Hydraulic Fracturing Chemicals Reporting: Analysis of Available Data and Recommendations for Policymakers

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Abstract

Twenty-eight states require disclosure of hydraulic fracturing chemicals. Twenty-three states direct reporting to FracFocus; additionally, companies in other states use this registry. FracFocus contains the most comprehensive dataset on fracturing chemicals but faces data quality and transparency criticisms. In response, FracFocus announced upgrades, and since May 2015, publishes aggregated data. We used Linux and R version 3.2.0 to clean and analyze 96,449 forms submitted between March 9, 2011 and April 13, 2015 for accuracy, completeness, and timeliness. We characterize data, and compare results to state law and industry practice, to suggest how to induce more accurate and complete disclosures. We find that rates of withheld chemical information have increased since 2013, and appear unaffected by different legal requirements. However, when companies report fracturing chemicals without attribution to the specific products in the fracturing fluid (a "systems approach" to reporting), withholding rates drop four-fold. State deadlines shortened reporting timelines, but compliance rates are low absent indication states will enforce. Automatic field population and prompts in FracFocus can reduce data error, while enforcement signals, education, and harmonized requirements may boost compliance and enhance disclosure. Systems reporting should occur, with states retaining authority to request product-specific ingredient lists.

Keywords: FracFocus; fracturing; chemicals; disclosure

1. Introduction

1.1 Background

The United States has led the world in annual natural gas production since 2009, and in 2013, was the world's top oil producer (BP (British Petroleum), 2014 and U. S. EIA (Energy Information Administration), 2014). Technological advances in horizontal drilling and hydraulic

fracturing have unlocked oil and natural gas reserves in low permeability formations, including shale and tight sands (U.S. EPA (Environmental Protection Agency), 2015c, U.S. EPA (Environmental Protection Agency), 2015a and U.S. EPA (Environmental Protection Agency), 2015b).

The unconventional oil and gas boom has generated jobs and wealth (IHS Economics, 2014 and U.S. BLS (Bureau of Labor Statistics), 2014), as well as questions about the environmental consequences of such development (Clark et al., 2013, Krupnick et al., 2013 and U.S. Geological Survey, 2013). Academic and trade literature have sought to define and quantify potential environmental risks posed by unconventional oil and natural gas production, including water demands (Nicot and Scanlon, 2012), air emissions (Pétron, 2014 and Litovitz et al., 2012), wastewater generation (Warner et al., 2013 and Jiang et al., 2014), and potential for surface water contamination from chemical and waste water spills (Entrekin et al., 2011 and 83), groundwater contamination from faulty well construction (Llewelyn et al., 2015), or both (Vidic et al., 2013). The public "fracking" debate has focused on the fracturing stage of development (Shonkoff et al., 2014 and Zoback et al., 2010), when millions of gallons of water and chemicals are shot into a well at high pressure, to fracture the target formation and enable the release of fossil fuels. In 2005, Congress exempted hydraulic fracturing from federal Safe Drinking Water Act requirements, including disclosure of the chemicals used (Energy Policy Act of 2005, 2005). Opposition to hydraulic fracturing has focused on this exemption (Scientific American editorial board, 2011 and New York Times editorial board, 2009), and public opinion polls reveal strong support for chemical reporting requirements (Brown et al., 2013).

In response, since 2010, twenty-eight states have required companies to report and disclose the chemicals used in hydraulic fracturing (Alabama, 2013; Alaska 2014; Arkansas, 2013; California, 2014; Colorado, 2012; Idaho, 2012; Illinois, 2014; Indiana, 2012; Kansas, 2013; Kentucky, 2015; Louisiana, 2011; Michigan, 2011; Mississippi, 2013; Montana, 2011; Nebraska, 2013; Nevada, 2014; New Mexico, 2012; North Carolina, 2015; North Dakota, 2012; Ohio, 2012; Oklahoma, 2012; Pennsylvania, 2012 and Pennsylvania, 2011; South Dakota, 2012; Tennessee, 2013; Texas, 2011a and Texas, 2011b; Utah, 2013; West Virginia, 2013; Wyoming, 2010). Requirements vary in their timing for submissions, content of submissions, justifications for withholding information, and method of disclosure.

Twenty-three states require or encourage reporting to FracFocus. Additionally, companies in at least four other states use this registry. FracFocus is an online system launched in 2011 and managed by the Ground Water Protection Council (GWPC) and Interstate Oil and Gas Compact Commission (IOGCC) (FracFocus, 2015). Well operators – and in some cases, the service companies that perform the fracturing operation – upload data into the registry for public viewing in well-specific Portable Document Format (PDF) files.

Of the states that direct reporting to FracFocus, Colorado and Pennsylvania placed conditions on their use of FracFocus, requiring the registry to maintain or upgrade certain capabilities (Colorado, 2012; Pennsylvania, 2012 and Pennsylvania, 2011). California legislation relies on FracFocus as an interim reporting tool only, until the state creates its own database (California, 2014).

FracFocus contains the most comprehensive dataset on chemical use in hydraulic fracturing. However, it has faced criticisms related to data quality, transparency, and accessibility (Elgin et al., 2012, Konschnik et al., 2013 and U.S. DOE (Department of Energy), 2014). One criticism

relates to the rate of withheld chemical data (U.S. DOE (Department of Energy), 2014). Based on data scraped from PDF forms submitted between January 2011 and February 2013, the federal Environmental Protection Agency (EPA) calculated that 11% of ingredient records were withheld from FracFocus as proprietary (U.S. EPA (Environmental Protection Agency), 2015a). GWPC found that 16.7% of ingredients were withheld in forms filed between June and December 2013 (U.S. DOE (Department of Energy), 2014). Protection of proprietary information rewards and encourages innovation. However, manufacturers of other proprietary products disclose ingredients while withholding formulas (Ritenbaugh, 2014; Warren, 2011; Warren, 2011).

In 2011, the Secretary of Energy Advisory Board (SEAB) recommended improvements to the environmental performance of shale gas production, including enhanced chemical disclosure (U.S. DOE (Department of Energy), 2011 and U.S. DOE (Department of Energy), 2011a). A 2014 SEAB task force evaluated FracFocus and state disclosure rules, and suggested ways to reduce trade secret claims in the registry (U.S. DOE (Department of Energy), 2014). Meanwhile, EPA issued an Advance Notice of Proposed Rulemaking (ANPR), soliciting input on ways to improve disclosure (U.S. EPA (Environmental Protection Agency), 2014). The ANPR suggested that EPA was poised to fill perceived gaps in FracFocus (U.S. EPA (Environmental Protection Agency), 2014).

In 2015, the Department of the Interior's Bureau of Land Management (BLM) finalized rules governing hydraulic fracturing activities on federal and tribal land (U.S. DOI (Department of the Interior), 2015). BLM's rule directs operators to make disclosures on FracFocus. BLM justified its decision based on pledged improvements to the website, and vowed to "continue to work with FracFocus in coordination with the U.S. Department of Energy (DOE) to ensure that the

recommendations of the [SEAB] for improvement of the database are made" (U.S. DOI (Department of the Interior),2015). Meanwhile, as noted above, Colorado and Pennsylvania law set conditions for continued reliance on FracFocus. Moreover, in early 2015, Pennsylvania announced it would begin building its own fracturing chemical disclosure registry, to replace FracFocus (Ferral, 2015).

To address public concerns, FracFocus managers and states completed one set of upgrades to FracFocus in 2012-13 (known as FracFocus version 2.0 or FF 2.0), and launched a second upgrade in 2015 (FF 3.0). The Harvard Environmental Policy Initiative participated in the 2015 upgrades, and proposed analyzing FF 1.0 and 2.0 forms in response to the SEAB Task Force's recommended audit of FracFocus (U.S. DOE (Department of Energy), 2014).

In the first iteration of FracFocus (FF 1.0), operators filled out Portable Document Format (PDF) forms and submitted them online. GWPC retained form header data in Microsoft SQL but did not receive or store substantive chemical information outside of the PDFs. In November 2012, FracFocus began offering an option to submit data in eXtensible Markup Language (XML). XML became the exclusive format for data entry after June 1, 2013. GWPC stores all FF 2.0 information in Microsoft SQL. Still, until recently, the public could only view FracFocus data in well-specific PDF. Therefore, previous reviews of FracFocus were based on small sample sizes (Konschnik et al., 2013) or data scraped from the PDFs by third parties (Elgin et al., 2012; Greene, 2014; US EPA, 2015a). As of May 2015, FracFocus.org now provides public access to the aggregated dataset, enabling analysis of data across all wells.

1.2 Objectives and Contribution of Work

We use the aggregated data to quantify certain data errors, calculate the rates of withheld data, and determine when disclosures were made. Our analyses provide a snapshot of the data,

and establish a baseline for future comparison with data submitted to FracFocus after the 2015 upgrades.

We compare results over time and between states, and to an EPA analysis of a smaller FF 1.0 data set. We also compare forms containing the "systems approach" method of disclosure-where companies report fracturing chemicals without attribution to the specific products in the fracturing fluid – with those forms reporting chemical ingredients by product. These comparisons could suggest requirements and practices that produce more accurate and complete information going forward for researchers, states, and the public.

2. Methodology and Data

We detail the methods for preparing our dataset in "FracFocus Chemical Disclosure Registry 1.0 and 2.0 Data Conversion, Cleaning, and Standardization Methods Paper," (Methods Paper) (Dayalu and Konschnik, 2015). The Methods Paper and our dataset, which we used for the analyses described herein, are available for review and use at 10.7910/DVN/EFNV5J.

2.1 Initial dataset

On April 14, 2015, GWPC provided a Microsoft SQL database backup file containing all disclosure data submitted in FF 1.0 and 2.0 forms through April 13, 2015, and retained in SQL. The file contained data from 97,964 forms.

The SQL file contained Upload, Purpose, and Ingredient tables. The Upload table contained well header data from FF 1.0 and 2.0 forms, while the Purpose and Ingredient tables contained ingredient-related data from FF 2.0 forms only.

The Upload table stores header data for FracFocus forms, including job start and end dates, state name, well number, and original and updated form submission dates. The Purpose table contains data pertaining to chemical additives, including trade names, suppliers, and the purpose of the additives. The Ingredients table contains ingredient records, including chemical ingredient

names and their corresponding Chemical Abstract Service (CAS) numbers. CAS Numbers are unique identifiers of chemical substances assigned by the American Chemical Society.

2.2 Description of Final Dataset Used in Analysis

The analysis subset contains 96,449 forms submitted to FracFocus between March 9, 2011 and April 13, 2015. These forms were submitted for wells located in 23 states. Texas has the most forms in the dataset (48.7% of the forms), followed by Colorado (9.67%), Oklahoma (8.05%), North Dakota (7.79%), and Pennsylvania (5.37%) (Table 1). We conducted our analyses in R version 3.2.0 (R).

After excluding 149 forms with state location discrepancies, our final subset includes 96,300 FF 1.0 and 2.0 forms, describing hydraulic fracturing jobs at 92,844 wells in 23 states. Of those forms, 53,073 are FF 2.0 forms containing chemical information. For analyses regarding location error rates and timeliness of submissions, we parsed Upload data from the subset's FF 1.0 and 2.0 forms. Our remaining analyses focus on Purpose and Ingredients data in FF 2.0 forms.

Before conducting any analysis, we standardized state name and major chemical supplier names in the analysis subset. We also removed extra spaces and leading zeroes entered before CAS numbers – these do not change the identity of the chemical referenced by the CAS number, but can confound field queries. Finally, we created seventeen new fields to facilitate data analyses while minimizing direct formatting of the original data. We queried most of these new fields in our analyses and specify the field used where appropriate.

2.3 Chemical ingredient records: assumptions and definitions

For purposes of our analyses, we assume that the information submitted to FracFocus accurately reflects the chemical ingredients injected into each well. Without additional resources, we could not confirm the accuracy of the information based on the input data alone.

To calculate rates of chemical ingredient data entry error and data withholding, we had to determine the total number of ingredient records reported across all FF 2.0 forms in our subset. We collectively define the CASNumber and IngredientName fields as an ingredient record, consistent with the approach EPA took in its analysis of scraped FF 1.0 data (U.S. EPA (Environmental Protection Agency), 2015a). Based on this definition, we analyzed 1,979,128 ingredient records.

For most ingredient record analyses, we focus on the CASNumber field because of its more consistent systematic format. We parsed the IngredientName field only to analyze the "systems approach" of reporting. To date, operators have manually entered ingredient name values. More than 10,000 unique values appear in the IngredientName field, and each entry can describe any of: (i) discrete ingredient names; (ii) chemical family names; (iii) multiple ingredient names (we only identified two clear instances of this type of entry); (iv) mixtures; and (v) other non-chemical values. While there were non-standard and unclear values present as well in the CASNumber field, CAS number values were more readily verifiable and therefore more reliable within the scope of our analyses.

We created a CASLabel field to facilitate analyses of CAS numbers. Here, we label a CAS number as valid when the value (i) is numeric; (ii) follows the CAS format (a number up to ten digits long, separated into three parts by hyphens) (CAS, 2015a); (iii) passes a standard check-digit algorithm (where the final digit of the CAS number solves a standard formula provided by the CAS Registry when the number's other digits are input as values) (CAS, 2015b); and (iv) corresponds to an actual chemical substance in a CAS database (Methods Paper). We then created an IngredientNameClean field and populated it with the standardized ingredient name corresponding to the respective CAS number obtained from querying the CAS databases. We

reference this field to identify the names of chemical ingredients in our data subset; in addition, the field could facilitate future chemical analyses including thorough comparison with the existing IngredientName field.

Numeric inputs that do not follow the CAS format, fail the check algorithm, or do not correspond to an ingredient after being run through seven CAS databases are labeled as invalid. We label non-numeric CAS values as withheld where keywords indicate proprietary concerns, or that the information was not available or not required to be reported (Methods Paper Table 1). We label CAS number values as systems approach when companies used keywords or phrases indicating use of this method (Methods Paper Table 2). As noted previously, the "systems approach" describes when companies report fracturing chemicals without attribution to the specific products in the fracturing fluid, to inhibit reverse engineering of any particular product used in the fracturing fluid. Any remaining ingredient record containing an otherwise uncategorized non-numeric CAS value is labeled as invalid.

2.4 Review of state requirements

Unless otherwise noted, we review disclosure requirements for the 21 states represented in our analysis subset that had requirements in place before April 13, 2015. (The remaining five states in our dataset either do not have requirements, or finalized requirements after the time period represented by our dataset.) In a few noted instances, we drop additional states out of an analysis for having too few forms to review for that particular time period or data value. We analyze the requirements for reporting deadlines (Table 2) and withholding justifications and procedures. We compare rates of filing timeliness and withholding with these requirements to test for correlations between state laws and operator behavior.

3. Results and Discussion

3.1 Data errors

We analyze two types of data error: location data error at the state level; and invalid CAS numbers. For the location error analysis, we query fields in the Upload table of all forms in our subset. For the CAS number analysis, we query information from FF 2.0 forms in the subset additionally filtered for valid state location.

3.1.1 State location data error

We calculated a 22% rate of data entry error in the State Name field in FF 1.0 forms (9600 out of 43,366 forms). Errors were most often misspellings of state names, which did not create discrepancies in reported location information. Moreover, this problem was addressed and eliminated in FF 2.0 – the State Name field was no longer manually entered but automatically populated based on the first two numbers in the form's API well number. An API well number is a unique identifier provided by the American Petroleum Institute. (American Petroleum Institute, 1979)

However, in a small percentage of forms – fewer than 0.2% of all submissions reported – the reported well coordinates conflict with the state designation embedded in the well's API number. We removed those 149 forms containing a state location discrepancy before conducting other analyses. We further found that 5.0% of FF 1.0 forms and 2.9% of FF 2.0 forms contained well coordinates that conflicted with the county designation embedded in the well's API number. This tracks EPA's findings that 4.6% of FF 1.0 forms reported conflicting state- or county-level location data (of which only 0.43% reported conflicting state-level data). (U.S. EPA (Environmental Protection Agency), 2015a)

Results suggest that where FracFocus can automate field entries, data precision increases. Even where a field must be populated by hand, carefully designed data entry systems can

improve data quality. For instance, FF 2.0 forms began prompting operators to enter the well API number piece by piece – the twodigits representing the state, the series representing the county, and finally the well number within that county. Following this change in data input, the rate of state location discrepancy dropped nearly 30-fold, from 144 forms to five. In addition, county-level location discrepancies dropped significantly, from 5.0% to 2.9%, a difference of 2.1% (95% CI of difference, 1.9–2.4%; p-value <0.001) further suggesting that decreased input error is related to altered field entry behavior from changes in systems prompts. FF 3.0 plans to include additional data entry enhancements that should further reduce error.

3.1.2 Rates of invalid CAS numbers reported to FracFocus 2.0

To identify invalid CAS numbers, we first identified and set aside valid CAS numbers. As noted above, we assume a CAS number is valid when the reported value: (i) is numeric; (ii) follows the required CAS format; (iii) passes a standard check algorithm (again, where the final digit in a CAS number solves a standard formula containing the remaining digits in the series); and (iv) corresponds to an actual chemical substance when entered into a CAS database. Nearly 80% of all CAS number values (approximately 1,577,305) reported in the FF 2.0 dataset were valid and referred to 983 unique chemical substances. By comparison, in its analysis of scraped FF 1.0 data, EPA found just 65% of CAS number values were valid, corresponding to 692 unique ingredients (U.S. EPA (Environmental Protection Agency), 2015a). (EPA employees heading up this analysis indicated that some data errors may have been created during the data scraping process employed for that analysis (U.S. EPA (Environmental Protection Agency), 2015b).) A few chemicals dominate our list – the 20 chemical ingredients (other than sand and water) most reported in our subset comprise 36% of the total number of reported ingredient records (Table 3). The top four chemical substances used in hydraulic fracturing, as reported to

FracFocus, are methanol, C13-14 isoparaffin (a hydrocarbon), hydrochloric acid, and ethylene glycol (Table 3).

Of the remaining CAS number values, some were missing, reported elsewhere on the form, or intentionally withheld. These are discussed later in the paper. We flag a CAS number value as invalid if it: (i) fails the first validity test; i.e., is non-numeric and does not contain keywords indicating the entry was purposefully withheld or relied on the systems approach to reporting ingredient records (4459 records; 0.23% of all CAS number entries); (ii) fails the second validity test; i.e., is not reported in correct CAS format (3848 records; 0.19% of all entries); fails the third validity test; i.e., the final digit does not solve the CAS Registry formula when the remaining digits are input as values (6569 records; 0.33% of all entries); or (iv) fails the fourth validity test; i.e., does not reference any chemicals in seven CAS databases (5 cases;<0.001% of all entries). A total of 14,881 or 0.75% of reported CAS numbers were invalid due to data error.

FF 2.0 forms began issuing a warning to operators when an entered CAS number failed the check-digit verification. This may have driven the marked reduction in invalid CAS number entries from EPA's analysis to ours.

While the rate of invalid CAS numbers is low, it remains that nearly 15,000 entries were entered incorrectly. In FF 3.0, FracFocus will issue an error message and require amendment of any CAS number that fails the check-digit verification. Moreover, entry of a CAS number will prompt appearance of a drop-down menu in the IngredientName field with the corresponding chemical ingredient name (and its synonyms for reference). This could help to validate the CAS number, while standardizing ingredient name values. This might also serve to increase the likelihood that the reported CAS number matches the corresponding ingredient name.

3.2 Withheld data

We examined state rates of nondisclosure by ingredient records and by forms. We also examined justifications for withholding. For these analyses, we queried the CASNumber field in 1,979,128 rows of FF 2.0 ingredient records. Also for these analyses, we excluded forms from states with fewer than ten FF 2.0 forms submitted (Illinois, Michigan, Nebraska, and Nevada).

3.2.1 Withholding rates

Approximately 18.9% of CAS numbers in FF 2.0 ingredient records were intentionally withheld from public disclosure, with a median withholding rate per form of 18.8% (25th, 75th percentiles: 8.89%, 26.5%). The five states with the highest withholding rates (i.e. the lowest rates of disclosure) were Arkansas (25.0%), Colorado (24.3%), Utah (24.1%), Ohio (21.7%), and Alabama (20.8%). The five states with the lowest withholding rates were California (0.00%), Pennsylvania (11.1%), Alaska (12.0%), Mississippi (12.5%), and West Virginia (12.5%) (Fig. 1). All told, 92.3% of FF 2.0 forms include at least one withheld ingredient record (Fig. 2).

We categorize withheld ingredient records as proprietary, confidential, trade secret, and n/a, based on key terms appearing in the ingredient records data (Methods Paper Table 1). Of the three proprietary justifications, the most utilized is proprietary – 41.1% of withholdings invoke this generic designation. The next most common justification is confidential (28.1%), followed by trade secret (18.3%). An additional 12.4% of withheld records are designated n/a.

EPA calculated an 11% withholding rate on FF 1.0 forms filed before February 28, 2013. GWPC calculated a 16.7% withholding rate on FF 2.0 forms submitted between June and December 2013, suggesting withholding rates are increasing. (U.S. DOE (Department of Energy), 2014 and U.S. EPA (Environmental Protection Agency), 2015a) Neither previous calculation considered n/a designations to be withheld records. We subtracted the percentage of n/a records (2.4%) from our withholding rate (18.9%), to arrive at an adjusted rate of 16.5%.

Using this number as the basis of comparison, we observe an increase of 5.6% in the withholding rate from EPA's FF 1.0 dataset to our FF 2.0 dataset (95% CI: 5.5% to 5.7%), and a comparable withholding rate to that calculated by GWPC on a smaller, earlier range of FF 2.0 forms. The comparison with EPA results supports the trend spotted by GWPC that rates of withheld chemical information increased since 2013.

Moreover, the less rigorous the standard for a proprietary justification, the more likely it has been used to justify withholding information in FracFocus. Of the three proprietary justifications for withholding information (trade secret, confidential, and proprietary), the clearest and most rigorous legal standards exist for trade secrets. In common law and under the Uniform Trade Secret Act enacted in 48 states, a trade secret is limited to information about a production method, process or formula which cannot be easily acquired or duplicated, and which the owner has taken steps to protect (NCCUSL (National Conference of Commissioners on Uniform State Laws), 1986 and Restatement, 1979). Some courts narrow protection to "a secret, commercially valuable plan, formula, process, or device … that can be said to be the end product of either innovation or substantial effort" (ABA, 2014 and Public Citizen Health Research Group v. Food and Drug Admin, 1983). "Information is given enhanced legal protection as a trade secret only if there is some indication that the information has value apart from its value in limiting competition – that it represents an investment on the part of the firm seeking to protect it" (American Family Mutual Insurance Company v. Roth, 2007). By contrast, confidential business information is a less clear standard. Although mentioned in federal statutes (Trade Secrets Act, 2008 and Freedom of Information Act, 2009) and some state disclosure requirements (New Mexico, 2012 and Pennsylvania, 2012), "confidential" information is often not defined.

Standards are more often negotiated in private contracts than established in law. There are virtually no definitions or standards for generic "proprietary" information.

We label as n/a those non-standard CAS number values described in Table 2 of the Methods Paper. Operators appear to use these values in three circumstances. First, n/a is used to explain that the reporting requirement is not applicable. Early state disclosure requirements, and FracFocus practice for voluntary submittals, limited disclosure to ingredients regulated by the federal Occupational Safety and Health Act (OSHA) – those previously "known to be present in the workplace", tested by a manufacturer, and determined to be hazardous (OSHA (Occupational Safety and Health Act), 2013). Most states now require disclosure of all ingredients, recognizing that new or untested ingredients may pose health risks (see, e.g., Colorado, 2012; Pennsylvania, 2012). Second, operators use n/a when information is not available, for instance when a field ticket is illegible or a vendor fails to provide complete information. Third, in a few instances an ingredient has not been assigned a CAS number (e.g., "walnut hulls"). As with the proprietary designation, states do not provide standards for invoking n/a, nor does this designation have any legal meaning.

3.2.2 Justifications for Withholding by State

We then compared withholding justifications between states. Twelve of the nineteen states represented in our dataset limit withholding to trade secret claims: Alabama, Arkansas, California, Colorado, Kansas, Louisiana, Mississippi, Montana, Ohio, Oklahoma, Texas, and West Virginia (Group A states). Seven states either also allow withholding on confidential or proprietary grounds – New Mexico, North Dakota, Pennsylvania, Utah, and Wyoming – or did not have requirements in effect during the relevant time period (Alaska, Virginia) and so placed no restrictions on proprietary designations (Group B states).

States limiting withholding to trade secrets (Group A) withheld only 0.38% more ingredient records (95% CI: 0.24–0.5%) than states without disclosure or requirements or with more lenient justifications for withholding (Group B). Given the similarity in overall rates of withholding between the two groups, our results suggest state policies do not affect withholding rates. They do, however, seem to drive re-allocation of withholding justifications. Group A withheld 9.7% fewer confidential records (95% CI: −10% to −9.4%), and 4.1% fewer proprietary records (95% CI: −4.6% to −3.8%) than Group B. Still, 190,564 ingredient records were withheld in Group A states on confidential and proprietary grounds – justifications not allowed in those states. This suggests some companies are unaware of state-specific rules or do not expect enforcement. Meanwhile, Group A withheld records as trade secrets 8.8% more often (95% CI: 8.5–9.0%) and n/a 5.1% more often (95% CI: 4.9–5.3%) than Group B (Fig. 3), suggesting that where companies knew of the limits, they re-allocated "confidential" and "proprietary" chemicals to these two categories.

We also examined whether different procedures affect withholding rates. Four states require operators to substantiate a proprietary claim at the time of reporting. These states have a collective withholding rate of 18.87% as compared to 18.93% across states without this requirement, a difference of 0.060% (95% CI: −5.1–5.0%; 2-sided p-value 1.0). Three states clearly require submission of the proprietary information to the state, which could increase the likelihood that a state will review the claim. (California, 2014, Utah, 2013 and Wyoming, 2010) They have a collective withholding rate of 17.90% as compared to 19.04% for other states, a difference of 1.1% (95% CI: −6.5% to 4.3%; 2-sided p-value 1.3). Finally, six states clearly allow challenges to hydraulic fracturing trade secret claims (California, 2014, Colorado, 2012,

Ohio, 2012, Pennsylvania, 2012, Texas, 2011a, Texas, 2011b and Wyoming, 2010). They have a collective withholding rate of 18.96% as compared to 18.85% for states without a clear basis for challenge, a difference of.11% (95% CI: −3.7% to 4.0%; 2-sided p-value=0.95). The statistically insignificant differences in the above three cases of withholding rates suggest that state procedures are not well understood or enforced, that the public is not engaged enough to make use of the trade secret challenge provisions, or that proprietary claims are unaffected by the procedure for asserting them. Going forward, determining whether proprietary claims were asserted consistently over the same ingredients could help to support or rebut each rationale.

3.3 Systems approach

Companies using the "systems approach" list all chemical ingredients added to hydraulic fracturing fluid, rather than linking those ingredients to particular fracturing fluid products. Commentators have recommended this approach believing it enables companies to share more information without fear of reverse engineering by competitors (Boling, 2012 and U.S. DOE (Department of Energy), 2014). The industry's largest service companies – Schlumberger, Baker Hughes, and to a much lesser extent, Halliburton– began using this method in FF 2.0 (Ritenbaugh 2014; Soraghan, 2014;Stynes, 2014).

These companies and a Halliburton affiliate account for 31% of ingredient records in the FF 2.0 dataset. We compared ingredient withholding rates among these companies and between methods of reporting, to test the theory that the systems approach can reduce withholding rates and enhance disclosure.

FF 2.0 forms do not explicitly provide for the systems approach; going forward, we recommend that FF 3.0 flag use of this method to facilitate analysis. For now, we determined that a record reflects the systems approach when: (1) the CASNumber or IngredientName field

include one of the keywords or exact phrases in Table 2 of the Methods Paper (which we previously noted in the new CASLabel field), and/or (2) a single TradeName field record reports multiple trade names (indicating that ingredients are not being listed under each trade name).

Based on this understanding, we determined that our four target companies reported 141,391 unique ingredient records using the systems approach, representing 7.1% of the FF 2.0 dataset. Schlumberger most often used the systems approach, employing the method on 64% of its forms in the dataset. Baker Hughes used the method on 13% of its forms, followed by Multi-Chem (4.2%) and Halliburton (0.34%). Schlumberger also has the lowest rate of withholding among these companies (5%, versus 16.9% for Baker Hughes and 12.1% for Halliburton). Across these companies, "systems approach" reporting reduced withholding rates more than four-fold, from 14.4% to 3.3%. Baker Hughes saw the largest drop in withholding rates when employing the systems approach, from 17.8% to 3.9% of its ingredient records, or a difference of 13.9% (95% CI: 14.3–13.5%; 2-sided p-value<0.001). However, Halliburton's and Multi-Chem's withholding rates increased with use of the systems approach (Table 4).

Our results suggest that companies are willing to disclose additional chemical information when they can separate chemical information from particular products. As this becomes a more widely accepted method of disclosing chemicals, we expect it will drive down rates of withheld chemical information. There are two caveats to this. First, Halliburton and Multi-Chem demonstrate that use of the systems approach alone may not lower withholding rates. Future analysis should determine what other factors drove withholding rates up for these companies. Second, states should retain backstop authority to request product-specific ingredient lists, whether for emergency response, to conduct spot checks of data accuracy, or for other purposes.

3.4 Timeliness of submissions

All twenty-one state disclosure requirements effective before April 13, 2015, contain post-fracturing reporting deadlines. In addition, four states key their reporting deadlines from the start of fracturing or drilling. Eight states require reporting within 60 days of the end of hydraulic fracturing or well completion (which may represent different dates in a well's development); six states and the BLM require reporting within 30 days of the end of hydraulic fracturing or well completion.

We calculated the median length of time companies took to submit disclosure forms in each state, using the OriginalSubmitTimeStamp, JobStartDate, and JobEndDate fields. We excluded forms from states without a deadline requirement during the date range of our data (Alaska, Virginia), or with fewer than a total of ten FF 1.0 and 2.0 forms submitted (Illinois, Nebraska, and Nevada).

For all but two states (Wyoming and West Virginia, where reporting deadlines had been imposed prior to the submission of any form in our dataset), we divide state results into the time periods before and after imposition of reporting deadlines. We create a third set of results for Colorado, to test whether timelines changed after this state announced it would enforce its deadline (Soraghan, 2013a). We use the start date specified in the deadline ultimately set by each state to calculate the median days to report for the pre-deadline period. Results were somewhat complicated by the fact that FracFocus forms do not publish a well's date of completion, a date that some states use to start the deadline clock; and, by the uneven coverage of state deadlines (some apply only to newly spudded wells). However, by keeping the method of calculating days to report consistent before and after imposition of the deadlines, the difference remains informative even if the absolute days to report are not entirely accurate.

Before reporting deadlines, operators across all states took an average of nearly 83 days to file a FracFocus form, weighted by the number of forms submitted by each state. There was wide variation between states – from Alabama, where operators took a median of 21 days to file, to Michigan, where operators took a median of 365 days.

After deadlines were imposed, operators across all states took a weighted average of 33 days to disclose chemicals to FracFocus, calculated from the start date of the deadline imposed in each state. The disclosure timeline in Texas dropped from a median of 98 to 29 days after that state imposed a reporting deadline (2-sided p-value≤0.001); the timeline in Montana dropped from a median of 289 to 41 days (2-sided p-value≤0.001) (Table 2). Therefore, enactment of deadlines generally shortened submission times. Only Alabama and California did not see a drop in the median numbers of days for filing after imposing a reporting deadline. In both cases, the pre-deadline median days to file were lower than the subsequent deadline. For example, before California had a deadline, operators took a median 36 days to report. In July 2014, California set a 60-day disclosure deadline; median reporting days subsequently increased to 47 days. However, the median disclosure timeline in Kansas dropped from 67 to 46 days (2-sided p-value=0.004), despite the fact that the deadline was far more lenient (120 days from drilling) than pre-deadline practice.

While reporting timelines shortened, compliance rates are generally low. The average late submission rate across all reporting states could be as much as 41% (given the caveats described above), ranging from 3.9% late filings in Kansas (which has the most lenient deadline of 120 days from drilling) to more than 70% in Alabama, Louisiana, and Mississippi.

Five states require companies to report the chemical ingredients they propose to use, before a hydraulic fracturing job (California, 2014, Alabama, 2013 and Montana, 2011; West Virginia,

2011; Wyoming, 2010). In addition, Arkansas requires service companies to report a master list of fracturing products that could be used in any job in the state (Arkansas, 2013). These six states also generally require (or retain the right to require) approval to use particular fracturing chemicals or substances, which necessitates pre-fracturing disclosure. Early disclosures should make it easier for an operator to make post-fracturing disclosures, since it should be easier to collect information on discrete changes made during the job than to collect all chemical information at that time. Yet, compliance rates were lower in states with pre-fracturing disclosure requirements – 50.7% of post-fracturing forms submitted in states with pre-fracturing disclosure requirements were late, as compared to 38.3% of forms submitted in states without pre-fracturing disclosure requirements. However, the 12.4% difference (95% CI: −0.55–32.4%; 2-sided p-value 0.2) is statistically inconclusive, primarily due to skewed sample sizes.

This suggests that pre-fracturing disclosure requirements are not being enforced or that companies in pre-fracturing states consider their reporting obligations over before the fracturing job, driving a more lax response to post-job reporting.

Colorado provides an interesting study. After the state imposed a 60-day deadline on April 1, 2012, the median number of days for filing dropped from 72 to 49. Yet 36.1% of Colorado disclosures were submitted more than 60 days after the end of fracturing. A 2013 article reviewing public records in Colorado and another state indicated low compliance rates and virtually no enforcement of deadlines (Soraghan, 2013 and Soraghan, 2013a). Colorado then announced it would begin enforcing its deadline after July 1, 2013. Following the announcement alone, the share of late submissions dropped significantly from 36.1% to 5.2% of the forms, indicating that simply by signaling a deadline (or other requirement) will be enforced, a state may boost compliance rates.

4. Conclusions and Policy Implications

FracFocus contains the most comprehensive dataset on fracturing chemicals in the United States. Some states are designing their own fracturing chemical repositories (California, 2014 and Ferral, 2015), and federal agencies may continue to explore methods for enhancing public disclosure of information related to unconventional oil and natural gas development (U.S. EPA (Environmental Protection Agency), 2014). These initiatives can and should co-exist with efforts to improve FracFocus data, to ensure that landowners, policymakers, public health researchers, industry, and other stakeholders have access to robust and comprehensive information about chemical use in unconventional oil and natural gas wells. One of first opportunities to use this information to inform policy will be in EPA's final Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources. The authors of this study hope that our analysis of more recent FracFocus entries will be used to supplement the analysis EPA undertook of 2011–2013 FracFocus entries for its Draft Assessment.

Data accuracy in FracFocus may be improved through better data entry design. From the first iteration of FracFocus to FF 2.0, our analysis suggests that the use of automatic field population and prompts (i.e., directing operators to enter API well numbers section by section) has reduced error rates. FF 3.0 will build on this work, for instance by providing drop-down menus for populating certain fields. It will be important to revisit these analyses and to run additional error inquiries, to determine whether the changes further enhance data quality.

State deadlines have shortened reporting timelines, but compliance rates are low. Timing may seem like a small aspect of chemical reporting. However, as a relatively easy requirement with an objective compliance determination (a form is either submitted on time or not), it can serve as a proxy for determining how seriously operators take disclosure obligations and for

identifying mechanisms that can enhance compliance. For instance, enforcement signals could boost compliance rates, as evidenced by compliance with Colorado's deadline after that state announced it would begin enforcement. Disclosure about the timing for submissions may help as well. For example, historically FracFocus has logged the submission date of each form internally, but has not published this information directly on its website. Therefore, the public cannot easily determine when a form was submitted. FracFocus has announced it will begin publishing submission dates by fall 2015; analysis after that point could be done to determine whether publishing submission dates leads to higher rates of compliance with state deadlines. These lessons may be transferable to other disclosure requirements as well.

That said, to date different state requirements do not appear to have affected chemical withholding rates. Educating the industry on state-specific requirements could raise awareness and enhance compliance. States might also consider harmonizing disclosure requirements, particularly as they relate to withholding standards and justifications, to reduce confusion for operators working in multiple jurisdictions. For instance, FracFocus and participating states might limit proprietary withholding to chemical ingredients meeting the trade secret definition, and then give trainings on trade secret identification to operators using the FracFocus system.

Finally, states and FracFocus should encourage the "systems approach" reporting method to minimize withholding rates, as this method appears to have reduced withholding rates more effectively than any state requirement. Currently, Oklahoma's requirements explicitly embrace the systems approach (Oklahoma, 2012). Other state rules can accommodate this approach to chemicals reporting. However, a handful of state requirements may not allow companies to report chemical information in a systems format. If those states – including Alaska, Idaho, Mississippi, Pennsylvania, and West Virginia – intend for companies to use the systems

approach on FracFocus, they may need to revisit their reporting requirements. While making these changes, however, states should retain authority to request product-specific ingredient lists.

More analysis is warranted. Future work could analyze and take steps to improve location data error rates at the county level – accuracy at this level of granularity is important, to ensure that local landowners and county officials can identify all of the wells located near their properties or within county lines. Additional analysis relating to pre-fracturing reporting compliance should be conducted, to shed light on reasons for the lower (or insignificantly different) compliance rates with post-fracturing reporting deadlines in states with pre-fracturing disclosure requirements. Consistency of reporting should be surveyed as well, to determine whether the same ingredients are withheld on proprietary grounds across forms. If chemical ingredients withheld in some forms have already been disclosed in others, GWPC and states could discuss whether a mechanism should exist to publish the chemical across forms, at least in the same shale play.

Still other work could compare CAS number and ingredient name values to determine whether they match across an ingredient record. For this analysis, researchers could compare our IngredientNameClean field, which we populated with standardized ingredient names identified in CAS databases, against the original ingredient name field. Once ingredient names are standardized and tested for discrepancies with the reported CAS number, analyses could track trends in chemical use between plays and over time, to track anecdotal reports of an increase in "green" fracturing fluid products or for other purposes. Finally, company surveys about state requirements and reporting practices would be enlightening.

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Tables

Table 1. Wells reported to FracFocus in analysis subset.

State Name	# of FF 1.0 Forms Submitted *This Study*	# of FF 2.0 Forms Submitted *This Study*	Total *Well to Form* Ratio (unique wells per all forms) ***This Study***	Total Forms Submitted (% of FF 1.0 & 2.0 forms) *This Study*	Total Forms Submitted (% of FF 1.0 forms) *EPA Study*
Alabama	55	71	1.00	126 (**0.13%**)	55 (**0.15%**)
Alaska	48	45	0.86	93 (**0.10%**)	37 (**0.10%**)
Arkansas	1459	1156	0.99	2615 (**2.72%**)	1450 (**3.83%**)
California	967	1297	0.98	2264 (**2.35%**)	718 (**1.90%**)
Colorado	5268	4046	0.98	9314 (**9.67%**)	4938 (**13.0%**)
Illinois	0	1	1.00	1 (<**0.001%**)	0 (**0.00%**)
Kansas	210	393	0.98	603 (**0.63%**)	136 (**0.36%**)
Louisiana	1121	512	0.97	1633 (**1.70%**)	1038 (**2.74%**)
Michigan	15	6	0.86	21 (**0.02%**)	15 (**0.04%**)
Mississippi	10	61	1.00	71 (**0.07%**)	4 (**0.01%**)
Montana	270	269	0.95	539 (**0.56%**)	213 (**0.56%**)
Nebraska	3	4	0.57	7 (**0.01%**)	0 (**0.00%**)
Nevada	0	6	0.83	6 (0.01%)	0 (0.00%)
New Mexico	1312	1403	0.96	2715 (2.82%)	1162 (3.07%)
North Dakota	2901	4602	0.96	7503 (7.79%)	2254 (5.95%)
Ohio	169	779	0.99	948 (0.98%)	148 (0.39%)
Oklahoma	2241	5516	0.94	7757 (8.06%)	1909 (5.04%)
Pennsylvania	2674	2496	0.98	5170 (5.37%)	2483 (6.55%)
Texas	20758	26126	0.96	46884 (48.7%)	18075 (47.7%)
Utah	1666	2078	0.94	3744 (3.89%)	1429 (3.77%)
Virginia	89	34	1.00	123 (0.13%)	90 (0.24%)
West Virginia	364	667	0.99	1031 (1.07%)	277 (0.73%)
Wyoming	1622	1510	0.96	3132 (3.25%)	1457 (3.85%)

Table 2. Timing of disclosures made to FracFocus.

State	Disclosure Deadlines, days from job Start/End)	Law Effective Date	Pre-law median delay days (25^{th}, 75^{th} Percentile)	Post-law median delay days (25^{th}, 75^{th} Percentile)	# forms, pre-law	# forms, post-law	p-value, Mood's test	Z statistic, Mood's test	% of post-law forms delayed
AR	30 (C)	02/09/13	54 (33, 107)	25 (21, 31)	1572	1043	<0.001	10.75	28
AL	30 (S)	09/09/13	21 (12, 37)	72 (32, 114)	63	63	0.98	-0.03	75
CA	60 (C)	07/01/14	36 (19, 65)	47 (41, 53)	1786	478	<0.001	19.53	7
CO	60 (C)	04/01/12	72 (38, 148)	49 (25, 80)	3399	2690	0.18	1.35	36
CO	*Enforcement	10/01/13	49 (25,80)	44 (25, 53)	2690	3225	<0.001	22.5	5
KS	120 (S)	12/02/13	67 (41, 113)	46 (27, 70)	375	228	0.04	2.08	4
LA	20 (C)	10/20/11	83 (42, 192)	35 (19, 66)	530	1103	0.02	2.32	71
MI	60 (C)	06/22/1[a]	365 (318, 403)	162 (58, 222)	4	17	0.04	2.05	71
MS	30 (S)	03/04/13	172 (63, 183)	39 (26, 78)	7	64	0.13	1.53	64
MT	30 (C)	08/26/11	289 (118, 343)	41 (20, 83)	19	520	<0.001	5.42	59
NM	45 (C)	02/15/12	70 (41, 163)	26 (14, 65)	543	2172	0.50	-0.67	32
ND	60 (C)	04/01/12	158 (42, 347)	30 (14, 56)	1053	6450	<0.001	24.63	22
OH	60 (C)	09/10/12	68 (37, 96)	47 (30, 59)	94	854	<0.001	4.20	19
OK	60 (S)	07/01/12	84 (38, 177)	39 (20, 68)	1205	6552	<0.001	10.24	30
PA	60 (C)	04/16/12	85 (41, 165)	39 (21, 60)	1607	3563	<0.001	9.35	25
TX	30 (C)	02/01/12	98 (47, 181)	29 (14, 64)	6313	40571	<0.001	30.09	48
UT	60 (C)	01/23/13	80 (41, 146)	27 (17, 40)	1531	2213	<0.001	15.52	7
WV	90 (C)	09/10/10	--	73 (37, 162)	--	1031	--	--	41
WY	30 (C)	09/14/10	--	43 (23, 105)	--	3132	--	--	59

[a] Michigan has a new rule effective March 11, 2015; however, the dataset contained no Michigan forms submitted after this date.

Table 3. Most common ingredient records reported in analysis subset.

Standardized Ingredient Name	Number (%) of Forms	% of all ingredient entries
Methyl alcohol/methanol	40892 (77.1)	4.9
C13-14 isoparaffin	38782 (73.1)	3.2
Hydrochloric acid	38641 (72.8)	2.8
Ethylene glycol	28957 (54.6)	2.2
Isopropyl alcohol	28447 (53.6)	2.6
Sodium chloride	28126 (53.0)	2.4
Guar gum	27874 (52.5)	1.8
Ammonium peroxydisulfate	23856 (45.0)	1.8
Sodium hydroxide	22580 (42.5)	1.7
Propargyl alcohol	19122 (36.0)	1.2
Acetic acid, glacial	18409 (34.7)	1.4
Potassium hydroxide	17822 (33.6)	1.3
Glutaral	16760 (31.6)	1.1
Citric acid, anhydrous	16174 (30.5)	1.1
Ammonium chloride	16175 (30.5)	1.2
Ethyl alcohol	16055 (30.3)	1.1
Sorbitan monooleate	15692 (29.6)	1.0
C12-16 pareth-9	14812 (27.9)	1.0
Ethylene glycol mono-n-butyl ether	13237 (24.9)	1.2
Thiourea, polymer with formaldehyde and 1-phenylethanone	13163 (24.8)	0.8

Table 4. Systems analysis in largest service companies.

Company	# of Regular Records	# of Systems Approach (SA) Records	WH Rate for Regular Records	WH Rate for SA Records (Difference from Reg WH Rate)	2-sided p-value	95% CI
Schlumberger	47,991	127,799	10.7%	2.9% (7.8%)	<0.001	8.1% – 7.6%
Baker Hughes	169229	12432	17.8%	3.9% (13.9%)	<0.001	14.3% - 13.5%
Halliburton	232618	315	12.1%	17.8% (5.6%)	<0.001	9.8% - 1.4%
Multi-Chem	20727	845	21%	43% (22%)	<0.001	252%-18.9%

Figures

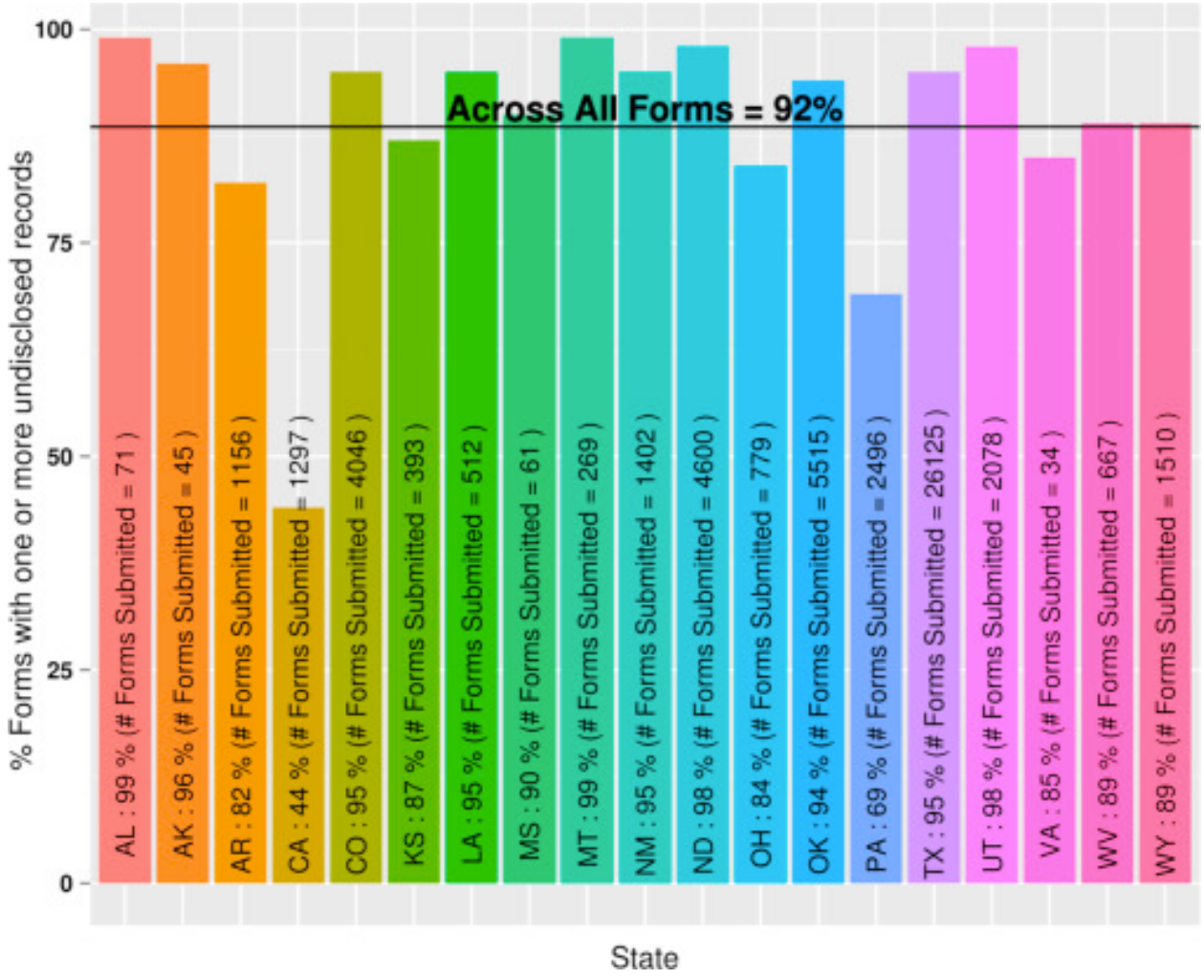

Fig. 1.
Rates of Nondisclosure: Percentage of forms with at least one ingredient withheld.

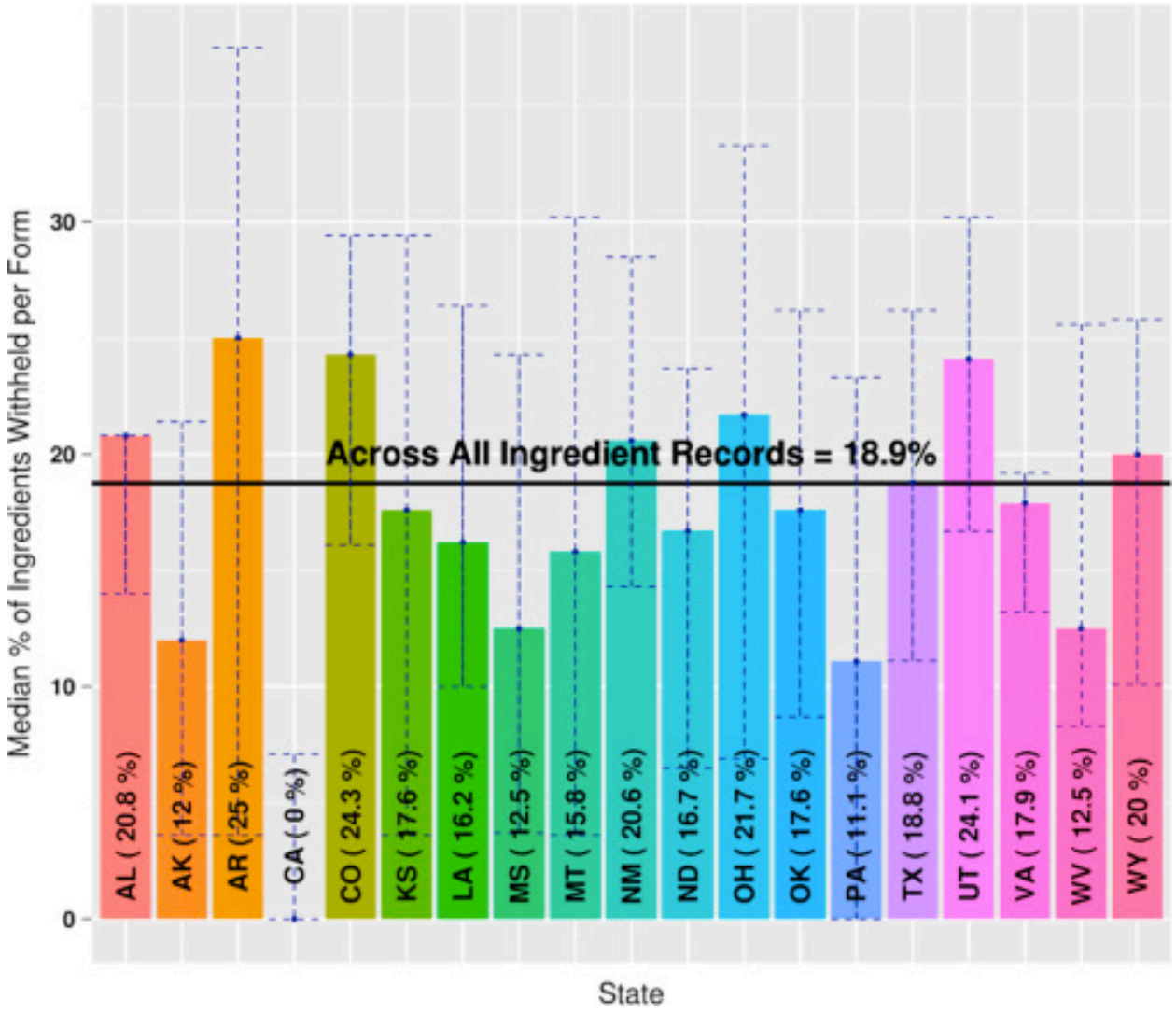

Fig. 2.
Rates of Nondisclosure: median percentage of ingredients withheld per form.
Error bars represent 25th and 75th percentiles of distribution.

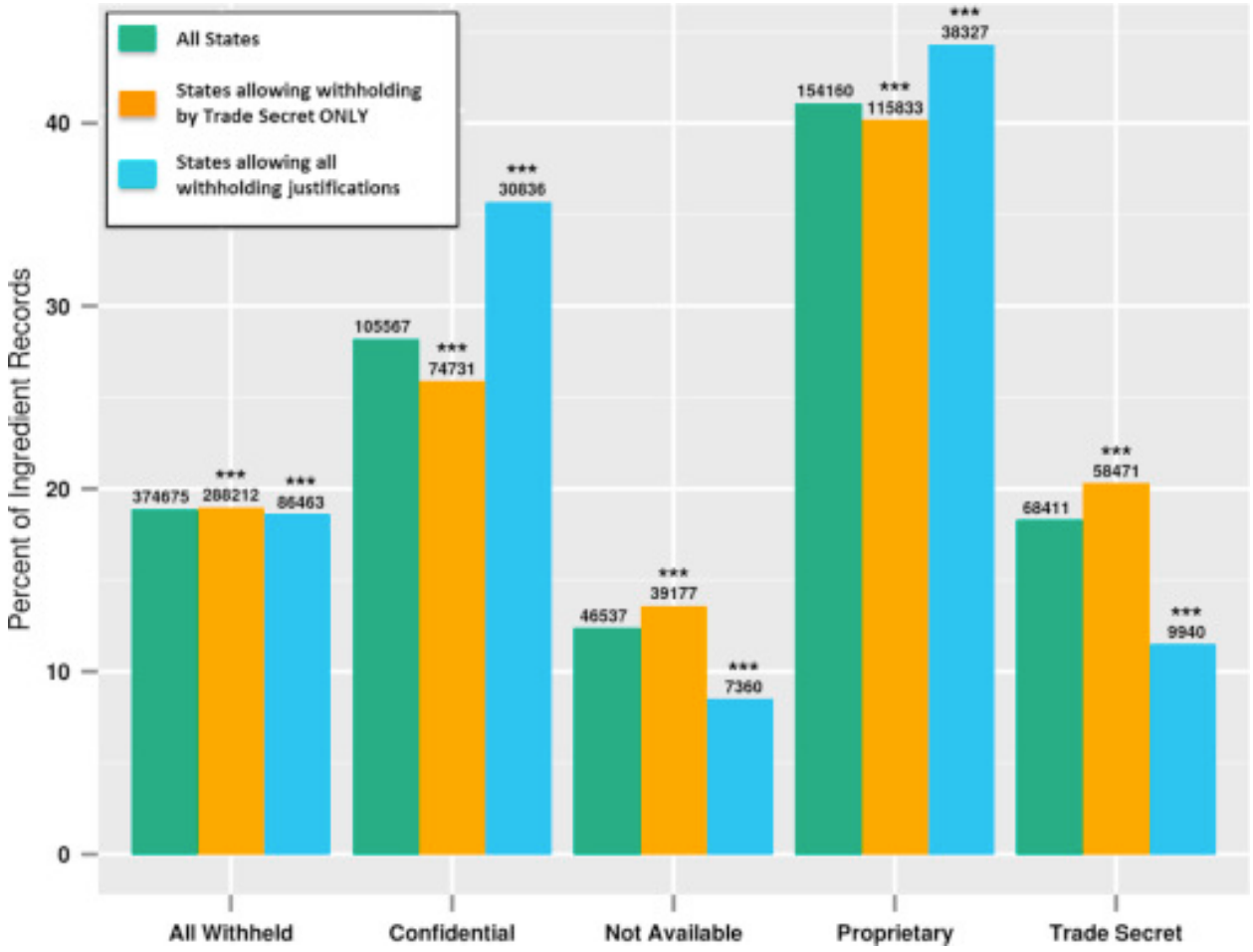

Fig. 3.
Justification of Nondisclosure by Percentage of Ingredient Records. *** Refers to the 2-sided *p*-value <0.001 obtained from testing the differences between Group A states (orange) and Group B states (blue) using an approximate test for equal proportions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).