunction with "*Fracturing*", "*Fracking*", or "*Fracing*". Following this procedure, we identify 3,193 articles. Lastly, we take the natural logarithm of one plus this number of newspaper articles as dependent variable.[36] In Table 9 (Column 1), we also use a binary indicator for the presence of a local newspaper in the county.

For the second variable, we count the number of volunteers helping local anti-fracking NGOs. We first assemble a list of local anti-fracking NGOs from *America Against Fracking*, *Pennsylvania Against Fracking Coalition*, and *Frack Action*. We merge this list with data from GuideStar, which provides the Form 990 filings of nonprofit organizations. To identify local environmental (or watershed) groups that focus on water quality issues, we retain nonprofit organizations with the following NTEE codes: C01, C02, C03, C011, C12, C20, C30, C32, and C34. We then restrict this list to those with institutional names that include the words: *watershed*, *river*, *water*, *creek*, *lake*, or *stream*. We use the organization's address to assign each environmental group to a local community defined as in a Census Core-Based Statistical Areas (CBSA) or a county if the address is not within any CBSA. We then use the Form 990 filings to obtain the number of volunteers for the local NGOs, which is reported annually. Following this procedure, we identify 1,132 NGOs with an average (a median) number of volunteers of 196 (25). We take the natural logarithm of one plus this count as dependent variable.[37] In Table 9 (Column 2), we also use a binary indicator

[36] Instead of adding one to the count, we also estimate Poisson regressions, which yield similar inferences.
[37] Instead of adding one to the count, we also estimate Poisson regressions, which yield similar inferences.

for the presence of local anti-fracking NGOs and watershed groups in the respective county or core-based statistical area (CBS).

For the third variable, we collect data on local anti-fracking protests. To construct this variable, we again use all HF-related articles in local newspapers, identified in Lexis-Nexis between January 2005 and December 2016 as described above, and code protests with a two-step procedure. First, we code articles as indicating the occurrence of anti-fracking protests when they have the following keywords in the header: "rally", "protest", "picket", "sit-in", "march", "mobiliz", "demonstrat" or when they are specifically marked as protest-related articles by Lexis-Nexis. We hand-check these articles to confirm that they indicate local anti-fracking protests and code them accordingly. Second, we identify articles containing either in the header or in the article body various combinations of the following keywords: "*signs*" "*posters*", "*placard*", "*crowd*", "*sitin*", "*picket*", "*protest*", "*rally*", "*ban*", "*against*", "*activist*", "*anti*", "*a group of*", "*support*", "*ban*", "*fight*". We manually check these articles to confirm that they indicate anti-fracking protests and code them accordingly. We conduct additional checks in the remaining articles to minimize the likelihood that this two-step procedure misses reported protests. In total, we find 243 articles in local newspapers covering anti-fracking protests, which is relatively rare once we assign protests to counties. We therefore code the *occurrence* of local anti-fracking protests by county-month-year with a binary indicator variable as there is almost never more than one protest by county and month.

OB9. Changes in the Dissemination of HF Disclosures via FracFocus

To link the documented improvements in water quality to the adoption of the state disclosure rules, we exploit changes in the accessibility and dissemination of the HF disclosures via the FracFocus website, which is the primary repository for the required disclosure forms. Here, we provide more details on these changes.[38]

After its initial creation in 2011, FracFocus implemented several changes to its website to improve the accessibility and dissemination of the HF disclosures. We identify three major changes during our sample period. In June 2013, the release of FracFocus 2.0 allows "users to more efficiently search for well site chemical information" according to description of the release. In July 2015, FracFocus starts providing disclosure data to the public in machine-readable (SQL) format. In June 2016, the release of FracFocus 3.0 provides a stronger "validation processes to improve data integrity, a new format for reporting company data entry, and newly designed forms to improve the company and regulatory agency user experiences when checking and completing disclosures." We examine whether these three changes to the FracFocus repository are associated with additional improvements in water quality in watersheds with HF activity (see Table 9 and Section 6).

[38] For an overview on the evolution of the FracFocus website see: https://fracfocus.org/learn/about-fracfocus.

OC1. Descriptive Statistics for the Spill and HF Incidents Data

The table below reports descriptive statistics for the variables in Table 6 using spills data from Brantley *et al*. (2014) and Patterson *et al.* (2017). Our sample includes 2,667 HF-related spills from Colorado, North Dakota, New Mexico and Pennsylvania between January 2005 and December 2015, covering much of the HF boom in the U.S. and much of the time period over which the HF transparency mandates were introduced. We also code incidents related to the handling of HF wastewater, including HF fluid, flowback, produced water, or brine spills.

Table C1. Descriptive Statistics for the spill data used in Table 6

Variables	N	Mean	p25	p50	p75	SD
All HF-related incidents	22,682	0.081	0.000	0.000	0.000	0.272
Wastewater incidents	19,320	0.045	0.000	0.000	0.000	0.207

Table C1 reports descriptive statistics for the dependent variables used in Table 6. *All incidents* is a binary variable equal to one if there is at least one HF-related incident in a given HUC10-month-year, zero otherwise. *Wastewater incidents* a binary variable equal to one if there is at least one HF incident related to the handling of wastewater in a given HUC10-month-year, zero otherwise.

OC2. Descriptive Information on the Disclosed Chemicals used in HF Fluids

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

Table C2 – Most Common Hazardous Chemicals in the Disclosure for HF Fluids

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

	United States Department of Labor, has set an 8-hour permissible exposure limit of 0.1 ppm in air (0.3 mg/m^3) for people working with chlorine dioxide.
Choline chloride	Irritating to eyes, respiratory system and skin. Toxic to aquatic organisms. Accidental ingestion of the material may be damaging to the health of the individual. Nausea, vomiting, gastro-intestinal discomfort and diarrhea have been reported after large doses of choline.
Cupric chloride	Cupric chloride can be toxic. Only concentrations below 5 ppm are allowed in drinking water by the US Environmental Protection Agency.
Dazomet	Dazomet is irritating to the eyes and its degradation product, MITC, is a dermal sensitizer. Dazomet is very toxic to aquatic organisms, and acutely toxic to mammals. Exposure to dazomet can occur through several means; interaction with unincorporated granules, inhalation of its decomposition product, MITC, and/or water runoff.
Didecyl dimethyl ammonium chloride	In mice this disinfectant was found to cause infertility and birth defects when combined with Alkyl (60% C14, 25% C12, 15% C16) dimethyl benzyl ammonium chloride (ADBAC). These studies contradict the older toxicology data set on quaternary ammonia compounds which was reviewed by the U.S. Environmental Protection Agency (U.S. EPA) and the EU Commission.
Dimethylformamide (DMF)	Reactions including the use of sodium hydride in DMF as a solvent are somewhat hazardous; exothermic decompositions have been reported at temperatures as low as 26 °C. On a laboratory scale any thermal runaway is (usually) quickly noticed and brought under control with an ice bath and this remains a popular combination of reagents. https://en.wikipedia.org/wiki/Dimethylformamide
Ethylene glycol	Ethylene glycol has relatively high mammalian toxicity when ingested, roughly on par with methanol. Upon ingestion, ethylene glycol is oxidized to glycolic acid, which is, in turn, oxidized to oxalic acid, which is toxic. It and its toxic byproducts first affect the central nervous system, then the heart, and finally the kidneys. Ingestion of sufficient amounts is fatal if untreated. Several deaths are recorded annually in the U.S. alone. https://en.wikipedia.org/wiki/Ethylene_glycol
Ethylene glycol mono-n-butyl ether	2-Butoxyethanol has a low acute toxicity, with LD_{50} of 2.5 g/kg in rats. Laboratory tests by the U.S. National Toxicology Program have shown that only sustained exposure to high concentrations (100–500 ppm) of 2-butoxyethanol can cause adrenal tumors in animals. OSHA does not regulate 2-butoxyethanol as a carcinogen.
Ehylene oxide	Ethylene oxide causes acute poisoning, accompanied by a variety of symptoms. Central nervous system effects are frequently associated with human exposure to ethylene oxide in occupational settings. Headache, nausea, and vomiting have been reported. Peripheral neuropathy, impaired hand-eye coordination and memory loss have been reported in more recent case studies of chronically-exposed workers at estimated average exposure levels as low as 3 ppm (with possible short-term peaks as high as 700 ppm). The metabolism of ethylene oxide is not completely known. Data from animal studies indicate two possible pathways for the metabolism of ethylene oxide: hydrolysis to ethylene glycol and glutathione conjugation to form mercapturic acid and meththio-metabolites. Ethylene oxide easily penetrates through ordinary clothing and footwear, causing skin irritation and dermatitis with the formation of blisters, fever and leukocytosis.
Formaldehyde	In view of its widespread use, toxicity, and volatility, formaldehyde poses a significant danger to human health. In 2011, the US National Toxicology Program described formaldehyde as "known to be a human carcinogen". The CDC considers formaldehyde as a systemic poison. Formaldehyde poisoning can cause permanent changes in the nervous system's functions.

Formic acid	Formic acid has low toxicity (hence its use as a food additive), with an LD_{50} of 1.8 g/kg (tested orally on mice). The concentrated acid is corrosive to the skin. Formic acid is readily metabolized and eliminated by the body. Nonetheless, it has specific toxic effects; the formic acid and formaldehyde produced as metabolites of methanol are responsible for the optic nerve damage, causing blindness, seen in methanol poisoning. Chronic exposure in humans may cause kidney damage. Another possible effect of chronic exposure is development of a skin allergy that manifests upon re-exposure to the chemical. Concentrated formic acid slowly decomposes to carbon monoxide and water, leading to pressure buildup in the containing vessel. The hazards of solutions of formic acid depend on the concentration. The principal danger from formic acid is from skin or eye contact with the concentrated liquid or vapors. The U.S. OSHA Permissible Exposure Level (PEL) of formic acid vapor in the work environment is 5 parts per million parts of air (ppm).
Hydrochloric acid	Being a strong acid, hydrochloric acid is corrosive to living tissue and to many materials, but not to rubber. Typically, rubber protective gloves and related protective gear are used when handling concentrated solutions.
Isopropyl alcohol	Isopropyl alcohol vapor is denser than air and is flammable, with a flammability range of between 2 and 12.7% in air. Isopropyl alcohol causes eye irritation and is a potential allergen. Isopropyl alcohol, via its metabolites, is somewhat more toxic than ethanol, but considerably less toxic than ethylene glycol or methanol. Death from ingestion or absorption of even relatively large quantities is rare. Both isopropyl alcohol and its metabolite, acetone, act as central nervous system (CNS) depressants. Poisoning can occur from ingestion, inhalation, or skin absorption. Symptoms of isopropyl alcohol poisoning include flushing, headache, dizziness, CNS depression, nausea, vomiting, anesthesia, hypothermia, low blood pressure, shock, respiratory depression, and coma. Overdoses may cause a fruity odor on the breath as a result of its metabolism to acetone. Isopropyl alcohol does not cause an anion gap acidosis, but it produces an osmolal gap between the calculated and measured osmolalities of serum, as do the other alcohols. Isopropyl alcohol is oxidized to form acetone by alcohol dehydrogenase in the liver and has a biological half-life in humans between 2.5 and 8.0 hours.
Magnesium nitrate	May cause irritation of the digestive tract. May be harmful if swallowed. Ingestion of nitrate containing compounds can lead to methemoglobinemia. Inhalation: Causes respiratory tract irritation.
Methyl isobutyl ketone	Exposure to high concentrations can cause you to feel dizzy and lightheaded, and to pass out. Prolonged contact can cause a skin rash, dryness and redness. Methyl Isobutyl Ketone may damage the liver and kidneys.
Naphthalene	Exposure to large amounts of naphthalene may damage or destroy red blood cells, most commonly in people with the inherited condition known as glucose-6-phosphate dehydrogenase (G6PD) deficiency, which over 400 million people suffer from. Humans, in particular children, have developed the condition known as hemolytic anemia, after ingesting mothballs or deodorant blocks containing naphthalene. Symptoms include fatigue, lack of appetite, restlessness, and pale skin. Exposure to large amounts of naphthalene may cause confusion, nausea, vomiting, diarrhea, blood in the urine, and jaundice (yellow coloration of the skin due to dysfunction of the liver). The International Agency for Research on Cancer (IARC) classifies naphthalene as possibly carcinogenic to humans and animals (Group 2B). Under California's Proposition 65, naphthalene is listed as "known to the State to cause cancer". A probable mechanism for the carcinogenic effects of mothballs and some types of air fresheners containing naphthalene has

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

Table C3 – Descriptive Statistics for the Chemical Variables used in Table 7

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

Table C3 reports descriptive statistics on the variables used in Table 7. The variables are constructed at the HUC10 level, averaging over all HF well disclosures for each HUC10-month-year. We compute averages for the amount of all hazardous chemicals and chloride-related hazardous chemicals, respectively. For each HF well, we scale the respective amount by the total amount of fluids injected. Hazardous chemicals are those (i) regulated as primary contaminants by the Safe Drinking Water Act; (ii) regulated as Priority Toxic Pollutants for ecological toxicity under the Clean Water Act; or (iii) classified as diesel fuel under EPA guidance on HF operations (EPA, 2014). For the pre-period, we use voluntary disclosures to calculate HUC10-month-year averages, following Fetter (2022).

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