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

Law Working Paper N° 676/2023
May 2025

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ECGI Working Paper Series in Law

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Abstract

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Keywords: Social movements, Public pressure, Fracking, Real effects, Disclosure, Water pollution, Sustainability, Externalities, Unconventional oil & gas development

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

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Internalizing Externalities through Public Pressure: Transparency Regulation for Fracking and Water Quality

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This draft: December 2024

Abstract

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Acknowledgments: We would like to thank Wes Austin, Jenn Baka, Marianne Bertrand, Thomas Bourveau, Susan Brantley, Matthias Breuer, Thomas Covert, Oussema El Ajel, Aytekin Ertan (discussant), Michael Greenstone, Jodi Grewal, Chris Hansen, Elaine Hill (discussant), Ginger Jin, Ryan Kellogg, Mark Maffett, Sendhil Mullainathan, Max Muller (discussant), Miao Liu, Felix Oberholzer-Gee, Joseph Shapiro, Hongping Tan, Luigi Zingales and workshop participants at the AEA 2022 Annual Meeting, Bocconi, Ruhr-Uni Bochum, Boston College, Chicago Booth Micro Lunch, Columbia Business School, EPA, FARS, Frankfurt School of Finance & Management, Goethe University Frankfurt, HEC Paris, Northwestern University, University of Mannheim, University of Maryland, McGill University, 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 2024 SITE conference, 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, the University of Bristol Business School and the University of Padova-Fondazione Cariparo Starting Package Grant.

1. Introduction

In this study, we ask what transparency and public pressure can do when it comes to corporate activities with negative 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). Despite its long tradition in the U.S., going back for instance to the 1986 Emergency Planning and Community Right-to-Know Act and the Toxic Release Inventory (TRI), we have little evidence as to whether and, importantly, how mandating transparency works, especially when it targets corporate behavior with dispersed externalities (e.g., air and water pollution) and stakeholders have to rely primarily on public pressure to drive changes in corporate activities.

Such a situation arises in the context of unconventional oil and gas (O&G) development, which combines horizontal drilling with hydraulic fracturing to extract shale gas and tight oil in deep formations (henceforth HF). HF is considered the most important innovation in the energy sector since the introduction of nuclear energy, and it has brought substantial economic benefits.[1] However, HF has been subject to minimal federal regulation, despite being very controversial due to its health and environmental risks, including air and water pollution (e.g., Currie *et al.* 2017; Hill and Ma 2021; Hill 2024). Chief concerns are the large amounts of toxic wastewater (Vidic *et al.* 2013; Vengosh *et al.* 2014; Levin et al. 2024) and the chemicals used in the HF fluids (e.g., EPA 2016). Given these concerns, many U.S. states introduced mandatory disclosure rules for newly fractured wells starting around 2010 to shed light on HF activity and practices. These rules require operators to disclose local information on HF activity, e.g., the exact location, operator identity 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).[2] Yet, many observers voiced skepticism that transparency alone would make operators change their practices and reduce the environmental impacts of HF (e.g., McFeeley 2012).

Conceptually, the transparency regime puts HF practices in the spotlight. It enables intermediaries like the media or NGOs, local communities or social movements to mount

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1 For example, HF has dramatically increased U.S. energy production, lowered consumer prices, and increased local wages and welfare (e.g., Allcott and Keniston 2018; Bartik *et al.* 2019).

2 A good example is the Underground Injection Control provision of the Safe Drinking Water Act, from which HF is exempt (except when using diesel fuel).

pressure on operators, to scrutinize their HF activities and ultimately to question their license to operate, which in turn could incentivize operators to improve practices and reduce pollution. In essence, public pressure fueled by transparency could act as an implicit tax (Pigou 1920; Baumol and Oates 1988). However, this effect depends on the accessibility and dissemination of information and the extent to which public pressure is costly to firms (Tietenberg 1998; Weil *et al*. 2013).

In light of the scant evidence on this nexus between transparency regulation, public pressure and corporate activities, we study HF disclosure regulation and the role of public pressure with respect to water pollution. The focus on water pollution reflects key environmental concerns about HF but also the substantial environmental and social costs of such type of pollution (Keiser and Shapiro 2019a, 2019b; Hill and Ma 2021). Several recent studies document a negative 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 activity and surface water pollution to assess changes in the environmental impact and operator practices, without having to rely on information that operators have to provide (as, e.g., Fetter *et al.* 2024) or having to limit the analysis to the post-disclosure period (as, e.g., studies of the U.S. TRI).[3]

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 (HUC10) [4] 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 HF surface water impact exists (Vidic *et al.*, 2013, Brantley *et al.*, 2014). For one, they are found in high concentrations in wastewater from HF wells and are therefore considered

[3] Some operators provided chemical disclosures voluntarily before the mandates. We exploit these data in one analysis similar to Fetter *et al.* (2024). However, voluntary disclosures are limited and selected.

[4] 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).

signatures (Vengosh *et al.*, 2014, Rosenblum *et al.*, 2017). 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 a fixed effect 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 the pre- and post-disclosure evolution of ion concentrations between watersheds with HF activity and near-by control watersheds without HF activity, i.e., those in the same sub-region or the same sub-basin within a state. We also perform analyses restricting the control sample to watersheds situated over shales to further reduce heterogeneity between treated and control watersheds.

We find that HF-related salt concentrations decrease between 9% and 14% after the state disclosure mandates become effective. 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.[5] Reassuringly, we do not find such declines for other water quality measures that are *not* signatures for HF-related water impact but might reflect broader changes in economic activity related to local O&G development. Along the same lines, we do not find significant decreases in salt concentrations for watersheds that have only conventional drilling to which the HF disclosure rules do not apply. Additionally, we check for other HF regulations, i.e., wastewater management rules and drilling standards, and show that controlling for them does not alter our inferences. We also conduct extensive tests to gauge the potential endogeneity of the states' adoption dates, e.g., due to public pressure, political forces, or economic activity. We conclude that the timing of the disclosure regulation across states is plausibly exogenous for our analysis.

After these standard identification checks, we perform a per-well analysis that explicitly connects the transparency regime to changes in ion concentration patterns that are tied to the timeline of the HF well development process. Bonetti *et al.* (2021) document spikes in all

[5] To address the concern that the estimated magnitudes of the declines are underestimated due to pollution spillovers into downstream watersheds (SUTVA violation), we also provide analyses using higher-elevation control watersheds that are likely upstream, and find slightly larger effects, as expected.

four HF-related ion concentrations between 91 and 180 days after the start of the drilling (i.e., well spudding). These spikes occur when HF wells generate large amounts of wastewater at the surface, linking HF well activity and water pollution. When we examine these ion concentration spikes after mandatory disclosure, we find that they decline by 22%. This finding links the introduction of the disclosure mandates and the reductions in the surface water impact of new HF wells. It also points to wastewater management and handling as a key margin that HF operators appear to adjust in response to transparency, which is aligned with evidence suggesting that spills and leaks of HF fluids and wastewater are a key pathway by which HF wells pollutes surface waters (Vengosh *et al.* 2014; Agarwal *et al.* 2020). We dig deeper into this pathway for water pollution and examine changes in HF-related incidents (e.g., spills and leaks) after the introduction of the transparency regime. We find a decline in the likelihood of HF-related incidents, especially those related to wastewater handling. Thus, there is direct evidence that targeted transparency materially improved HF practices. We explore other margins of adjustment and find small declines in the well entry rates after mandatory disclosure but no changes in production volumes (conditional on drilling). These results confirm that most of the improvements come from adjustments along the intensive margin, which makes sense from an economic perspective.

Having established water quality effects and explored the margins of adjustment, we turn to the mechanism question: how does targeted transparency create public pressure? Transparency over HF activity boosted by the disclosure mandates could enable social movements led by the media, environmental groups, and local communities that exert pressure on HF operators.[6] For instance, the disclosures could lead to protests or public shaming operators for their use of toxic chemicals. 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) or allow social movements to pressure regulators with respect to monitoring and enforcement (Buntaine *et al.* 2024; Colmer *et al.*, 2023). In addition, HF disclosures can stimulate public debate about stricter regulations (e.g., bans) incentivizing operators to improve their practices.

Consistent with the idea that transparency enables social movements and creates public

[6] 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).

pressure, we document 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 shortly after the state mandates come into force. Moreover, the local magnitude of the water quality improvements following the transparency mandates is linked to local public pressure. We document larger decreases in HF-related ion concentrations in counties where a local newspaper or a local environmental NGO are present, consistent with these intermediaries making targeted transparency more effective. We further show that the water quality improvements after the disclosure mandates are more pronounced in counties with more news articles covering HF concerns and anti-HF protests as well as in areas that see larger increases in volunteers at local anti-fracking NGOs. The presence of such intermediaries as well as the increase in local public pressure after targeted transparency are also associated with larger declines in HF-related incidents, linking pressure to changes in operator practices and to improvements in water quality. Water quality improvements are also larger in areas where more wells are owned by publicly traded O&G firms, consistent with the idea that these firms face more scrutiny than private ones. We find incremental (post-mandate) water quality improvements as the dissemination of HF disclosures via the central FracFocus repository further improves. All these results underscore the role of public pressure galvanized by targeted transparency regulation.

Our study makes two primary contributions. First, we provide novel evidence that and, importantly, how transparency regulation mitigates dispersed environmental externalities, contributing to the literature on transparency regulation. Our work is related to studies showing that disclosure or dissemination of corporate violations of standards, rules, accidents or complaints can correct or improve regulated behavior (e.g., Bennear and Olmstead 2008; Dyreng *et al.* 2016; Christensen *et al.* 2017; Johnson 2020; Rauter 2020; Buntaine *et al.* 2022). However, it is not clear that such public shaming works to correct dispersed externalities. Moreover, in our setting, the regulation simply spotlights regular corporate activities, i.e., targets HF with transparency. In this sense, our analysis is closer in spirit to the seminal study by Jin and Leslie (2003) on restaurant hygiene disclosure and recent studies on disclosure mandates for greenhouse gas (GHG) emissions in the U.K. and the U.S. (e.g., Downar *et al.* 2021; Yang *et al.* 2021; Tomar 2023). However, these studies provide little evidence on the mechanism.[7] In contrast, we unpack the transparency mechanism using granular data and provide extensive evidence demonstrating how targeted transparency changes corporate practices. We show that transparency serves locally as a catalyst that enables social movements and galvanizes public pressure, and provide evidence of such pressure (e.g., local anti-fracking protests) and that this is what pushes operators to improve corporate practices and reduces water pollution. Our evidence highlights the importance of both having intermediaries like the media or NGOs and having local information for the creation of (local) public pressure.

Such evidence on when and how transparency regulation works is important, as targeted transparency does not always work and can have unintended consequences (Weil *et al.* 2013; Dranove *et al.* 2003). Despite the latter, policy makers increasingly rely on transparency regulation to address environmental and societal issues (e.g., Dranove and Jin 2010; Christensen *et al.* 2021), even in settings in which it is not ex ante obvious that it would work. This applies also in our setting, given HF's dispersed externalities and that stakeholders' main recourse is public pressure. In particular, any observed water pollution cannot be easily attributed to a specific HF operator in a watershed, which is different from the TRI setting or the GHG disclosure mandates, where emissions belong to the disclosing facility or entity.[8]

Our second major contribution is to the literature on water quality and regulatory tools to mitigate water pollution. As Shapiro (2022) points out, we lack evidence from natural experiments with respect to water pollution. The state transparency mandates for HF allow us to study regulatory effects on water pollution.[9] Our evidence differs from other studies of

7 Tomar (2023) is an exception in this regard. He attributes reductions in GHG emissions due to the U.S. GHG Reporting Program primarily to inter-firm benchmarking and learning. As we show in Section 6.3, this channel is unlikely to be at play in our setting.

8 Our study differs from the TRI literature. The evidence on real effects in these studies is mixed and difficult to attribute to the disclosure mandate. Studies lack data on emissions in the pre-TRI period and instead study the initial information release (e.g., Konar and Cohen 1997; Khanna et al. 1998) or the post-TRI period only (e.g., Khanna and Damon 1999; Graham and Miller 2001). For this and other reasons, the TRI results have been heavily debated (e.g., Bui and Mayer 2003; Bui 2005; Oberholzer-Gee and Mitsunari 2006; Shapiro 2022). In contrast to all TRI studies, we can estimate environmental impacts in a difference-in-differences analysis and can pinpoint transparency and public pressure as the drivers of the decrease in water pollution.

9 In terms of its setting, our paper is related to Fetter (2022) and Fetter et al. (2024). The former finds, as do we, that operators use fewer hazardous chemicals after the HF mandates, but does not analyze water quality. The latter presents evidence suggesting that the HF mandates encourage the imitation of chemical mixes of more productive wells, similar to the GHG results in Tomar (2023). However, convergence towards more productive practices does not imply less pollution (e.g., Knittel 2011). Moreover, variation in the chemical composition is likely of second-order importance for HF water pollution. The critical factors are wastewater

major regulatory initiatives, like the Clean Air Act or the Clean Water Act, aimed at limiting environmental pollution (e.g., Greenstone, 2002, Greenstone, 2004, Keiser and Shapiro, 2019a, Keiser and Shapiro, 2019b). Mandating HF disclosure does not directly regulate pollution; it instead enlists market forces or social movements to exert public pressure and change corporate behavior. Our study also provides the first long-run assessment of the environmental impact of HF on U.S. surface water, covering much of the fracking boom. Such evidence is important given the significant role of HF for U.S. energy production and recent political developments in support of the O&G industry, but also considering that the industry has been difficult to regulate directly as well as the substantial costs of and challenges posed by water pollution (e.g., Keiser et al. 2018; Levin *et al*. 2024).

2. Institutional Setting: HF Water Pollution, Transparency and Public Pressure

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 has increased dramatically, creating substantial economic benefits (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; Levin et al., 2024). 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, which is 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

management and the avoidance of leaks and spills, not changes in fluid compositions (see Section 2.1). Consistent with this notion, we show in Section 6.3 that fluid composition changes are unlikely to explain our water quality results.

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-1), having identified cases of impact for all stages of the HF water cycle. Subsequently, several studies provide more systematic evidence of impact. 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 HF 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. In Pennsylvania, 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. Covering several U.S. states and 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.

Based on the evidence to date, the primary pathways for surface water contamination are accidents, leaks and spills of HF fluids, flowback or produced water (on-site, from cementing or casing failures, wastewater pits or trucking), as well as 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; Levin *et al.* 2024). Thus, management and handling of HF fluids and wastewater by the operators are key to avoiding water contamination. Furthermore, there is significant scientific evidence that the chemical concentrations in HF fluids and wastewater would pose significant risks to human health and the environment, in particular aquatic ecosystems, if released into surface waters (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 sets 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 chemicals used in HF fluids. As public concerns about the environmental and health effects of HF grew, several states mandated more transparency of HF activity on a well-by-well basis. There are currently eighteen states with HF activity and disclosure laws for the HF fluids (Konschnik and Dayalu 2016).[10] These rules were adopted at different points between 2010 and 2015 (Table 1, Panel A and Figure OB1).[11]

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 Online Appendix OA1 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 2024).[12] If granted, the form still discloses the volume, 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,[13] 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 within 30-120 days after the spudding or the completion of the well. In addition, all states require HF operators to submit completion

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[10] 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.

[11] 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.

[12] 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 6).

[13] 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).

reports to their 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.[14]

In sum, the state disclosure mandates substantially change the public information environment for HF activities in at least 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 provide information about the use of harmful or toxic chemicals in HF fluids, which makes it easier for the media and NGOs to raise concerns about HF, to galvanize social movements, and to question the industry's license to operate. Third, posting the information on FracFocus improves the accessibility and dissemination of this information. All these changes imply that the transparency of HF activities substantially increases with the introduction of the state disclosure mandates.

2.3 Transparency Regulation and Public Pressure

Unlike traditional regulatory approaches to pollution control, targeted transparency does not restrict or prescribe specific practices. Instead, it enlists market forces and public pressure to change corporate behavior (Weil *et al*. 2013). Specifically, the spotlighting of HF activities by the transparency regime makes the HF-related environmental risks more visible and salient and empowers social movements, stakeholders or the public to impose pressure and ultimately costs on HF operators. Operators could respond by drilling less or by taking additional precautions to avoid environmental impact, especially spills or accidents, which could challenge their license to operate. However, the critical question is whether the HF disclosures generate enough pressure on HF operators to affect their practices.

Public pressure due to the required disclosures can arise in numerous ways and from various institutional actors. First, HF operators could expect the public to react negatively to the hazardous chemicals used in the fluids. As the disclosures are well-specific, they could

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[14] 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.

facilitate pressure and protests at HF wells by local communities or NGOs (e.g., Green 2014). Such social movements can impose reputational costs on HF operators through public 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 chemicals in the 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 by facilitating citizen complaints or private litigation (Olmstead and Richardson 2014; Colmer et al. 2023).[15]

Second, public debate about HF spurred by the increase in transparency could threaten the license to operate and 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, especially if the practices entail regulatory or litigation risks that are ultimately borne by investors.[16]

We collect many detailed anecdotes illustrating the demand for information about HF activity by local communities, environmental groups, policymakers, regulators, investors, the media as well as plaintiffs in HF-related lawsuits (see Background Information on GitHub). We also furnish anecdotes illustrating public pressure from NGOs and social movements arising *after* the transparency mandates come into force (see Online Appendix OA2).

In addition to the public pressure channel, disclosure could also facilitate peer learning (Tomar 2023). In our setting, HF operators could learn from the other operators' disclosures

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[15] Identifying the operator responsible for contamination is very difficult, however, even when the HF fluids are known. For one, information on the often more relevant produced water or wastewater composition is not disclosed. Moreover, the burden of proof in litigation is high, which often leads to the dismissal of tort cases (Tsekerides and Lowney 2015).

[16] 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/)

and imitate high-productivity practices and fluid mixes (Fetter *et al.* 2024). However, it is not obvious that higher productivity maps into less water pollution, even if more productive mixes were less environmentally damaging (which is not known). The critical factors for HF water pollution are wastewater management and the avoidance of spills and leaks, rather than the specifics of the chemical mix at injection or changes therein (see Section 2.1). Consequently, peer learning and imitation of high-productivity mixes are an unlikely channel in our setting. We provide evidence supporting these arguments in Section 6.

3. Data

We analyze changes 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). 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). 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 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 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 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.[17]

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

[17] 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.

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.[18]

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 (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.

We perform our analysis at the watershed (HUC10) level because the literature shows that HF-related water impacts are detectable at the watershed level (Agarwal *et al.* 2020; Bonetti *et al.* 2021).[19] We retain water readings from monitoring stations that are located in states that have adopted HF disclosure mandates, restricting the sample to 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. 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

[18] 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.

[19] We assign each monitoring station and HF well to a watershed through the QGIS geographical software. 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 4.

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. surface water quality has been analyzed.

Table 1 reports the distribution of water quality observations and HF activity across states with HF disclosure mandates. Section OB1 in the Online Appendix plots the time trend in HF activity in our sample, with the staggered adoption of the state disclosure mandates. Section OB2 in the Online Appendix 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.[20]

Our final estimation sample consists of water measurements from (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.[21] By using nearby control HUC10s *without* any HF activity, we avoid the potential for operational spillovers (which otherwise could occur if HF operators in control HUC10s change their practices in response to the disclosure mandates).

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).[22] We provide descriptive statistics for the distribution of monitoring stations and water measurements per ion and HUC10 in the Online Appendix OB3. 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

[20] The data 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.

[21] The assignment of treated watersheds is based on the pre-disclosure period. However, HF activity could also start in the post-disclosure period. In fact, we have 85 watersheds without HF activity in the pre-period but some HF activity in the post-disclosure period. We exclude these watersheds from the main analysis because using them as controls could overstate the results. As a robustness, we re-run our analyses including these 85 watersheds and obtain results that are indistinguishable from those reported in the paper.

[22] We gauge the role of truncation and logarithmic transformation for the results in Online Appendix OB6.

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 transparency regulation. Our tests exploit variation in the timing of the state disclosure mandates as well as within-state or alternatively within-sub-basin variation in HF activity across watersheds. The choice between the specifications involves 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 1, Panel B). Moreover, some of these control HUC10s are downstream from treated HUC10s and hence could be polluted by upstream HF activities. Such a STUVA violation would reduce the estimated treatment effects. The within-state specification relies on many more control HUC10s, but they are further away, which could make them less comparable but also less prone to downstream spillovers.[23] Thus, we estimate two versions of 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 a 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,[24] 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

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23 To ensure reasonable comparability of treatment and control watersheds, the within-state analysis does not use all watersheds in a state. Instead, it requires control watersheds to be part of a larger sub-region where there is some HF activity (Section 3). See Online Appendix OB7 for robustness.

24 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].

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. Robustness tests for alternative clustering of standard errors are reported in Online Appendix OB6.

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 monitoring station; and (iii) local weather conditions at the time of the water measurement. The model essentially estimates the effect of the 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 Online Appendix OB4). 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, changes in operator practices or swings in public pressure. We later gauge these two assumptions in additional analyses. Moreover, given the potential for downstream spillovers into the control watersheds, we also perform tests using only water measurements from higher-elevation control HUC10s.

5. Results: Effects on Water Quality 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. 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 Online Appendix OB3). We therefore pool the water measurements for all ions in one regression to harness statistical power.[25] In these models, the coefficients on *HUC10_HF×POST* are negative 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 suggest that the disclosure mandates are followed by 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 1, Panel A, 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.[26]

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[25] 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.

[26] In Table 3 and Figure 1, 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. Using such a 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 these magnitudes, it is important to consider the potential for downstream spillovers, which would likely bias the coefficients downwards. 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 only measurements from 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 results emerge (Table 3, Panel B). First, the estimated declines in ion concentrations increase in magnitude for all within-sub-basin specifications, suggesting pollution spillovers into the control HUC10s. Second, the estimated magnitudes become more consistent across the within-state and the within-sub-basin specifications. The estimated declines pooling all ions are now closer to -17%. 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 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 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).[27]

Recent studies in econometrics show 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).[28] We thus assess whether our inferences are affected by these potential issues,

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27 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).

28 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

employing 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 and never-treated watersheds as controls. Already-treated watersheds are removed from the sample. The findings reported in Online Appendix OB5 shows 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. We also explore the timing of the ion reductions in the "stacked" regression framework in Figure 1, Panel B, using the same approach as for Figure 1, Panel A. As before, we do not find different pre-trends for treated and control HUC10s and the decrease in ion concentrations starts right after the HF disclosure mandates come into force.

We further 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) control sample composition; and (v) changes in the frequency of water measurement. These sensitivity analyses are presented in the Online Appendix OB6, OB7, and OB8. They show that our findings and estimated magnitudes are robust to a range of alternative design choices.

5.2 Addressing Alternative Explanations for the Changes in Water Quality

In this section, we summarize several analyses to address standard identification concerns about the timing of regulation as well as concurrent events. A concern in our context is that states adopted the disclosure mandates in response to local shocks to water quality (e.g., due to spills or accidents) or in response to rising public pressure. Such pressure or local shocks could also lead to changes in operator practices and reduced HF water impact, irrespective of the disclosure mandates. We perform a series of tests to gauge this alternative explanation and report the results in the Online Appendix OB9. We do not find evidence supporting this concern.[29] As the dynamic between transparency regulation and public

effects can lead to negative weights attached to specific group-period estimates.

[29] We first add lagged changes in the ion concentrations to the model to control for states responding to local water quality shocks (Table B8). 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 B9). Third, we

pressure is central to the proposed mechanism, we analyze it in detail in Section 6.

Next, we conduct two "placebo" tests (see Online Appendix OB10). 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 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.[30]

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. We thus 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 concurrent events confound 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 regulation or common trends in HF technology or 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

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 B10).

30 In un-tabulated analyses, we also test whether our results are influenced by changes in water pollution due to agricultural activity.

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.[31] We find that the key variable of interest, *HUC10_HF×POST*, is still negative and statistically 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 Linking Water Quality Changes to the HF Process and At-Risk Water Measurements

Prior research suggests that mishandling of wastewater, accidental or deliberate, is likely a key pathway by which HF pollutes surface water (Vidic *et al.* 2013; Vengosh *et al.* 2014; EPA, 2016). 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 wells generate large amounts of flowback and produced wastewater that need to be collected at the surface. Thus, this evidence ties ion increases directly to a critical phase of the HF development process, which is important for causality.

Based on this finding, 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-regime period, respectively (Figure 2). The idea is to visualize changes in HF-related water impact after the transparency regime is introduced. To further tighten the causal link and to increase the power of the test, we use only at-risk water measurements. These measurements are more likely to detect HF-related water impact, if and when it exists, because they stem from water monitoring stations that sit closer to wells and are likely downstream (for details see caption of Figure 2). Consistent with Bonetti *et al*. (2021), we find concentration spikes in the [91, 180]-day window. More importantly, the spike in the same window is significantly smaller (by 22%) after mandatory disclosure ($p<0.05$; F-statistic of 4.05). This per-well result for water impact implies improvements

[31] In Online Appendix OA3, we provide more details on these other regulatory changes and list their respective adoption dates. In Online Appendix OB10, we explain the coding of the indicator variables and present the results controlling for other HF regulatory changes.

along the intensive margin and shows that the changes in at-risk water measurements after the transparency regime are directly linked to the development process of HF wells.

5.4 Changes in HF Operators' Practices

In this section, we dig deeper into the mechanism for water pollution and study changes in HF operator practices to further link the improvements in water quality to the introduction of the transparency regulation. As discussed in Section 5.3, the handling of HF fluids and wastewater, including spills and leaks, are likely a key pathway for surface water contamination, especially early in the production process when most of the water comes back to the surface. The transparency regime and the ensuing public scrutiny likely make spills, leaks and accidents more costly to operators and hence should incentivize them to exercise more care in drilling and managing HF wastewater. We therefore 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 HUC10 and month×year fixed effects to account for location-specific differences as well as technological changes, respectively. Table 4 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 (between 5 and 6%) as well as those related to the handling of HF wastewater (around 6%).[32]

Aside from operating more carefully, HF firms could also drill fewer wells, which would also contribute to reduced water pollution. However, considering the profitability of O&G development, adjustments along the extensive margin are likely very expensive to operators.[33] Consistent with this conjecture, we document a small but statistically significant

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[32] Corroborating the results in Section 6, we find that larger declines in the number of HF-related incidents in areas where transparency is expected to create more public pressure and indeed where public pressure increases after the transparency mandates (Table B16).

[33] The drilling, fracturing and completion of HF wells involve substantial up-front costs. The costs of

decrease in the well entry rate, relative to the pre-disclosure period and relative to the entry rate for conventional wells (Table B13).[34] However, conditional on drilling a new HF well, it would make little sense for operators to lower production volume in response to public pressure. Consistent with this argument, we confirm in un-tabulated analyses that the disclosure mandates have no significant effect on HF production volumes. Moreover, focusing on the intensive margin, we combine volume and pollution in the analysis to assess changes in environmental performance, measured as the ratio of production volume (in barrels) to ion concentrations (in μg/l) at the HUC10-month-year level. Table B14 documents that operators produce the same volume with less water impact after mandatory disclosure (4-7%). This analysis confirms operators' adjustments along the intensive margin and shows that the improvements in water quality do not stem from production volume changes.

Finally, we examine changes in the use of hazardous chemicals after disclosure becomes mandatory. As discussed, for HF water pollution, wastewater management and the avoidance of spills and leaks are likely the critical factors, rather than the specifics of the chemical mix at injection or changes therein. However, the use of toxic chemicals can be a lightning rod for the public and hence it is conceivable that operators reduce the use of hazardous chemicals in response to the transparency and public pressure. In Online Appendix OB12, we examine the use of hazardous chemicals around the introduction of the transparency regime. The results in Table B15 show that operators report using a lower share of hazardous chemicals in the HF fluids once they have to disclose the HF fluid composition.

6. Internalizing Externalities through Public Pressure

6.1 Targeted Transparency and Public Pressure

In the second part of our analysis, 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,

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constructing a well vary depending on its location, depth, and pressure. The International Energy Agency (IEA, 2011) recommends several best practices to achieve safer and cleaner fracking, such as improving well integrity and preventing leaks from casing and cement failures (an estimated additional $800,000) and properly handling and treating wastewater (an estimated additional $1.6 million). Given that the total cost of a well can range from $4 to $12 million, these additional expenses for implementing safer practices are significant but manageable.

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

more transparency for HF activities due to the disclosure regime 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 this channel and the sources of public pressure more formally.[35]

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 OB13 for 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 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 5 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 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. In these analyses, we control for concurrent local HF activity to make sure the increases in public pressure are not driven by HF activity itself. Moreover, we find for all three variables that the coefficient for the effect of the disclosure mandates on public pressure is larger in magnitude in counties with wealthier and more educated households, further corroborating our interpretation of the link between transparency and public pressure. Importantly, we map out the changes in the three public pressure variables in event time and find that the increases in public pressure occur *after* the states introduce transparency regulation (Figure 3). Taken together, our analyses suggest that targeted transparency enables social movements and increases public pressure on HF operators locally.

[35] 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 5 and, in particular, the pre-trends in Figure 3 address this concern empirically, showing that the introduction of state regulation leads to more public pressure, rather than the other way around. See also Online Appendix OB9 for several other tests examining the potential endogeneity of the state adoption dates.

6.2 Public Pressure and Water Quality Improvements

Having established that targeted transparency unleashes public pressure, we examine whether differences and changes in public pressure are associated with changes in water quality 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 pre-determined public pressure variables: the presence of a local newspaper and the presence of a local NGO or watershed group. The existence of these intermediaries should make targeted transparency more effective when it is introduced. Thus, 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 6, 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 targeted transparency is likely to be more effective due to the presence of intermediaries that can create 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 5 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 6, 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. Mimicking these results for the role of public pressure in Table 6, we also see larger declines in HF-related incidents (e.g., spills) in areas with the presence of intermediaries and larger increases of public pressure (Table B16).

Third, we explore heterogeneity in the effects with respect to well 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. 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 6, 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.

Overall, we obtain consistently stronger treatment effects for the HF disclosure mandates where transparency is expected to be more effective in creating public pressure and when the mandates indeed increase public pressure in the respective areas.

The three final tests presented in Table 6 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.[36] We identify three major improvements during our sample period (see Online Appendix OB14 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 6, 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,

[36] 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/]

in untabulated analyses, we find that the FracFocus dissemination improvements are associated with significant increases of public pressure locally using each of the three variables used in Table 6, which further links the transparency mandates, the HF disclosures and the rise of 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 a HF 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). The more conditions a state requires, the more difficult it is for operators to obtain the trade secret exemption (see coding in OA4). In Table 6, 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 coefficient is larger in magnitude in states making it more difficult to obtain a trade secret exemption, though the difference in coefficients 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 6, Column 8, we find larger increases in water quality for states with timelier disclosure mandates.

6.3 Exploring an Alternative Channel for the Water Quality Improvements

Public pressure unleashed by targeted transparency may not be the only channel leading to water improvements. As discussed in Section 2.3, disclosure regimes can also facilitate peer learning (e.g., Tomar 2023). In our setting, HF operators could learn from other operators' disclosures and imitate their fluid mixes (Fetter *et al.* 2024). However, this channel is unlikely to explain the results of our water quality analysis because the four salts that we analyze occur in high concentrations in the deep formation brines (Vidic et al., 2013; Rosenblum et al. 2017), which are brought to the surface during production. Thus, HF-related surface water contamination leads to higher salt concentrations irrespective of the specific chemical composition of the HF fluids, making peer learning and imitation of high-productivity mixes an unlikely channel in our setting.

In this section, we confirm this conjecture with two tests described in more detail in the Online Appendix. First, we explore whether the treatment effect for the disclosure regime depends on changes in the HF fluid mixes. Table B17, Column (1), shows no significant differences in water quality improvements between HUC10s with larger and smaller changes in the toxicity of their chemical mixes. Thus, using fewer toxic chemicals after the disclosure mandates does not map into less water pollution, consistent with our point that HF-related water pollution primarily stems from wastewater management, spills or leaks (see Sections 2.3 and 5.4). Second, we explore whether the treatment effect of the disclosure regime depends on changes in HF well productivity. Table B17, Column (2), documents that the improvements in water quality are quite similar across HUC10s with larger and smaller well productivity changes. Thus, the water quality improvements after the introduction of the disclosure mandates are present across the board and not necessarily coming from the worst performing wells, as the learning channel would suggest.

7. Conclusion

We study targeted transparency and the role of public pressure in mitigating dispersed externalities of corporate activities. We examine this nexus for HF (or fracking) in the U.S. The dramatic rise of HF in many U.S. states triggered a major public debate about its environmental and health risks. Given these concerns, U.S. states passed disclosure rules for HF wells in an effort to increase transparency and put HF practices in the spotlight.

We examine the environmental effects of this regulation with respect to surface water pollution 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. In particular, we document smaller water impact of HF wells in the early phases of production and fewer spills and accidents related to wastewater handling as well as 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 enable public pressure and to enlist social movements. We unpack the transparency mechanism and 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. Next, we show that water quality improvements after the disclosure mandates are greater in areas where transparency is expected to be more effective in creating public pressure. 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 post-mandate increases in public pressure, such as increases in the number of newspaper articles, in the number of volunteers joining local NGOs and watershed groups or in the occurrence of anti-fracking protests.

Finally, our study provides the novel 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 HF boom in the U.S., it provides the most extensive evidence on the evolution of the industry's surface water impact to date. Our analysis suggests that HF transparency regulation has played an important role for the documented improvements in water impact through 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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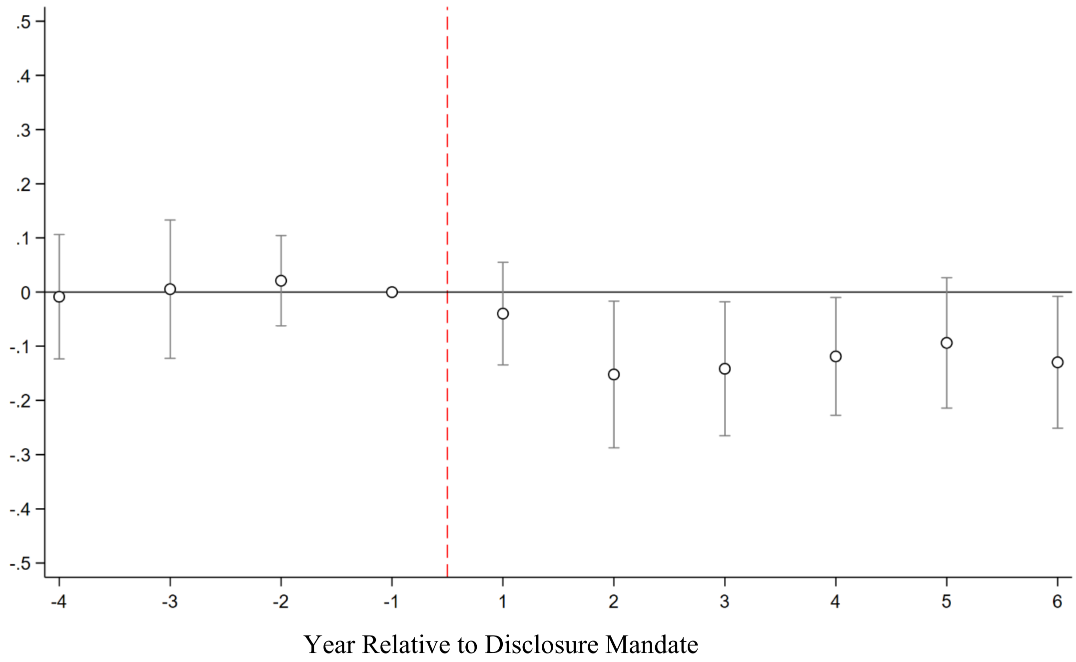
Figure 1 – Mapping Out the Effect of HF Disclosure Regulation

Panel A – Standard Estimation



Panel B – "Stacked Regression" Cengiz et al. (2019)

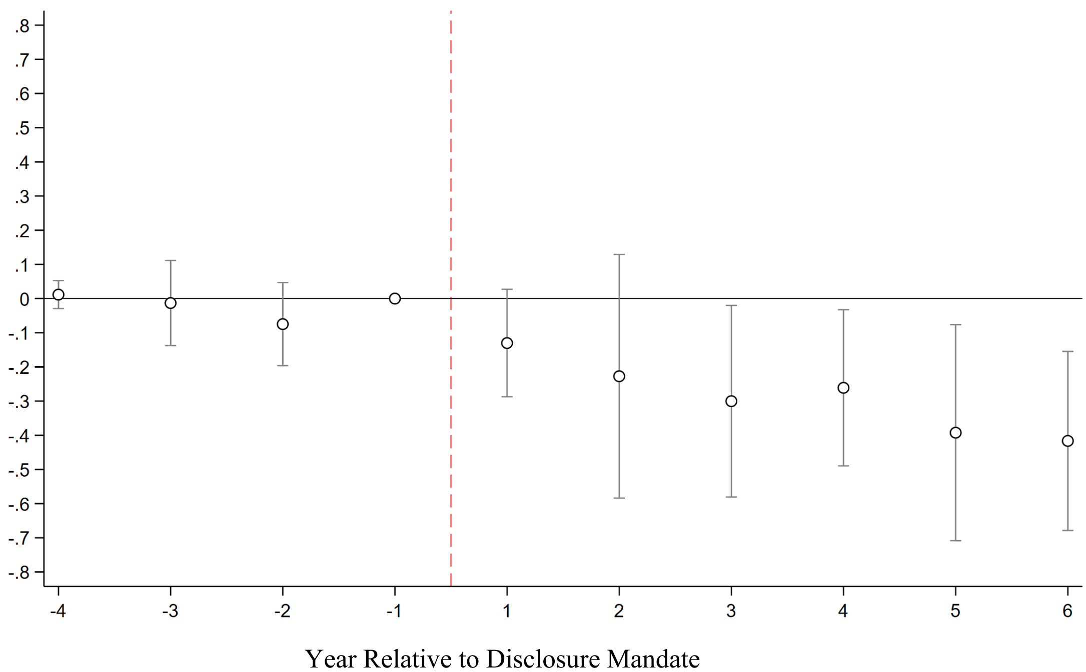
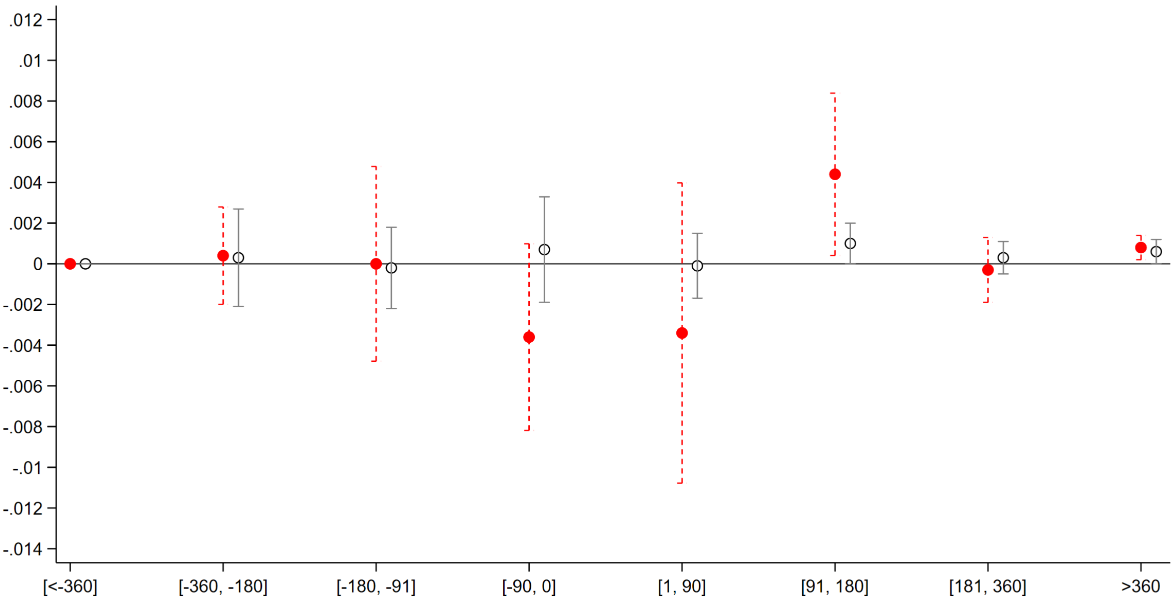


Figure 1, Panel A, plots coefficients from the estimation of Eq. (1), together with the respective 95% confidence intervals, adding indicators for the years relative to the introduction of the disclosure mandate. Year 1 comprises all water measurements that take place within the first 365 days from the 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. In Panel B we perform the same exercise employing the "stacked" regression approach proposed by Cengiz et al. (2019).

Figure 2 – Mapping Out Per-Well Impact Before and After Transparency Regulation



Days relative to well spud date

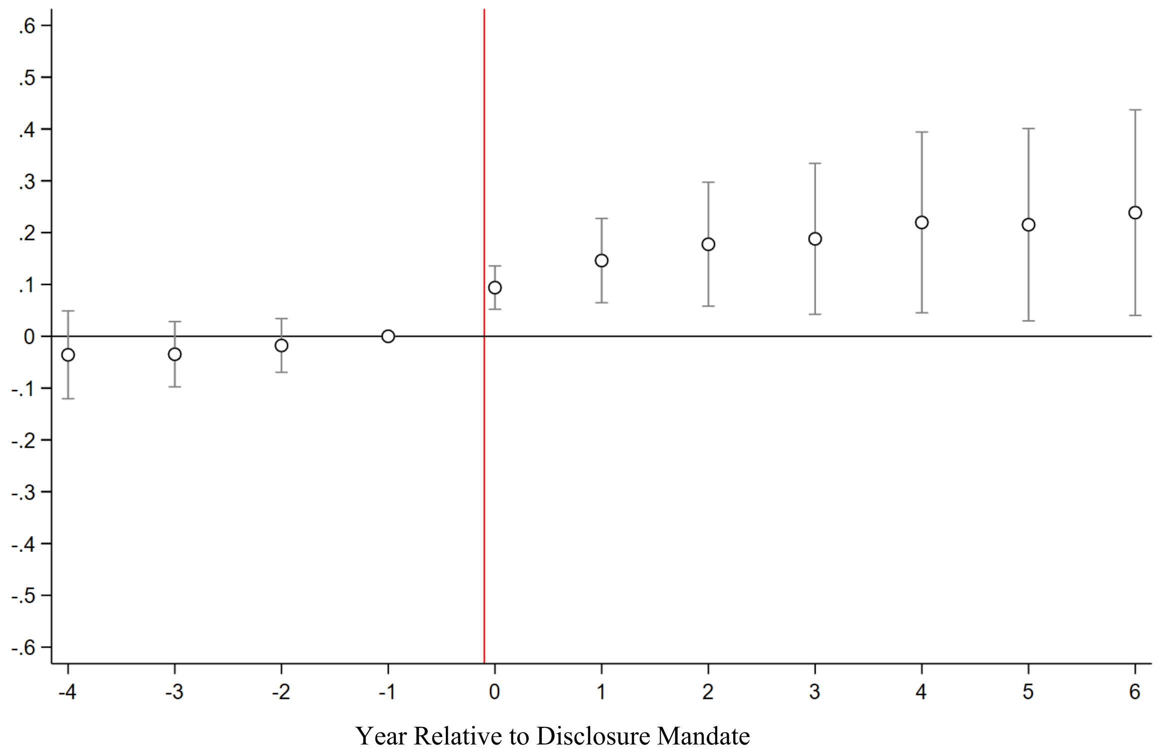
Figure 2 plots coefficients from the estimation of the model shown below, together with the respective 95% confidence intervals, using separate HF well counts calculated over fixed time windows relative to the well spud date. We estimate the coefficients on the well count variables for the pre- and post-disclosure 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):

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

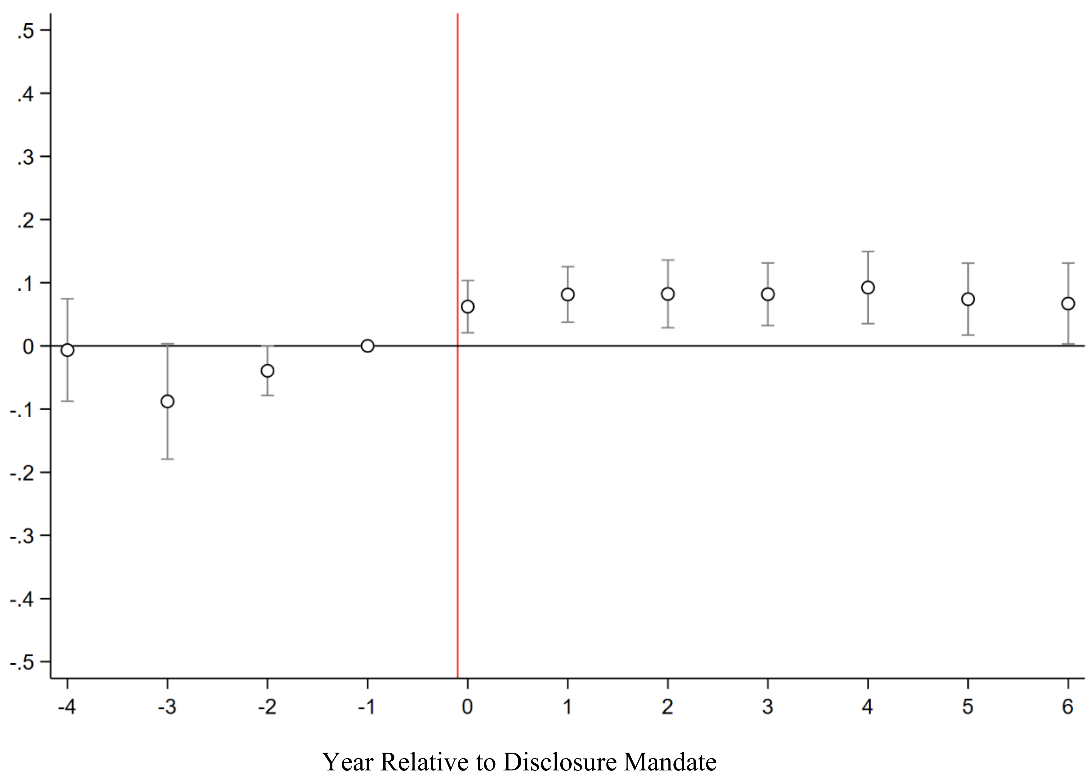
To illustrate the well count variables, *#wellsHUC10 [91, 180]* counts all wells in the respective HUC10 that were spudded between 91 and 180 days ago, relative to the date of the respective ion concentration measurement, in either the pre- or post-disclosure periods. The [<−180] window is the omitted 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 3 –Changes in Public Pressure after the State Transparency Mandates

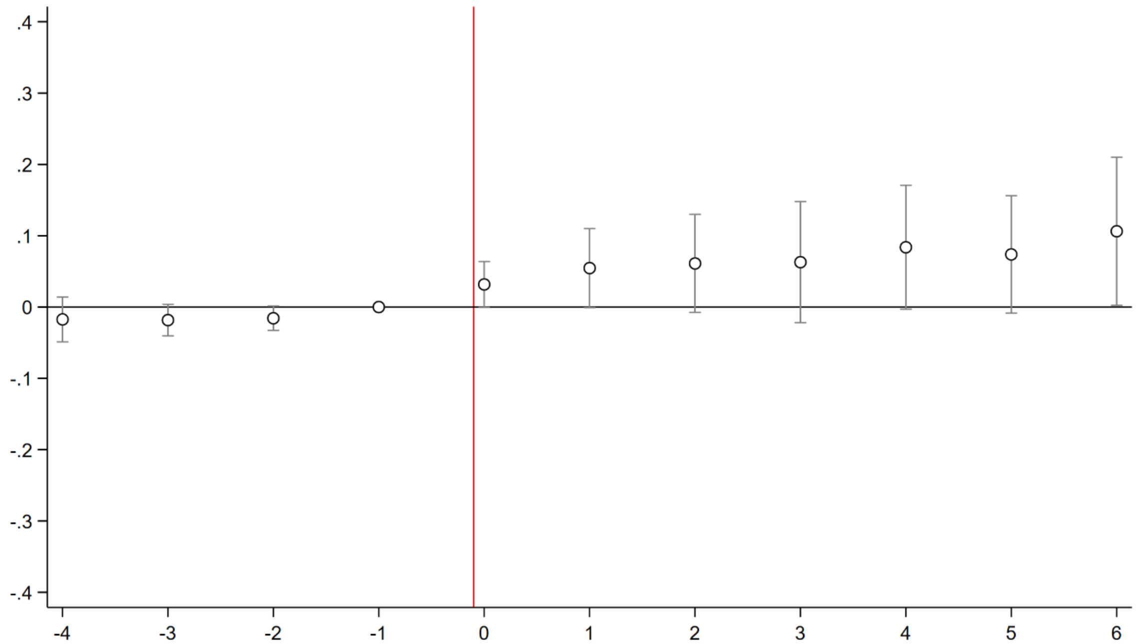
Panel A – Changes in HF-Related Newspaper Coverage



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



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



Year Relative to Disclosure Mandate

Figure 3, Panels A, B, and C, plots coefficients from estimating the models shown in Column (2), Column (4), and Column (6) of Table 5 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).

Table 3 – Targeted Transparency 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 – Targeted 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 4 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 5 – Targeted Transparency and Increases in Public Pressure

	HF Newspaper Coverage			*Local NGO Volunteers*			*Anti-HF Protests*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
POST	**0.0951**[***]			**0.0576**[**]			**0.0338**[*]		
	[0.0209]			**[0.0253]**			**[0.0165]**		
POST_HIGH		**0.1524**[***]	**0.1472**[**]		**0.0939**[**]	**0.0853**[***]		**0.0470**[*]	**0.0497**[*]
		[0.0386]	**[0.0493]**		**[0.0342]**	**[0.0179]**		**[0.0221]**	**[0.0231]**
POST_LOW		0.0315	0.0497[**]		0.0060	0.0340		0.0201	0.0175
		[0.0281]	[0.0228]		[0.0273]	[0.0356]		[0.0144]	[0.0112]
#WELLS_HF	0.0013[***]	0.0015[***]	0.0015[***]	0.0002[**]	0.0002[**]	0.0003[***]	0.0008[***]	0.0008[**]	0.0009[**]
	[0.0004]	[0.0003]	[0.0003]	[0.0001]	[0.0001]	[0.0001]	[0.0002]	[0.0003]	[0.0003]
Observations	8,844	8,844	8,844	600	600	600	7,788	7,788	7,788
R-squared	0.334	0.343	0.340	0.620	0.631	0.624	0.141	0.144	0.145
	Counties over shales								
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month×Year FE	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Year FE	No	No	No	Yes	Yes	Yes	No	No	No

Table 5 reports OLS estimates for the impact of the state disclosure mandates on three public pressure variables. The dependent variable in Columns (1)–(3) 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 (4)–(6) 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 (7)–(9) is a binary variable equal to one indicating an anti-fracking protest in a given county-month-year, zero otherwise. In Columns (2), (5), and (8) we replace *POST* with two non-overlapping binary indicators marking in the post-disclosure period counties with an above (below) pre-disclosure median of the county-level per-capita income, *POST_HIGH* (*POST_LOW*). In Column (3), (6), and (9) we replace *POST* with two binary indicators marking in the post-disclosure period counties with an above (below) pre-disclosure median level of education, *POST_HIGH* (*POST_LOW*), measured as the share of the population in a county with at least a college degree. The HIGH and LOW coefficients are statistically different from each other, except in (8) and (9). *#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 6 – 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	*Local NGO Presence*	*Increase in Media Coverage*	*Increase in Local NGO Volunteers*	*Publicly Traded Operators*	*FracFocus Dissemination*	*Trade Secret Exemptions*	*Disclosure Timeliness*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(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 6 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.

Online Appendix

This Online Appendix provides anecdotal and descriptive evidence as well as supplemental analyses and additional descriptive statistics. We also provide additional Background Information on the setting and the HF fluid chemicals on GitHub.

Section OA – Anecdotal and descriptive evidence

Section OB – Supplemental analysis

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

OA1 – 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

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.

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. 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. 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

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
Pennsylvania	*SECTION 95.10/SECTION 78.60* 1989/7/29		*RULE 3215* 2012/4/16	*SECTION 78.56* 2013/12/13 (1)		*SECTION 3211-3227* 2012/4/16(3)		
Texas	*SECTION 3.8* 2013/4/15	*SECTION 3.9* 2014/11/17		*SECTION 3.8* 2013/4/15(2)		*SECTION 3.13* 2014/1/1(4)		
Utah	*CODE 649-9-3* 2013/8/1	*CODE 649-3-39* 2012/11/1	*CODE 649-3-16/CODE 649-9-3* 2013/8/1	*CODE 649-9-4* 2013/8/1(2)		*CODE 649-3-8* 1989/3/17		*CODE 649-3-13* 1989/3/17
West Virginia			*SECTION 35-8-17* 2016/6/9(2)			*SECTION 22-6-21-30* 2011/2/14		
Wyoming		*CHAPTER 4 SECTION 4* 2005/1/1	*CHAPTER 4 SECTION 1* 2015/6/4	*CHAPTER 4 SECTION 1* 2015/6/4		*CHAPTER 3 SECTION 4* 2010/8/17	*CHAPTER 3 SECTION 28* 2010/8/17	*CHAPTER 18 SECTION 9* 2018/11/13

The same Section includes an additional provision on the overflow system.
The same Section/Rule/Code includes an additional provision on the leak detections system.
The same Section/Rule includes an additional provision on proximity to water bodies.
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.

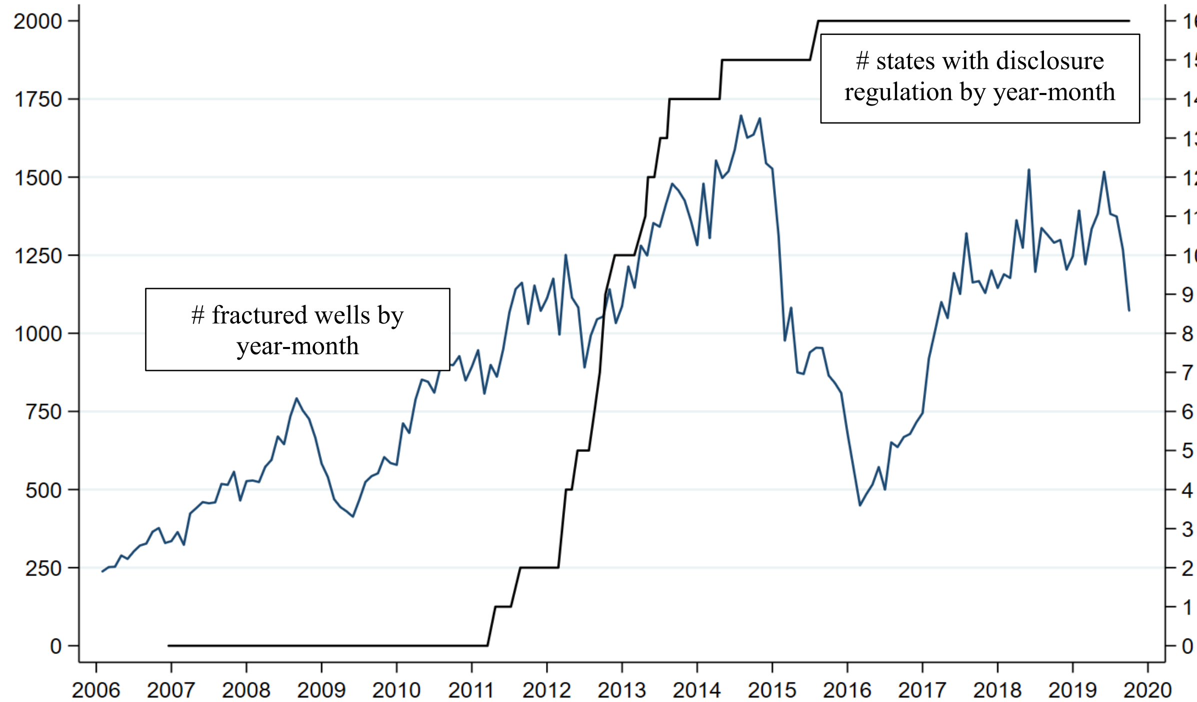
OA4 – Summary of the Trade Secret Regulations

	(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.

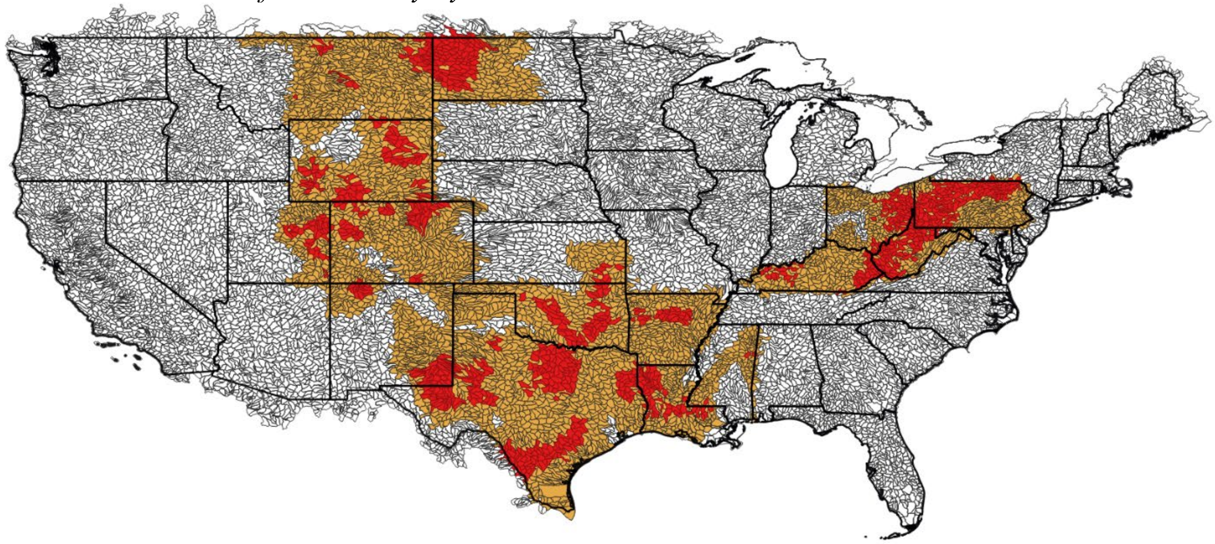
OB1 – Trends in HF Activity and the Evolution of Disclosure Mandates in the U.S.



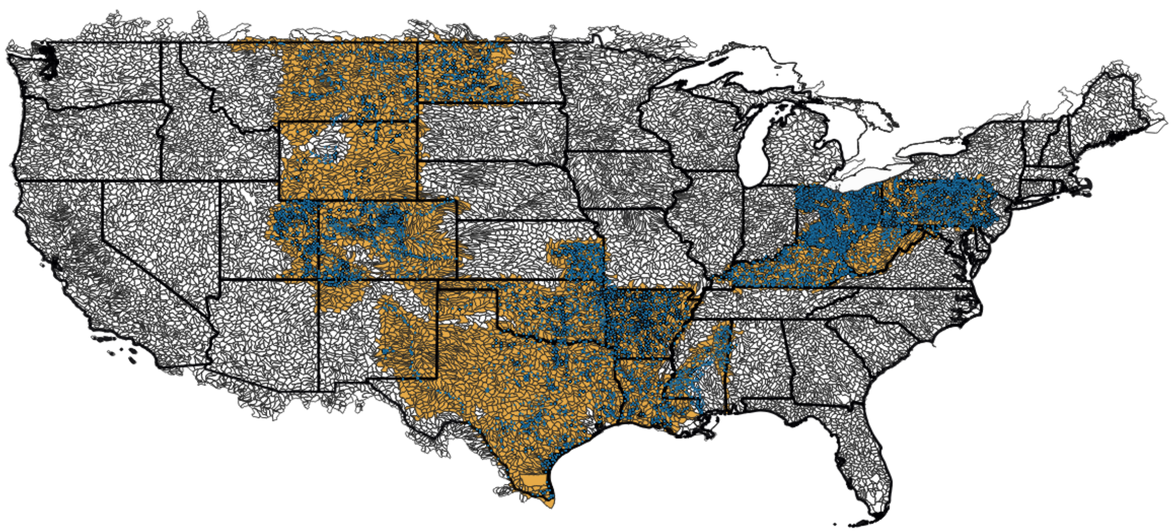
The figure plots the time trend in HF activity in the U.S. along with the adoption timing of the HF disclosure regulation by the U.S. states with HF activity. The *x* axis shows the year. The *left-y* axis shows the number of new HF wells by spud year-month. The *right-y* axis shows the cumulative number 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.

OB2 – 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



The figure 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.

OB3 – Distribution of Surface Water Measurements

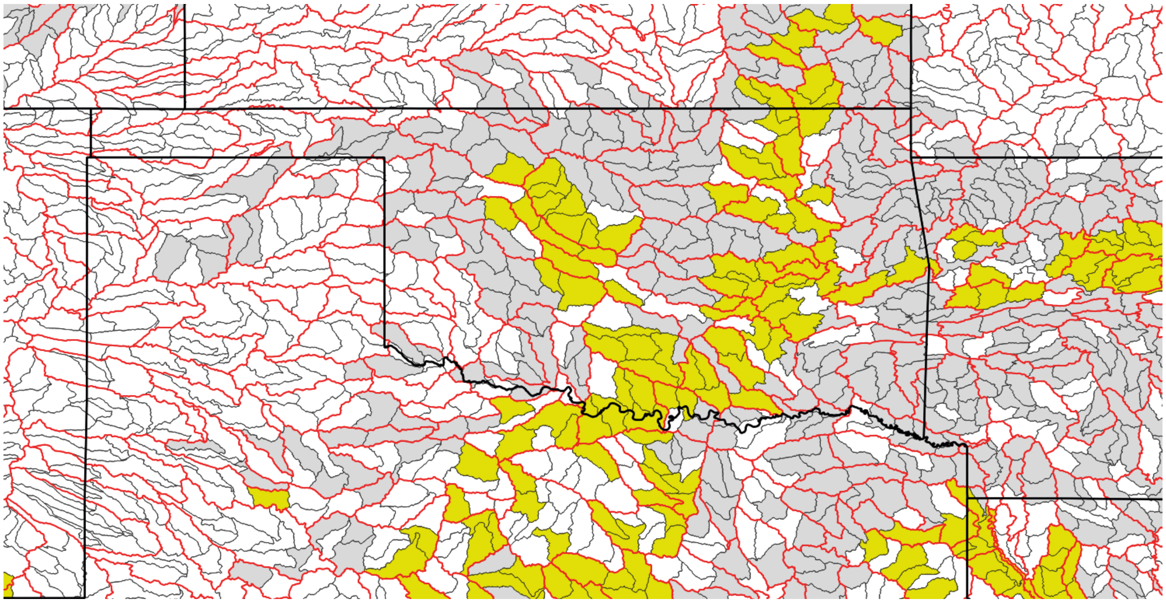
Table B1 – Distributional Information

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

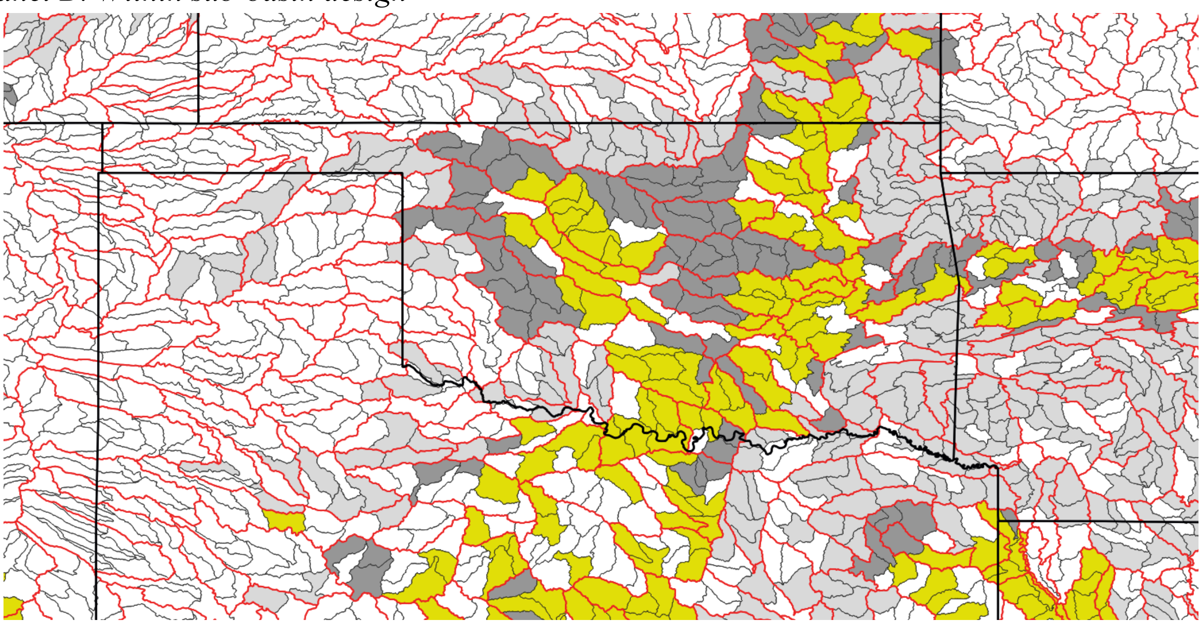
This table presents distributional information for the number of HUC10s by state, sub-basin (HUC8) and by state and ion, the number of water quality monitoring stations by HUC10 and by HUC10 and ion as well as the number of surface water measurements quality by HUC10 and ion.

OB4 – 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.

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. Table B2 reports the results. 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, as is the mapping out of the treatment effect over time (Figure 1), both of 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.

Table B2 – Transparency Mandates and Water Quality – Cengiz et al. (2019) "Stacked" Regression

	All Ions pooled (μg/l)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HUC10_HF×POST	**-0.2419***** **[0.0803]**	**-0.1035***** **[0.0378]**	**-0.2238***** **[0.0795]**	-0.0684 [0.0528]	**-0.2616***** **[0.0725]**	**-0.1026***** **[0.0385]**	**-0.2569***** **[0.0710]**	-0.0682 [0.0539]
Estimation Sample	Each state separately		Each state separately with all control HUC10s		Each state separately (HUC10s w/o HF over shales)		Each state separately with all control HUC10s (HUC10s w/o HF over shales)	
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

Table B2 reports OLS coefficients estimating Eq. (1) to assess the impact of the state disclosure mandates on the respective ion concentrations using the Cengiz et al. (2019) "Stacked" Regression approach. The models pool all four ion concentrations in one model, as described in Section 4. In Columns (1)-(2), 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 (1)-(2) we estimate Eq. (1) each state separately using only control HUC10s in that state. In Columns (3)-(4) we estimate Eq. (1) each state separately using only control HUC10s in that state. In Columns (5)-(6) we estimate Eq. (1) each state separately using all control HUC10s (across all states), and control HUC10s are restricted to those located over shales in treated states. In Columns (7)-(8) we estimate Eq. (1) each state separately using all control HUC10s (across all states), and control HUC10s are restricted to those located over shales in treated states. *HUC10_HF* is a binary indicator marking watersheds with HF activity (treated HUC10s). *POST* is a binary variable marking water quality measurements taken in the post-disclosure period. The sub-panel at the bottom indicates the fixed effects (FE) included in the model. Standard errors (in parentheses) are clustered by HUC10 and reported below the coefficients. *, **, *** denote statistical significance at the 10%, 5%, and 1% level (two-tailed), respectively.

OB6 – Robustness Tests for Standard Errors and Ion Measurements

OB.6.1 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 B3 remain statistically significant even when conservatively clustering by state.

Table B3 – 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.6.2 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 B4 show that the inferences from Table 3 are robust to alternative truncations.

Table B4 – 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.6.3 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,[37] 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

[37] 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 B5 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 B5.

Table B5 – 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******	**-0.1084******	**-0.1685******	**-0.1081******	**-0.1744******	**-0.1060****	**-0.1732******	**-0.1057****	**-0.1256******	**-0.0788****	**-0.1200******	**-0.0784****
	[0.0442]	**[0.0405]**	**[0.0479]**	**[0.0408]**	**[0.0465]**	**[0.0417]**	**[0.0507]**	**[0.0419]**	**[0.0307]**	**[0.0313]**	**[0.0329]**	**[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.6.3 for 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.

OB7 – 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 B6 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 B6 – 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.

OB8 – 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.[38] 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 B7, 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 B7 – 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.

[38] 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 B7.

OB9 – 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 conduct 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 B8 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 B9 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 capturing local factors to which state lawmakers might respond when introducing the disclosure mandates. We propose the following 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 experienced by state lawmakers 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 B10 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 B12) 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 B10. 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 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 B8 – 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 B9 – 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 B10 – 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.

OB10 – "Placebo" Tests and Analyses Controlling for Concurrent Regulatory Events

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 B11 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 B11 Panel B).

Table B11 – 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.

Controlling for 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 B12, 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 B12 – 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.

OB11 – 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 (i.e., fewer wells), i.e., the extensive margin, or from less production or less water impact of each HF well, i.e., intensive margin.

Drilling activity is primarily driven 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. Thus, we restrict the analysis to watersheds over shales, i.e., to areas where HF is feasible, and/or to watersheds in sub-basins that cross state borders and hence are located in two neighboring states, which essentially compares 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.[39] Table B13, 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*, as described in Section 5.2, and measure HF well entry *relative* to the entry rate of conventional wells (Table B13, 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 B1 plots coefficients from the model in Column 6 of Table B13, mapping out the effect by quarter relative to the disclosure mandate. Figure B1 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

[39] 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.

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 is likely expensive for HF operators.

To estimate intensive margin adjustments following the transparency regulation, we examine changes in the environmental performance of HF wells, defined as the ratio of O&G production volume (in barrels) and 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.[40] Table B14 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.[41] In un-tabulated analyses, we also confirm that the disclosure mandates do not significantly affect the production volumes of HF wells, suggesting that effects documented in Table B14 are driven by decreases in ion concentrations, rather than production volume changes.

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40 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.

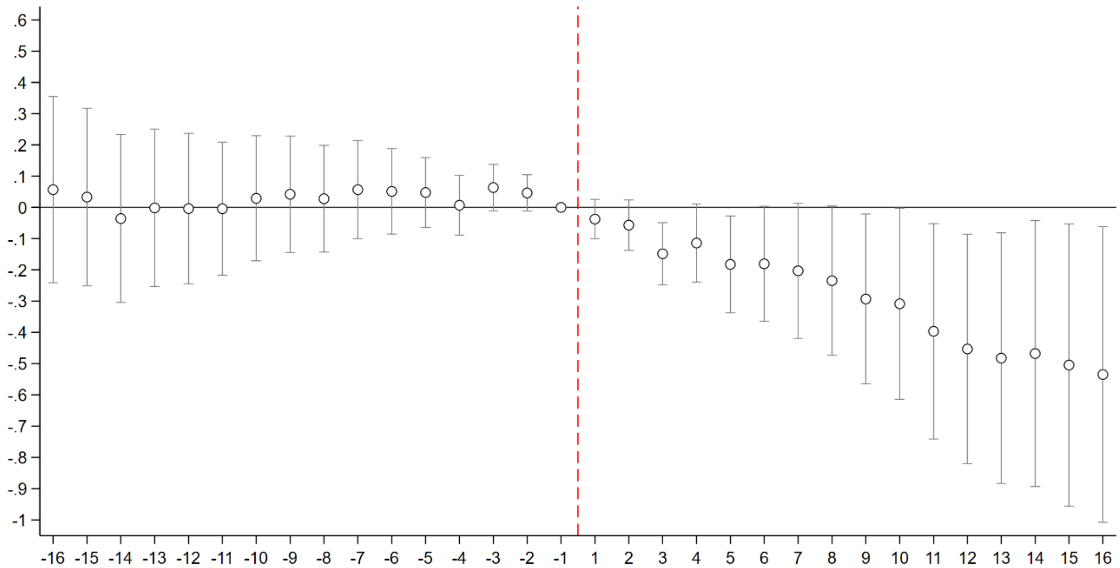
41 A simple quantitative decomposition (untabulated) suggests that more than 90% of the overall reduction in ion concentrations comes from the intensive margin.

Table B13 – 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***** **[0.0162]**	**-0.0629***** **[0.0213]**	**-0.0559***** **[0.0196]**	**-0.0506*** **[0.0285]**	**-0.0505**** **[0.0257]**	**-0.0692*** **[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

This table 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 OB10). 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.

Figure B1 – Extensive Margin: Changes in HF Activity after Disclosure Regulation



Quarter Relative to Disclosure Mandate

Figure B1 plots coefficients from the estimation of the model shown in Column (6) of Table B13, 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).

Table B14 – 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

This table 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.

OB12 – Transparency and Hazardous Chemical Use in HF Fluids

In this section, we examine whether HF operators reduce the use of hazardous chemicals after the HF fluid disclosures become mandatory. As discussed in Section 6.3, changes in the use of chemicals in the HF fluids cannot explain the documented changes in water quality. The four ions also occur in high concentrations in the deep formation brines and hence would likely be present in surface waters, if and when there is HF impact, irrespective of the exact chemical mix in the HF fluids. Nevertheless, the use of toxic chemicals can be a lightning rod for the public and hence it is plausible that operators reduce the use of hazardous chemicals in response to public pressure.

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.[42] 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 water quality analyses are based on salts and, in particular, on Cl^{-} concentrations. We provide a list of the most common hazardous chemicals in HF fluids including those related to Cl^{-} as Background Information on GitHub. Table C2 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 B15 show that operators disclose using a lower share of all and Cl^{-}-related hazardous 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.

[42] 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.

Table B15 – 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

This table 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.

OB13 – Measurement of Public Pressure and Results for HF-Related Incidents

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. In addition, we present results for the role of public pressure in reducing HF-related incidents (e.g., spills).

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.[43] In Table 6 (Column 1), we 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

43 Instead of adding one to the count, we also estimate Poisson regressions, which yield similar inferences.

one plus this count as dependent variable.[44] In Table 6 (Column 2), we use a binary indicator 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. 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.

In Table B16, we present evidence that the impact of transparency regulation on HF-related incidents is more pronounced in areas where it is expected to create more public pressure and where public pressure increases *after* the state mandates are introduced. We rely on our results in Table 6 and create four split variables. The first two indicate areas with higher (lower) levels of public pressure at the time the transparency mandates are introduced using indicators for the presence of a local newspaper or a local anti-fracking NGO. Targeted transparency is expected to be more (less) effective here. The second two indicate areas with higher (lower) changes in public pressure: (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). Results are consistent with those in Table 6.

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

Table B16 – Targeted Transparency and HF-Related pills and Wastewater Incidents: Role of Public Pressure

Partitioning on	*Local Media Presence*		*Local NGO Presence*		*Increase in Media Coverage*		*Increase in Local NGO Volunteers*	
	All Incidents	Wastewater Incidents	All Incidents	Wastewater Incidents	All Incidents	Wastewater Incidents	All Incidents	Wastewater Incidents
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
POST×High Group	**-0.0717***	**-0.0339***	**-0.0949*****	**-0.0514*****	**-0.0883*****	**-0.0414****	**-0.0916*****	**-0.0530****
	[0.0384]	**[0.0183]**	**[0.0273]**	**[0.0188]**	**[0.0302]**	**[0.0196]**	**[0.0277]**	**[0.0252]**
POST×Low Group	0.0298	0.0119	0.0284	0.0169	0.0352	0.0176	0.0239	0.0142
	[0.0350]	[0.0192]	[0.0345]	[0.0197]	[0.0346]	[0.0195]	[0.0341]	[0.0194]
Observations	15,001	12,840	15,001	12,840	15,001	12,840	15,001	12,840
R-squared	0.189	0.100	0.189	0.101	0.189	0.100	0.188	0.100
Sample	HUC10s over shales & HUC8s across two or more states							
F-Test	**0.0085**	**0.0079**	**0.0000**	**0.0003**	**0.0001**	**0.0026**	**0.0000**	**0.0068**
HUC10 FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month×Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table B16 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). We split *POST* by four 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 *at least one* (*no*) local newspaper that has been active in the 360 days leading up to the adoption of the state's disclosure mandate; (2) 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) areas 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) areas with an *increase* (*no change*) in the number of volunteers in local anti-fracking NGOs between the pre- and post-disclosure period. The sample comprises HUC10s over shales in four states from 2005 to 2015 and is further restricted to HUC10s within HUC8s that are partially located in at least two neighboring states, i.e., are crossing state lines . This is the stricter of the two specifications shown in Table 4. In Columns (1)-(2) and (5)-(6) 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) and (7)-(8) 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 (see Section OC1). *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.

OB14 – 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.[45]

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 6 and Section 6).

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

OB15 – Exploring an Alternative Channel for the Water Quality Improvements

In this section, we describe two additional analyses that aim to rule out an alternative learning channel (as in Tomar 2023 and Fetter *et al.* 2024) as the main driver of our results. First, we explore whether the treatment effect of the disclosure regime on water quality depends on changes in the HF fluid mixes. We split treatment HUC10s into two groups, using the 50th percentile of the HUC10-level changes in the proportion of total hazardous chemicals as reported in the disclosure form as cutoff. Table B17, Column (1), shows no significant differences in water quality improvements between HUC10s with larger and smaller changes in the toxicity of their chemicals mixes. Thus, using fewer toxic chemicals after the disclosure mandates does not map into less water pollution, consistent with our point that HF-related water pollution primarily stems from wastewater management, spills or leaks (see Sections 2.3 and 5.4).

Second, we explore whether the treatment effect of the disclosure regime depends on changes in well productivity. We split treatment HUC10s into two groups, using the 50th percentile of the HUC10-level changes in average production volumes (in barrels) as cutoff. Table B17, Column (2), documents that the improvements in water quality are quite similar across HUC10s with larger and smaller well productivity changes. Thus, the water quality improvements after the introduction of the disclosure mandates are present across the board and not necessarily coming from the worst performing wells, as the learning channel would suggest.

Table B17 – Transparency and Changes in Chemical Use and Productivity

	All Ions Pooled (μg/l)	
	Partitioning on	
	Changes in the HF fluid mixes	*Changes in HF well productivity*
	(1)	(2)
POST×HUC10_HF×High Group	-0.11942	**-0.1165****
	[0.09059]	**[0.0496]**
POST×HUC10_HF×Low Group	-0.16590	**-0.0866****
	[0.10588]	**[0.0382]**
Observations	231,236	293,517
R-squared	0.969	0.968
Treatment Sample	HUC10s with HF activity in the pre-disclosure period	
F-Test	0.5488	0.4212
Monitoring station FE	Yes	Yes
Weather controls	Yes	Yes
HUC8×Month×Year FE	Yes	Yes

Table B17 reports coefficients estimating an alternative version of Eq. (1). 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 assigned as follows: (1) HUC10s with an *above the median* (*below the median*) changes in the pre- and post-disclosure average proportion of total hazardous chemicals reported in the disclosure form; (2) HUC10s with an *above the median* (*below the median*) changes in the pre- and post-disclosure average well production volumes, per HUC10 in barrels. 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

OC1 – Descriptive Statistics for the Spill and HF Incidents Data

The table below reports descriptive statistics for the variables in Table 4 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 Variables used in Table 4

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 4. *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 Statistics for Disclosed Chemicals used in HF Fluids

Table C2 – Descriptive Statistics for Variables used in Table B15

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 C2 reports descriptive statistics on the variables used in Table B15. 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).

Appendix References

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