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# Keeping Invention Confidential

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**Abstract.** This study investigates the use of a prevalent but rarely studied form of intellectual property protection: trade secrecy. Building on existing survey evidence of firm-level, cross-sectional use of secrecy, we document the effect of stronger legal protections for trade secrets on the project-level use of such secrets. Our setting is the U.S. oil and gas hydraulic fracturing industry, from 2014 to 2018, in states where firms are required to disclose fracturing fluid ingredients to regulators except for substantiated claims of trade secrets. We examine how the enactment of the federal 2016 Defend Trade Secrets Act (DTSA) affects well-level trade secret use across states with varying levels of pre-DTSA protection. We find substantial increases in the use and novelty of trade secrets. Further, wells with trade secret ingredients are, on average, more productive. However, the DTSA exerts limited additional effect on trade secret–related productivity. Supplementary tests address alternative explanations, show no evidence of intellectual property substitution, and provide additional support that we are capturing policy effects. Our results provide rare empirical evidence on actual trade secret use and enhance our understanding of how appropriability shapes use of trade secrets and associated inventive activity.

**History:** Accepted by Toby Stuart, entrepreneurship and innovation.



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**Supplemental Material:** The online appendix and data files are available at <https://doi.org/10.1287/mnsc.2022.01138>.

**Keywords:** research and development • innovation • organizational studies • strategy • technology

## 1. Introduction

Intellectual property (IP) protection incentivizes innovation and, thus, shapes firm performance and economic growth. IP protection takes many forms, yet much of the empirical evidence on innovation focuses narrowly on patented inventions, likely because patenting requires detailed public disclosure that promotes empirical study. Firms report that other forms of IP protection, namely secrecy, are used more frequently and are more effective in protecting innovation (Levin et al. 1987, Hall 1992, Cohen et al. 2000, Linton 2016, Sofka et al. 2018, Mezzanotti and Simcoe 2023). Secrecy is both prevalent and economically important. For instance, the value of trade secrets (TS) for U.S. public firms is estimated to be more than \$5 trillion and two thirds of intangible assets (U.S. Chamber of Commerce 2014, Chen et al. 2021), and trade secret theft may cost up to 3% of the gross domestic product in industrialized economies (Ciuriak and Ptashkina 2021, Searle 2021). Trade secrets are hard to study

systematically because their value and legal protection hinge on nondisclosure. Yet, because of their ubiquity, documenting firms’ use of trade secrets is fundamental to understanding innovation.

Existing research provides two main empirical insights into secrecy use and the effects of trade secret–related policies on invention. First, using secrecy to protect inventions is common across firms, industries, locations, and time (Cohen et al. 2000, Arundel 2001, Jensen and Webster 2009, Thomä and Bizer 2013, Sofka et al. 2018). Second, stronger trade secret–related legal protections tend to increase research and development (R&D) (Png 2017a, Ganglmair and Reimers 2019) and, in some sectors, lead to a decrease in patenting (Png 2017b, Contigiani et al. 2018). If patents were the only IP protection for invention, this would imply a decrease in innovation. However, firms use secrecy (and other means) to protect inventions even more than they use patents (Cohen et al. 2000, Mezzanotti and Simcoe 2023). Yet we lack direct

evidence on how changes in the appropriability regime, including in the legal protections of trade secrets, affect their use.<sup>1</sup>

Accordingly, this paper examines the effects of an increase in legal protection of trade secrecy on how and when firms use trade secrets. We posit that stronger legal protection lowers knowledge leakage risk: the risk of a firm failing to fully appropriate value from its IP. As such, increases in legal protection should lead firms to increase trade secret use. Further, the effect of stronger protections on use should be somewhat mitigated when substitute protections from knowledge leakage (e.g., noncompete enforcement) are present. Stronger protection should also lead to novel trade secret use, that is, indirect evidence of trade secret-protected inventive activity.

Our context is hydraulic fracturing within the U.S. oil and gas industry. Whereas conventional oil and gas extraction involves drilling wells into reservoirs to access oil/gas, hydraulic fracturing involves forcing high-pressure fluids—containing water, proppant, and various chemicals—into a well to fracture the surrounding shale rock and enable oil and gas extraction. Though fracturing is not wholly new (Montgomery and Smith 2010, Hall 2013), the percentage of U.S. wells using fracturing increased from less than 5% in the early 2000s to more than 75% by 2019 (U.S. Energy Information Administration 2016, 2018, 2020). Alongside this growth, firms experimented and invented new fracturing techniques and inputs (Curtis 2016, Fetter et al. 2018). Secrecy is a common means to protect IP (Cohen et al. 2000)<sup>2</sup> and likely particularly relevant in fracturing because of both the speed of production and the difficulty of reverse engineering fracturing fluids (Maynard 2013). Novel fracturing fluid recipes can increase well productivity (Fetter et al. 2018) and, thus, if protected, can be a source of competitive advantage.

Two key features of this industry enable us to study trade secret use systematically. First, since the early 2010s, regulators have mandated the disclosure of all non-trade secret fracturing fluid ingredients in nearly all U.S. states with meaningful fracturing activity (McFeeley 2012, Fetter et al. 2018).<sup>3</sup> Second, in a subset of the disclosure mandating states, regulators require firms that claim certain ingredients are trade secrets to justify their claims (McFeeley 2012).<sup>4</sup> These two features—disclosure of ingredients combined with substantiated and, therefore, bona fide trade secrets—allow us to observe trade secret use at a granular level and thereby to create (1) a well-level data set of fracturing ingredients, including indicators for trade secret ingredients, and (2) measures of novel trade secrets (i.e., indirect measures of trade secret-protected invention).<sup>5</sup>

To measure an increase in legal protection of trade secrets, we use the federal Defend Trade Secrets Act (DTSA), enacted in May 2016. The DTSA increased trade

secret protection by adding a federal jurisdiction for trade secret cases stronger than existing state-level protections. We examine heterogeneous effects of the DTSA, distinguishing states with lower pre-DTSA protection (referred to hereafter as high-treatment states) from states with higher pre-DTSA protection (low-treatment states) (Png 2017a, b). We estimate the effects of DTSA on (1) the use of trade secrets, measured as any use and proportion of trade secret ingredients used to fracture the well, and (2) the use of novel trade secrets. We also examine the association between trade secret use and well productivity and post-DTSA changes in this association.

We find that trade secret use increases substantially. Use of a trade secret ingredient at the well level increases by 22 percentage points (pp) post-DTSA in high-treatment states. Consistent with knowledge leakage risk driving use, we find that the effects are stronger under three conditions: in states with less stringent indirect secrecy protection policies (lower noncompete enforcement); in situations with lower levels of interfirm trust between service firms and their fracturing customers (producer firms); and when location-related leakage to rival firms is more likely. Further, firms substantially increased their use of novel trade secrets. For instance, the use of new-to-the-firm secret ingredients increased by 1 pp from 0.1% in high-treatment states pre-DTSA. Wells with trade secret ingredients are also more productive, consistent with trade secrets providing a source of competitive advantage, though DTSA-induced increases in protections do not appear to unequivocally increase productivity. Supplementary analyses show little evidence of IP substitution (no evidence of decreased use of new disclosed ingredients or substitution between secrecy and patenting) or of increased attempts to cloak toxicity via trade secrets.

We provide, to our knowledge, the first direct evidence that firms respond to increased trade secret legal protection with increased use of such secrets. The study also provides some indirect evidence of increased trade secret-protected invention. Research shows that stronger trade secrecy protection leads firms to decrease patenting in some sectors (Png 2017a, Contigiani et al. 2018, Contigiani and Testoni 2023). However, trade secret protection was also found to increase R&D spending (Png 2017b). Our research suggests a missing piece in these findings: stronger trade secret protection may lead to increased trade secret-protected invention. Thus, we add suggestive evidence for a positive effect of stronger TS protection on innovation protected by trade secrets.

More broadly, we provide systematic study of a common and important but rarely analyzed form of IP. Given the widespread codification and cross-sector availability of patent data, scholars understandably focus almost exclusively on measuring innovation using

patents. Yet much innovation is not patented (Cohen et al. 2000, Fontana et al. 2013, Arora et al. 2016), and patents serve several noninnovation aims (Hall and Ziedonis 2001, Ziedonis 2004, Noel and Schankerman 2013, Kang and Lee 2022). In short, we have a limited picture of when and how firms invent and innovate. Our in-depth empirical study of the use of trade secrets, therefore, adds to growing non-patent-based empirical research relating appropriability to innovation, a literature that generally explores copyright and trademarks (Block et al. 2015, Li et al. 2018, Nagaraj 2018, Castaldi 2020, Biasi and Moser 2021).

The paper proceeds as follows. The first section below provides background on trade secrets as IP protection and the relationship between increased protection and use. The section thereafter introduces our context, the U.S. hydraulic fracturing sector. Then, we provide some motivation for our empirical analyses. We then outline our data, empirical approach, and results. Last, we discuss the findings, limitations, and their implications for management and policy.

## 2. Trade Secrets as IP Protection: Background

A trade secret is a commercially valuable item of information that derives value from being secret and that firms must actively and effortfully conceal (Friedman et al. 1991).<sup>6</sup> As they are both difficult to imitate and valuable (Hall 1992), trade secrets can be a source of competitive advantage (Penrose 1959, Risch 2007, Lemley 2008, Sharapov and MacAulay 2022).

Across industries, locations, and time, firms often report secrecy as the most effective mechanism for protecting inventions (Cohen et al. 2000, Arundel 2001, Jensen and Webster 2009, Hall et al. 2014, European Union Intellectual Property Office 2017).<sup>7</sup> Recent survey evidence suggests that 52% of R&D-active U.S. firms consider trade secrets important for protecting their IP—more than twice the rate for patents (Mezzanotti and Simcoe 2023). Typical inventions protected, in whole or in part, as trade secrets include recipes (of which a successful example is that of Coca-Cola), chemical formulae (WD-40), algorithms (Google search), manufacturing processes (the Mistron 604AV production process by the Luzenac Group, the world's largest talc producer), and blueprints (the foldable Apple iPhone prototype).

As a form of IP protection, trade secrets have several distinguishing features. First, and fundamentally, capturing the profits from them relies on nondisclosure. To enjoy legal protection, firms must engage in ongoing, demonstrable effort to prevent disclosure. Second, firms need not wait for government agencies to grant IP protection to use inventions protected as trade secrets; firms can use and protect them immediately.<sup>8</sup> Third, there is no time limit on the legal rights associated with a trade secret

(Almeling et al. 2010b, Schwartz 2013).<sup>9</sup> Last, the type of information that is potentially protectable using trade secrets is relatively broad: trade secrets can be invoked to protect “valuable information,” which can include technological information, such as successful and failed inventions, and also nontechnological information, such as customer lists or pricing algorithms. Patents protect only novel, nonobvious, and useful technological information (Lemley 2008). Our focus is on technological information protected by trade secrets. Importantly, firms cannot claim information as a trade secret if it is “readily ascertainable,” already publicly known, or previously disclosed (Uniform Law Commission 1985). Therefore, trade secrets must be useful and involve some form of novelty, uniqueness, and/or nonobviousness.<sup>10</sup>

Much research examining when firms are likely to use secrecy to protect inventions contrasts secrecy and patents. Whereas patents require inventors to publicly disclose the invention in exchange for legal protections (though disclosure quality can vary) (Amore 2020, Dyer et al. 2024), protection via secrecy relies on the inventor effectively concealing the crucial inventive steps. Thus, for inventors, the benefits of trade secrets may outweigh those of patents when reverse engineering is difficult (Png 2017b); when codification is challenging (Arora 1997); when the patent regime is weak (Katila et al. 2008); when firms are mandated to disclose other valuable information (Sofka et al. 2018); or when, because secrecy does not require approval, firms highly value speed to market (Zaby 2010, Gans and Stern 2017). Firms may seek to protect their more novel inventions via secrecy in order to completely avoid disclosure (Anton and Yao 2004) and to have the option to maintain protection indefinitely. Notably, firms may use secrecy to complement patents and other forms of IP. For instance, secrecy can be complementary to future patenting given that the contents of patent applications are typically kept secret prior to disclosure (Graham and Hegde 2015, Hegde and Luo 2018). Secrets and patents can also be contemporaneously complementary, for example, when a particular technology requires know-how for its productive implementation (Parker 2015).<sup>11</sup>

Trade secret loss can happen through three channels. First, the secret can be illegally misappropriated, via theft, bribery, breach of contract, espionage, or other illegal means (Schwartz 2013). Second, secrets may inadvertently leak if firms do not take reasonable precautions. Such precautions include labeling, physical locks, secure facilities (e.g., the Coca-Cola vault), cybersecurity efforts, restricting access via need-to-know rules, and/or contracts including nondisclosure agreements (NDAs) and confidentiality agreements (Schwartz 2013).<sup>12</sup> Secrets are typically stolen or leak out via business partners, employees, or rival firms (Lemley 2008; Almeling et al. 2010a, b). For instance, in *Wyeth v. Natural Biologics*, a former employee was found to have divulged Wyeth's

hormone therapy–related trade secret to a rival firm, which, within a year, replicated it (Bell et al. 2025a).<sup>13</sup> Employees may also inadvertently share potential trade secrets, such as when Samsung engineers posted proprietary code on ChatGPT.<sup>14</sup> Additional examples of both misappropriation and inadvertent disclosure are in Online Appendix A. Third, other parties may independently discover or reverse engineer an invention (Cronin 2015). Trade secret law protects against illegal misappropriation—the definition of which varies under different legal protection regimes—but not against inadvertent disclosure or if the secret is independently discovered or reverse engineered.

In sum, secrecy is commonly used to protect inventions and substantively differs from other forms of IP protection, such as patents. Trade secrecy laws determine what constitutes illegal misappropriation as well as the degree of punishment associated with misappropriation. Legal trade secret protections affect firms' expectations of trade secret–related appropriability and should therefore influence their use of trade secrets.

## 2.1. Increased Trade Secret Protection and the Use of Trade Secrets

We know that secrecy is a common and important means of appropriating value from invention (Cohen et al. 2000, Arundel 2001, Jensen and Webster 2009, Thomä and Bizer 2013, Sofka et al. 2018). Further, secrecy-protected inventions can be highly innovative (Anton and Yao 2004) and valuable.<sup>15</sup> Historically, in countries with weaker patent laws and more reliance on secrecy, inventions were more novel and impactful (Moser 2013). Stronger trade secret policies lead firms to increase their R&D investments as evidenced by responses to the pre-DTSA Uniform Trade Secrets Act (UTSA)<sup>16</sup> (Png 2017a, Ganglmair and Reimers 2019). Also, in some sectors, increased secrecy protection is associated with lower rates of patenting (Png 2017b, Contigiani et al. 2018, Contigiani and Testoni 2023).

However, a direct link between legal trade secret protection and the use of trade secrets has not been established. To begin to fill this gap, we examine the relationship between stronger legal protection of trade secrets and the use of trade secrets. Simply put, because increased legal protection decreases knowledge leakage risk, we expect use of trade secrets to increase. We also investigate trade secret–protected inventive activity and provide some indirect evidence of an uptick following increased legal protection of trade secrets. Finally, we explore the productivity-related consequences of using trade secret–protected inputs.

## 3. Context: U.S. Hydraulic Fracturing

Our empirical context is hydraulic fracturing in the U.S. oil and gas industry from 2014 to 2018. During the 2010s,

hydraulic fracturing grew significantly in scale and economic importance worldwide, but especially in the United States (Feyrer et al. 2017). Fracturing use in U.S. oil and gas wells increased from less than 5% in the early 2000s to more than 75% by 2019, which contributed to the United States becoming a net exporter of oil in 2019 (U.S. Energy Information Administration 2018, 2020).<sup>17</sup>

Hydraulic fracturing enables extraction of unconventional oil and gas deposits, that is, those highly dispersed in shale rock or in deep coalbed formations. Because it enables extraction of otherwise trapped oil and gas, fracturing has significantly expanded areas of oil and gas development. The fracturing process first involves inspecting the underlying geology and selecting and calibrating the ingredients of the fracturing fluid—comprising water, proppant materials, and chemicals—used to stimulate the shale rock and enable the flow of oil and/or gas. Service firms then drill and perforate a long horizontal well, into which they inject their selected fracturing fluid.

Typically, hydraulic fracturing service firms fracture wells for oil and gas producers, who hold leases and, thus, property rights over the extracted oil and gas (Ma and Holditch 2015). As service firms compete to gain contracts from producers, they aim to demonstrate a higher net output of their services, including through their use of technological advances that improve well productivity (Kellogg 2011). Although several important factors can impact well productivity—including, for instance, well location—a key input is fracturing fluid ingredients (Ma and Holditch 2015). Service firms have actively experimented with fracturing inputs, including fracturing fluid ingredients, since hydraulic fracturing first became commercially viable in the late 1990s (Curtis 2016, 2017). Such experimentation continues today (Quosay et al. 2020).

Since the early 2010s, most U.S. states with measurable hydraulic fracturing activity have required firms to publicly disclose fracturing fluid ingredients at the well level except for ingredients held as trade secrets (Fetter et al. 2018). We limit our sample to wells in states that both (1) require detailed fracturing ingredient disclosure<sup>18</sup> and (2) require substantiation of the legal validity of trade secret claims by the fracturing firms to preclude disclosure of trade secret ingredients (as state requirements for claiming a trade secret vary (McFeeley 2012) with only some requiring detailed justification to state regulators).<sup>19</sup> We employ the first limit out of necessity and the second because our study aims to examine the use of trade secrecy to protect valuable intellectual property rather than secrecy for other strategic motives, such as potential obfuscation of known ingredients from competitors (Fisk 2013, Tang 2024) or concealment of harmful input use from government and the public.<sup>20</sup> Our included states are Arkansas, Colorado, Louisiana, Oklahoma, Pennsylvania, Texas, and Wyoming, and

these encompassed roughly 80% of U.S. fractured wells from 2014 to 2018—all the years following ingredient disclosure mandates and for which we have data access.

To measure increased legal protection, we use the DTSA.<sup>21</sup> Enacted in May 2016, the DTSA increased trade secret protection by creating the first-ever federal jurisdiction for adjudicating trade secret disputes and establishing additional legal remedies for misappropriation (for instance, the seizure of assets and remedies up to triple damages) in the United States. At the time of its passing, legal experts considered the DTSA the most significant expansion of federal IP law for at least 30 years (Levine and Seaman 2018).<sup>22</sup> Using the state-level index constructed by Png (2017a, b),<sup>23</sup> we use pre-DTSA state-level variation in trade secret protection to explore heterogeneity in the effects of DTSA on use of trade secrets.<sup>24</sup> States have different levels of pre-DTSA trade secret protection through diverging state-level applications of the UTSA (Sandeem 2010) and state common law.

Our approach relies on pre-DTSA levels of secrecy protection being exogenous to other factors that might cause trade secret use to disproportionately increase following DTSA enactment in high-treatment states. Several pieces of evidence suggest that this is not a concern. First, Png (2017a, b) found that state adoption of the UTSA was unrelated to state-level economic and policy-related drivers of inventive activity (e.g., R&D tax credits, state legislature composition). Second, in supplementary analyses, we find no evidence of a relationship between pre-DTSA variation in secrecy protection and various relevant fracking disclosure and other relevant policies that could otherwise be generating our results (see Online Appendix B).

#### 4. Knowledge Leakage in Hydraulic Fracturing

To motivate our empirical analyses, consider a typical fracturing service firm with a portfolio of existing assets, including IP. As it performs a fracturing service on a given well, the firm faces a key choice: which ingredients to include in its fracturing fluid recipe.<sup>25</sup> In choosing whether to use a trade secret ingredient in a particular well, the service firm trades off the expected value of using the ingredient against the risk of knowledge leakage, that is, the use-specific risk that the secret will leak out to rivals, ending the ingredient's IP protection forever.<sup>26</sup> This trade-off suggests that service firms only use trade secret fracturing fluid ingredients when the value of using them exceeds such risk.<sup>27</sup>

Within this simple setup, we consider the effect of the DTSA. Stronger legal protections for trade secrets expand what constitutes misappropriation and/or increase the penalties for misappropriation (Png 2017a). Such extensions discourage misappropriation by increasing the

concomitant expected costs and the likelihood that firms will be able to recoup losses if misappropriation occurs.<sup>28</sup> Because the DTSA lowered knowledge leakage risk, the expected value threshold for use decreased. We, thus, expect that the DTSA increased the use of trade secret ingredients. Further, we expect the increase to be largest in states that had relatively lower trade secret protection pre-DTSA.

Knowledge leakage risk is not just a consequence of trade secret policy. Leakage commonly happens through ex-employees leaving for rivals or through business partners (such as customer firms) stealing confidentially disclosed information both across all industries (see Online Appendix A) and in hydraulic fracturing specifically (see Online Appendix Q). Relatedly, knowledge leakage risk is likely to be lower pre-DTSA depending on three related drivers. First, knowledge leakage risk was likely lower in states with other strong policies that protect against firm's confidential knowledge leaking to competitors via ex-employees, for example, relatively strong noncompete enforcement laws (Starr et al. 2021). Second, given that firms build relationships and trust through repeated exchange, knowledge leakage risk is mitigated when the producer firm represents a relatively large share of the service firm's business (Poppo and Zenger 2002, Poppo et al. 2016). Third, given that proximity to rivals can facilitate leakage (Tallman et al. 2004, Ryu et al. 2018), pre-DTSA, the risk should have been lower in locations with fewer rival service firms.<sup>29</sup> Notably, these factors may also have competing implications for the value of trade secret use. For instance, higher local rivalry may lead to increased differentiation-related value of trade secret ingredients and thereby drive up their use. We leave it to the empirics to parse the net effects.

Beyond choosing from its existing set of trade secret fracturing fluid ingredients, a firm also has the ongoing choice to develop (and use) new ingredients and to protect them as trade secrets. To become valid trade secrets, such ingredients must have an element of novelty and/or nonobviousness and derive value from being secret. The trade-off is a simple extension of the one above for the service firm: does the expected value of developing and using novel trade secrets outweigh the costs, including, importantly, the leakage risk across the service firm's expected future uses? If stronger laws decrease the knowledge leakage risk associated with trade secret use, a firm will expect to appropriate more value out of any investments in developing new secrecy-protected inputs (Teece 1986). The DTSA should again increase secrecy-protected inventive activity through lowering future leakage risk and thereby lead to increased novel trade secret ingredient use.<sup>30</sup> There is one important caveat here: secrecy is generally believed to have a dampening effect on knowledge spillovers (Cohen 2010),<sup>31</sup> which are a key input into invention

(Jaffe 1986, Harhoff 1996, Png 2017b). Thereby, increased use of secrecy might indirectly depress follow-on inventive activity (Gross 2023). However, if, rather than disclosed invention (i.e., patents), the counterfactual is little to no invention and copying of disclosed productive practices, as it is in fracturing (Fetter et al. 2018), there are few spillovers to lose from increased secrecy protection and trade secret use. We, therefore, expect the indirect negative effects relating to spillovers to be muted in our setting.

Last, we consider the relationship between trade secret use and productivity. Productivity linkages are typically difficult to show at a granular level; for instance, researchers have looked at the relationship between patent filings and firm-level returns (Pakes 1985, Bloom and Van Reenen 2002). We link trade secret use and productivity at the well level. Developing IP and protecting it via secrecy involves up-front investment (e.g., R&D) and ongoing costly effort (e.g., confidentiality agreements, electronic protections). Given such added cost, we expect trade secret-protected inputs to provide additional value.<sup>32</sup> Moreover, if trade secrets are protecting valuable IP, their use should be associated with higher productivity on average. The DTSA-related impact on the association between trade secret ingredient use and productivity is more ambiguous for reasons we elaborate below.

## 5. Data

We use data on well fracturing from the Shale Well Database of Rystad Energy. Rystad Energy collects and compiles data on the oil and gas industry from governmental databases and archives, company presentations, and industry reports, and it has been used both by academics (Aguilera 2014, Krane 2017) and policymakers (U.S. Energy Information Administration 2014, Department for Business Energy & Industrial Strategy 2019).<sup>33</sup> Our analytical data set includes data for 47,500 wells fractured from 2014 to 2018.<sup>34</sup> Figure 1 maps our full analytical sample of wells across high- and low-treatment states.

We examine trade secret use, use of novel trade secrets, and productivity outcomes using well-level data. Well-level analyses allow us to account for time-invariant characteristics of involved firms: both the focal service firms that hydraulically fracture the wells and the producer firms that are the customers of the service firms and that own the rights to the oil and/or gas produced. Such analyses also allow us to account for geological formation differences and time-related variance by including well location (basin) and month fixed effects.

## 6. Analyses

To analyze the effect of stronger legal protection on trade secret use and associated novelty, we take a repeated

cross-section, difference-in-differences approach with a well as the unit of analysis (Hong 2013, Sequeira 2016, Cunningham 2021).

The sample includes 46 service firms (such as Schlumberger, Halliburton, and Patterson-UTI) and 461 producer firms (such as EOG Resources, ExxonMobil, and Chevron). An average service firm is associated with 1,033 wells and a producer with 103 wells. Service firms specialize in hydraulic fracturing and bid for projects (well contracts). Their customers (producer firms) allocate projects based on cost, service firm expertise, and other relevant characteristics. Because a producer firm typically works with multiple service provider firms in and across geographic areas, service firms may worry about their trade secrets leaking to competitors via producer firms or (ex-)employees.

### 6.1. Key Dependent Variables

Our dependent variables measure (1) trade secret use and (2) novel trade secret use. Our measures capture the use of trade secret fracturing fluid ingredients.<sup>35</sup>

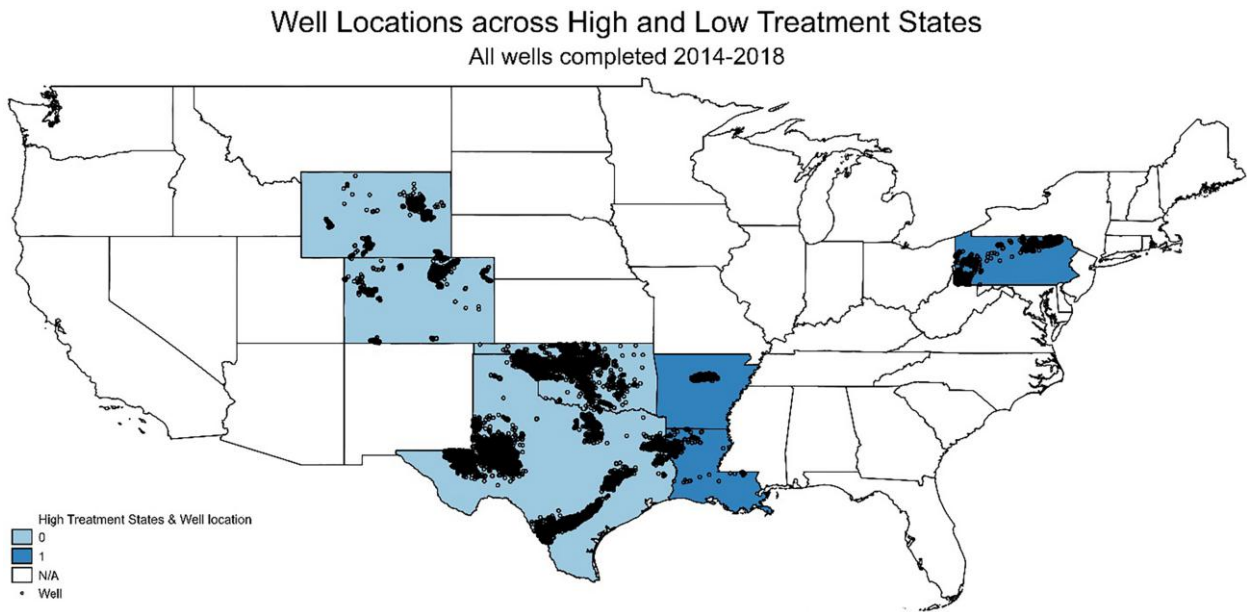
### 6.2. Trade Secret Use

We measure secret use in two ways. First, we use a binary variable indicating whether a well uses any trade secret ingredient (*Trade Secret*). We considered an ingredient a trade secret if both the ingredient name and the Chemical Abstract Service (CAS) number, a generic chemical identifier, are not disclosed. We choose this conservative definition of a trade secret because, for a portion of ingredients, the CAS number is not listed, but the ingredients are easily identifiable from their name (or vice versa) to experts, which contradicts the legal definition of a trade secret.<sup>36</sup>

Second, to ensure that our results do not result from the DTSA increasing the number of ingredients used (and, proportionally, trade secret ingredients), we also include a measure of the *Share of TS ingredients*.

### 6.3. Novel Trade Secret Use

We measure novel trade secret use as an imperfect proxy for secrecy-protected inventive activities. Because trade secret ingredients are necessarily undisclosed and their specific details thereby unobservable to researchers, we must indirectly infer the novelty of trade secrets. However, for both disclosed and trade secret ingredients, firms disclose and, therefore, we can observe the ingredient's chemical purpose category (CPC). Our sample of wells encompasses more than 2,300 disclosed ingredients (e.g., hydrochloric acid, glutaraldehyde, sorbitol tetraoleate, crystalline silica (quartz), potassium metaborate) as well as trade secret ingredients, across 19 CPCs. The 19 CPCs are well-established by the beginning of our study period and remain stable throughout.<sup>37</sup>

**Figure 1.** (Color online) Well Locations

As a first measure, we infer that a trade secret is a new-to-the-firm trade secret ingredient if it is in a CPC in which the service firm has not previously used a trade secret ingredient (*New secret category*).<sup>38</sup> For example, if a firm did not use a trade secret ingredient in the category of acids before July 2016 but did so in that month, this counts as a use of a new secret category in July 2016 (and as zero in any subsequent month). To establish novelty, we use 2013 and 2014 as a look-back window and use 2015–2018 as our years in this analytical sample. Notably, this is a somewhat conservative measure as it is likely (though unobservable) that firms also generate new trade secrets in CPCs in which they already had trade secret ingredients. Further, because the CPCs are relatively broad and, ultimately, we cannot know the content of the trade secrets, our novelty measure cannot capture universal novelty with certainty.<sup>39</sup> New-to-the-firm trade secret ingredients may represent new-to-the-world inventions, or they may represent unknown duplicative efforts. Given that trade secrets are not observable to rival firms, it is impossible even for firms to know if their new trade secret ingredients are new to the world.

We include two additional measures of novel trade secret ingredients leveraging the CPC information. First, we create a measure that captures a *New secret category combination*, that is, the first time a firm uses a secret ingredient from category A and category B together in the same well. Second, we create a measure that uses the number of secret ingredients in a category used in each well and that captures if a well represents an *Additional TS in category*. For example, if a firm has only ever used one buffer trade secret ingredient in a well and then uses

two buffer trade secrets in a well, this counts as an *Additional TS in category*.

#### 6.4. Key Independent Variables

We measure stronger legal protection via a binary variable that takes zero for the months before the DTSA was enacted (i.e., before May 2016) and one thereafter (*Post-DTSA*).<sup>40</sup> We measure heterogeneous treatment based on variations in the pre-DTSA state-level trade secret regime, using an index created by Png (2017a, b). The Png (2017a, b) index consists of six elements of trade secret law: three relating to substantive law (degree of use, protective effort, use/disclosure required for misappropriation), one to civil procedure (time limits for owner to take legal action), and two for remedies (injunction limits, damages multiple). The stronger the protection, the higher the (state-level) Png index.<sup>41</sup> We categorize states into high-treatment states (those that had below median level of trade secret protection prior to DTSA: Arkansas, Louisiana, and Pennsylvania) and low-treatment states (those that had above or equal to median level of trade secret protection prior to DTSA: Colorado, Oklahoma, Texas, and Wyoming).<sup>42</sup> Note that, because we are using repeated cross-sections for our difference-in-differences analyses (Hong 2013, Cunningham 2021), we also investigated if activity moved from low- to high-treatment states post-DTSA, that is, if there is evidence of compositional changes driven by treatment. We find the share of wells across locations remains stable (see Online Appendix D). In addition, whereas we opt for a binary treatment variable, *High-treatment state*, for ease of presentation across our main analyses, we also run the analyses using indicator

variables for each state separately and use a continuous index variable to measure treatment intensity instead of the binary variable (see Online Appendix E). Both provide consistent results. Because lawsuits are tied to the location of trade secret use and misappropriation, we use state-level policies tied to well location.<sup>43</sup>

### 6.5. Control Variables

We include firm fixed effects (for both the service firm and the producer firm) to control for any time-invariant firm characteristics, such as quality or inventiveness, that may also drive use of trade secrets. We also control for the type of well (oil, gas, mixed oil and gas) and the location (basin) in which the well is completed; different output mixes and geological formations may require different inputs and, thus, more (or less) secret ingredients on average. Also, we include month fixed effects (e.g., June 2017) to capture economic and technological factors that may affect secrecy use.<sup>44</sup>

### 6.6. Moderators

We contend that trade secrecy use is driven in part by concerns around knowledge leakage risk and that strengthening of legal protections of trade secrets increases use because it alleviates some of this risk. Therefore, we investigate whether firm response to the DTSA is muted in contexts in which leakage concerns are less acute for reasons relating to other relevant policies, interfirm trust, and/or rival proximity.<sup>45</sup> First, we use the noncompete enforceability (NCE) index of Starr et al. (2021) and separate states into those with *High NCE* and *Low NCE*.<sup>46</sup> As noncompetes restrict the mobility of (former) employees, one key channel of secret loss, we expect that knowledge leakage risk is lower when enforcement is higher. Second, we distinguish the service firm’s customer firms (producers) based on *High customer trust* and *Low customer trust* based on the amount of the service firm’s business the customer represents (with an above-median annual share of business proxying for higher trust). Higher interfirm trust should lead to a lower expectation of knowledge leakage. Third, we examine how the number of proximate

competitors relates to knowledge leakage risk. We denote *Many Rivals* as a binary variable if the number of firms in a county completing wells in the month of completion of the focal well was above the sample median (four firms) and *Few Rivals* otherwise.

### 6.7. Econometric Specification

The main specification is the following:

$$Y_{ijklt} = \beta_1 PostDTSA + \beta_2 HighTreatment + \beta_3 PostDTSA \times HighTreatment + \sigma_i + \omega_j + \theta_k + \lambda_l + \tau_t + \varepsilon_{ijklt},$$

where  $Y_{ijklt}$  represents our well-level dependent variable, *PostDTSA* captures the time period following the passage of the DTSA, *HighTreatment* indicates well location in a state with lower state-level trade secret protection, and *PostDTSA*  $\times$  *HighTreatment* captures the effects of DTSA in states with lower state-level protection (and, thus,  $\beta_3$  is the main coefficient of interest). We include fixed effects for well fracturing month ( $\tau_t$ ), service firm ( $\sigma_i$ ), producer firm ( $\omega_j$ ), well type ( $\theta_k$ ), and location (basin) ( $\lambda_l$ );  $\varepsilon_{ijklt}$  is the error term. We cluster standard errors at the state-level, that is, the level of treatment assignment.<sup>47</sup> For ease of presentation and interpretation, we use linear models throughout.<sup>48</sup>

## 7. Results

Table 1 includes the descriptive statistics at the well level for the entire 2014–2018 sample period. Of 47,500 wells, 56% contain at least one trade secret ingredient. On average, 5% of all ingredients are trade secrets. Also, nearly 1% of wells include new-to-the-firm trade secrets, that is, trade secret ingredients in categories in which the fracturing firm has not previously used a trade secret ingredient.<sup>49</sup>

In addition, we include sample statistics for the main outcome variables pre- and post-DTSA (Table 2). On average, trade secret use increased from 45% to 77% of wells, whereas new secret use rose from 0.4% to 0.8% of wells.

Moving to our main analyses, in Figures 2 and 3, we plot the raw patterns in trade secret use pre- and post-

**Table 1.** Descriptive Statistics: Well Level

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Trade secret (TS) (0/1)	47,500	0.56	0.5	0	1
Share of TS	47,500	0.05	0.08	0	0.75
New TS category (0/1)	30,468	0.01	0.08	0	1
New TS category combination (0/1)	30,468	0.01	0.11	0	1
Additional TS in category (0/1)	30,468	0.01	0.09	0	1
Number of categories	47,500	11.66	2.82	1	19
Number of secret ingredient categories	47,500	1.06	1.51	0	14
Number of disclosed ingredient categories	47,500	10.6	3.1	0	19
New disclosed ingredient (0/1)	30,468	0.07	0.25	0	1
Post-DTSA (0/1)	47,500	0.35	0.48	0	1
Well in high-treatment state (0/1)	47,500	0.11	0.32	0	1

**Table 2.** Descriptive Statistics for Main Dependent Variables Pre- and Post-DTSA by Treatment, Well Level

		Pre-DTSA, %	Post-DTSA, %
<i>Trade secrets</i>	All wells	44.8	76.9
	High treatment	25.2	73.2
	Low treatment	47.4	77.4
<i>Share of TS</i>	All wells	3.8	6.9
	High treatment	2.2	8.4
	Low treatment	4.0	6.8
<i>New TS category</i>	All wells	0.4	0.8
	High treatment	0.1	1.4
	Low treatment	0.4	0.7
<i>New TS category combination</i>	All wells	1.1	1.5
	High treatment	0.5	1.4
	Low treatment	1.2	1.5
<i>Additional TS in category</i>	All wells	0.6	1.0
	High treatment	0.4	1.4
	Low treatment	0.6	0.9

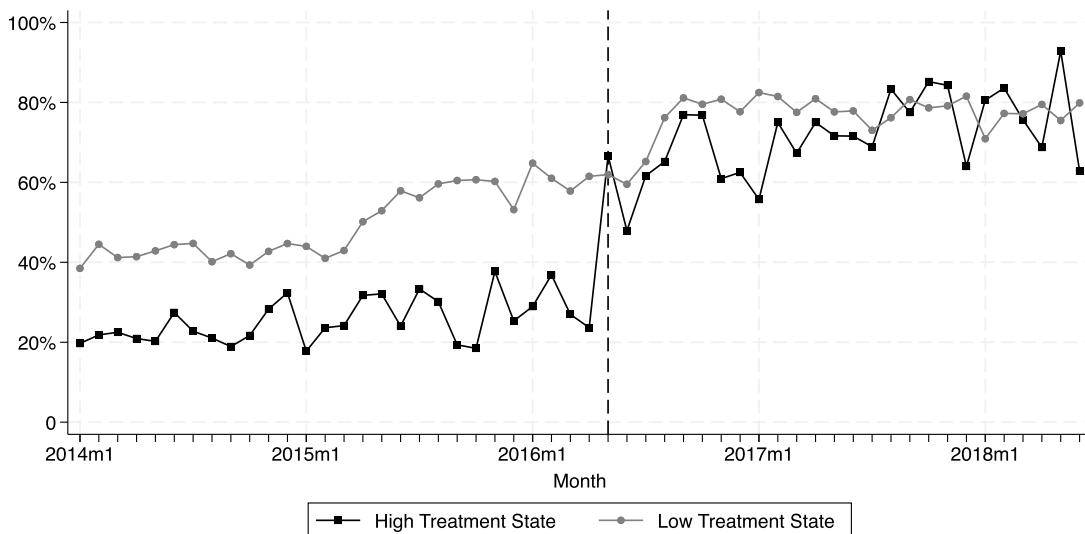
DTSA across high- and low-treatment states. Figure 2 shows the proportion of wells using any trade secret ingredient. In Figure 3, we depict the share of trade secret ingredients used per well. These figures show clear evidence of increases post-DTSA with high-treatment states having a more pronounced increase in the use of any trade secret ingredient (Figure 2) and in the share of trade secret ingredients used (Figure 3).<sup>50</sup> These graphs also highlight similar trends for low- and high-treatment states pre-DTSA.

In Table 3, we depict the effect of increased secrecy protection on the use of trade secret ingredients. First, we investigate whether a well contained any secret ingredient (column (1)). We find that, following the enactment of DTSA, the likelihood of using a trade secret ingredient increases by 22 pp in high-treatment states relative to low-treatment states (over the pre-

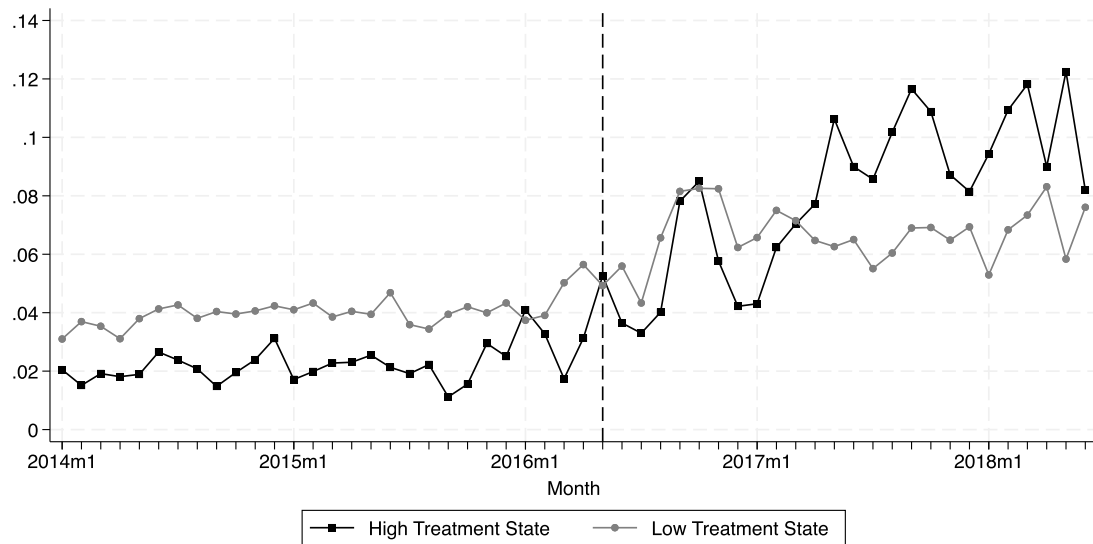
DTSA baseline of 25% in high-treatment states).<sup>51</sup> Second, we find that the share of trade secret ingredients increases in high-treatment states by 3.7 pp relative to low-treatment states (over the baseline of 2.2% in high-treatment states (column (2)). Put simply, trade secret use increases disproportionately. Taken together, these results show that the use of trade secret-protected ingredients increased substantially with increased legal protection.<sup>52</sup>

Next, we study the use of novel trade secret-protected ingredients. As outlined above, because we cannot observe the details of each secret ingredient to know with certainty if it is new to the world, we infer novel trade secret ingredient use via three measures that leverage CPC details and suggest firm-level novelty: *New TS category* (the strictest measure), *New TS category combination*, and *Additional TS in category*.

**Figure 2.** Share of Wells with Trade Secret Ingredients Pre- and Post-DTSA



**Figure 3.** Share of Trade Secret Ingredients per Well Pre- and Post-DTSA



We present these results in columns (3)–(5) (Table 3). Post-DTSA, the likelihood of using a trade secret in a new category increased substantively by 1pp in high-treatment states. Though using a trade secret in a new category is a rare event (0.4% average likelihood pre-DTSA across all states and 0.1% chance in high-treatment states), the 1 pp increase indicates a significant increase with respect to the pre-DTSA baseline. For *New TS category combination*, the likelihood increases by 0.9 pp (from a pre-DTSA average of 0.5% in high-treatment states). For *Additional TS in category*, the likelihood increases by 1.1 pp from 0.4% pre-DTSA in high-treatment states. In sum, we find some indirect support

for an increase in trade secret-protected inventive activities as proxied by increased use of new-to-the-firm trade secret ingredients.

In addition, we examine how knowledge leakage risk conditions the effects of increased legal protection on the likelihood of using trade secret ingredients. We expect trade secret legal protection to have the strongest effects in situations in which firms had previously been more wary of using trade secret ingredients out of heightened fear of knowledge leakage. In Table 4, we find that post-DTSA, high-treatment states with lower NCE have a higher increase in the use of trade secrets (columns (1) and (2)). Notably, the NCE analysis is based

**Table 3.** Trade Secret Use and Stronger Appropriability

	(1) <i>Trade secret</i>	(2) <i>Share of TS</i>	(3) <i>New TS category</i>	(4) <i>New TS category combination</i>	(5) <i>Additional TS in category</i>
High-treatment state	−0.083 (0.076)	−0.014 (0.017)	0.003 (0.007)	0.011* (0.005)	−0.009 (0.009)
Post × High-treatment state	0.220*** (0.032)	0.037** (0.012)	0.010*** (0.002)	0.009** (0.003)	0.011*** (0.002)
Observations	47,500	47,500	30,436	30,436	30,436
R <sup>2</sup>	0.408	0.614	0.110	0.080	0.060
Producer firm fixed effects	Yes	Yes	Yes	Yes	Yes
Service firm fixed effects	Yes	Yes	Yes	Yes	Yes
Well type fixed effects	Yes	Yes	Yes	Yes	Yes
Basin fixed effects	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes

*Notes.* Each column represents a separate regression examining well-level fracturing fluid trade secret use. The dependent variables are indicated at the top of each column: *Trade secret* is a binary variable for whether there are any trade secrets in the well, *Share of TS* is the number of trade secrets over the total number of ingredients, *New TS category* indicates the introduction of a new-to-the-firm category of trade secrets in the well, *New TS category combination* signifies a new combination of trade secret categories used in a well, *Additional TS in category* captures additional trade secrets in a category. High-treatment state refers to the key independent variable of interest in the analysis. Post × High-treatment state is an interaction term between a postperiod indicator (post-DTSA) and the high-treatment state indicator. In columns (3)–(5), the sample is based on the years 2015–2018 because we use 2013 and 2014 as a look-back window to begin identifying novel ingredients for 2015 and subsequent years. Robust standard errors are in parentheses below each coefficient estimate and are clustered at the state level.

Statistical significance levels are denoted as follows: \*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

**Table 4.** Trade Secret Use and Knowledge Leakage Risk: Noncompete Enforcement, Interfirm Relationships, and Rival Location

	(1) <i>Low noncompete enforcement</i>	(2) <i>High noncompete enforcement</i>	(3) <i>Low customer trust</i>	(4) <i>High customer trust</i>	(5) <i>Few rivals</i>	(6) <i>Many rivals</i>
	<i>Trade secret</i>					
High-treatment state	0.391*** (0.010)	−0.091 (0.064)	−0.196*** (0.042)	−0.053 (0.114)	−0.074 (0.072)	−0.058 (0.040)
Post × High-treatment state	0.501*** (0.001)	0.236 (0.101)	0.296*** (0.036)	0.019 (0.058)	0.186*** (0.039)	0.390*** (0.049)
Observations	34,604	12,892	23,690	23,788	19,684	27,762
R <sup>2</sup>	0.407	0.467	0.464	0.491	0.479	0.410
Producer firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Service firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Well type fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Basin fixed effects	No	No	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

*Notes.* The dependent variable for all columns is *Trade Secret*, indicating the presence of any trade secret in the well. Columns (1) and (2) present results on trade secret use under different noncompete enforcement regimes. Columns (3) and (4) present results on trade secret use under different levels of trust with customer firms, captured by a binary variable above and below the median share of business carried out with a particular customer. Columns (5) and (6) present results on trade secret use under different rival levels within a county, captured by a binary variable based on the number of competitor firms contemporaneously operating in the county, split at the median. High-treatment state refers to the key independent variable of interest in the analysis. Post × High-treatment state is an interaction term between a postperiod indicator (post-DTSA) and the high-treatment state indicator. Robust standard errors are provided below each coefficient estimate and are clustered at the state level.

Statistical significance levels are denoted as follows: \*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

off state-level variation and should be interpreted with care. In columns (3) and (4), we show that the results are stronger for wells completed in situations of relatively low trust between service and producer firms. Wells fractured in high-treatment states post-DTSA in lower interfirm trust contexts see a 30 pp increase in trade secret use, whereas wells in higher interfirm trust contexts do not experience such an increase. In other words, these results suggest that stronger legal protections create conditions amenable to using trade secrets even when interfirm relationships may be relatively weak. Finally, in columns (5) and (6), we see that wells in proximity to many rivals are more likely to contain secrets following the passage of DTSA in high-treatment states.<sup>53</sup> Being proximate to many rivals may drive higher use of trade secrets for value-related reasons (i.e., differentiation). However, we find that having many nearby rivals is only associated with increased trade secret use post-DTSA (see Online Appendix M), and this is consistent with the logic of decreased knowledge leakage risk. Collectively, the Table 4 results are consistent with stronger legal protection attenuating knowledge leakage concerns.

### 7.1. Alternative Explanations

We now turn to investigating alternative explanations for our results.

One main concern is that, instead of measuring increased use of trade secret-protected IP, we are capturing relabeling effects, that is, firms are labeling previously disclosed ingredients as trade secret. Given that

the details of trade secret ingredients remain secret to us, we cannot investigate this possibility directly. However, we consider it unlikely for several qualitative reasons and because of wide-ranging indirect evidence inconsistent with relabeling.

First, it is not clear why incentives for relabeling would increase discretely in May 2016 and be particularly focused in states with lower pre-DTSA protection and, thus, explain our results. Second, and more generally, firms can only legally defend trade secrets if the inventions have not been previously disclosed and are not publicly known (Johnson 2021). We expect this argument against relabeling to apply particularly strongly in our sample states, where firms incur costs in claiming trade secrets (including a high-ranking employee, typically head of engineering, signing a document that the trade secret ingredients have not previously been disclosed).<sup>54</sup> Third, given the disclosure requirements in our setting, we assume that competitors would be able to infer the relabeled “secret” ingredients from previously disclosed recipes. Fourth, additional analyses suggest overall changes of the well-level recipes that contradict relabeling explanations. Specifically, there was an increase in the number of trade secret ingredient categories with no significant change in the number of disclosed ingredient categories used by wells in high-treatment states (Table 5, columns (2) and (3)). Further, the likelihood of using a new disclosed ingredient increases rather than decreases (Table 5, column (4)).<sup>55</sup> Fifth, service firms increase their external sourcing of trade secret ingredients (i.e., from third party chemical

**Table 5.** Recipe Changes Post-DTSA

	(1) <i>Number of categories</i>	(2) <i>Number of secret categories</i>	(3) <i>Number of nonsecret categories</i>	(4) <i>New disclosed ingredient</i>
High-treatment state	−1.526** (0.454)	−0.417 (0.368)	−1.109*** (0.199)	−0.008 (0.007)
Post × High-treatment state	0.760* (0.324)	1.154** (0.372)	−0.394 (0.646)	0.022** (0.008)
Observations	47,500	47,500	47,500	30,436
R <sup>2</sup>	0.601	0.388	0.575	0.126
Producer firm fixed effects	Yes	Yes	Yes	Yes
Service firm fixed effects	Yes	Yes	Yes	Yes
Well type fixed effects	Yes	Yes	Yes	Yes
Basin fixed effects	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes

*Notes.* This table presents an analysis of overall recipe changes. The dependent variables are described as follows: *Number of categories* indicates all distinct categories of ingredients present in a well, *Number of TS categories* represents the distinct categories of ingredients that are trade secrets, *Number of disclosed categories* represents the distinct categories with no trade secret ingredients, and *New disclosed ingredient* represents the introduction of a new-to-the-firm ingredient that is not kept as a trade secret. High-treatment state refers to the key independent variable of interest in the analysis. Post × High-treatment state is an interaction term between a postperiod indicator and the high-treatment state indicator. Robust standard errors are provided below each coefficient estimate and are clustered at the state level.

Statistical significance levels are denoted as follows: \*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

providers), which, again, is not consistent with relabeling.<sup>56</sup> Sixth, our analyses of productivity associations (see below) suggest that recipes with trade secrets are, on average, more productive than those without, suggestive of meaningful differences inconsistent with relabeling. In sum, the legal landscape of trade secret protection, the disclosure environment in our context, the requirements to claim trade secrets in our sample, and the broader findings of changes in fracturing fluid composition all fail to support the conjecture that firms' increased use of trade secrets is relabeling of previously disclosed ingredients.

A second alternative explanation is potential IP substitution. In other words, the strengthening of trade secrecy protection may cause firms to switch from protecting their fracturing fluid-related IP (for instance, via patenting) to protecting it via secrecy.

Two sets of analyses suggest that substitution is not driving our results. First, we find no evidence of decreases in new disclosed ingredient use (Table 5). Instead, our results are consistent with complementarity between disclosed and trade secret-protected innovation. Second, to explore the potential of IP substitution further, we examine patterns in the relationship between the DTSA, associated increases in trade secret use, and firm-level patenting. It is important to note that most firms in our sample patent relatively little, either before or after the DTSA, which makes it doubtful that patent-related IP substitution drives our results. However, to investigate patenting more directly, we examined the relationship between fracturing-related patenting (Kapoor and Murmann 2024) and trade secret ingredient use at the firm-month level, pre- and post-DTSA (see Online Appendix H). Whereas the analyses are descriptive associations, we find no evidence of a negative relationship between the firm patenting—whether we count

all fracturing-related patents or just those covering chemicals (those most narrowly related to fracturing fluid ingredients)—and trade secret use. Further, we see larger increases in secrecy use post-DTSA among patenting firms, suggesting that our results are not because of firms changing IP protection type (i.e., IP substitution).

A third alternative explanation, given the environmental and policy stakeholder attention to the industry (Osborn et al. 2011), is that a firm's use of secrecy is driven not by protecting IP but instead by trying to conceal bad behavior, that is, the use of environmentally damaging and toxic ingredients. We cannot directly observe if secret ingredients are more toxic than those disclosed as such information is, by definition, secret. However, to examine this third alternative explanation, we explored patterns in the toxicity of disclosed ingredients. To do so, we use the Environmental Protection Agency Toxics Release Inventory list of toxic chemicals to identify toxic fracturing ingredients as well as the subset of toxic ingredients that are environmental pollutants. We link these lists into our data using CAS number, which is a unique numerical identifier for chemical substances and is available for all disclosed ingredients. Across our sample, 98.8% of wells had at least one disclosed toxic chemical, which suggests both pervasive and publicly disclosed use of toxic ingredients. Further, on average, six disclosed ingredients per well are toxic, and there is no difference across wells with and without trade secret ingredients. We ran regressions to explore if there is evidence that firms that use trade secret ingredients post-DTSA in high-treatment states decrease their relative use of disclosed toxic (or pollutant) ingredients. The results (in Online Appendix I) show no evidence of relative changes in line with cloaking. In other words, toxic ingredients are commonly and intensely used and similarly disclosed across

wells with and without secret ingredients, and this pattern does not change with stronger secrecy protection. We also see no evidence of post-DTSA increases in court cases relating to fracturing toxicity and damages in high-treatment states (Online Appendix I), further supporting our contention that increases in trade secrets are not merely directed toward cloaking toxic ingredients.

## 7.2. Decomposing the Post-DTSA Period

Next, we explore if there is any evidence of potentially decreased opportunities for knowledge spillovers across firms post-DTSA. To do so, we decompose our post-DTSA indicator variable into four six-month periods (e.g., July–December 2016, January–June 2017, etc.). If a general increase in secrecy curtailed knowledge spillovers, we might expect to see some decreases over time. Yet we find that increases persist in high-treatment states, suggesting that spillover-related constraints are not (or at least not yet) binding (Table 6).<sup>57</sup> In terms of novel trade secrets, in high-treatment states, firms use new trade secret ingredients more after about a year post-DTSA, which suggests some ramp-up is needed postpolicy to invent and use new ingredients. This lag also provides additional corroborating evidence that our novel trade secret use analysis implies increased secrecy-protected inventive activity rather than relabeling or copying. Overall, these additional analyses show little evidence of negative effects of reduced spillovers emerging during our study period.

## 7.3. Trade Secret Use and Productivity

Finally, we investigate the association between trade secret use and well productivity. In general, a service firm's ability to obtain lucrative contracts with a producer firm depends on its ability to demonstrate value, that is, to extract more oil and/or gas for the producer. We argue that hydraulic fracturing firms choose to develop and use trade secret ingredients if they result in higher well productivity and depending on whether they can keep their trade secrets protected (Png 2017b). Alternatively, they may use more commonly known, non-trade-secret ingredients.

In this section, we explore the relationship between trade secret use and well productivity. If trade secret ingredients provide value, we should, on average, see a positive association between trade secret use and well productivity. However, it is not ex ante clear whether the DTSA-induced use of trade secrets is associated with increased productivity. On the one hand, if we assume that firms trade off the value from use against the risks of leakage in deciding when to use trade secret ingredients, we might expect trade secrets to be used when they are most productive pre-DTSA. Following this logic, when the risk of leakage decreases post-DTSA, the productivity bar for use would also decrease. Thus, productivity post-DTSA would be lower compared with pre-DTSA wells using trade secrets on average. On the other hand, if the pre-DTSA leakage risk is strong, firms may decide to use their valuable trade

**Table 6.** Trade Secret Use and Novelty: Decomposing the Post-DTSA Effect

	(1) <i>Trade secret</i>	(2) <i>Share of TS</i>	(3) <i>New TS category</i>	(4) <i>New TS category combination</i>	(5) <i>Additional TS in category</i>
High-treatment state	−0.080 (0.075)	−0.013 (0.017)	0.003 (0.007)	0.012* (0.005)	−0.009 (0.009)
Post 1 × High-treatment state	0.206** (0.076)	0.016** (0.005)	0.018 (0.010)	0.006 (0.004)	0.008 (0.006)
Post 2 × High-treatment state	0.157** (0.057)	0.031** (0.011)	0.002 (0.007)	0.001 (0.003)	0.011*** (0.002)
Post 3 × High-treatment state	0.232*** (0.039)	0.046** (0.018)	0.008** (0.003)	0.012*** (0.003)	0.011** (0.004)
Post 4 × High-treatment state	0.292*** (0.026)	0.054*** (0.013)	0.011*** (0.003)	0.014** (0.004)	0.016*** (0.003)
Observations	47,500	47,500	30,436	30,436	30,436
R <sup>2</sup>	0.408	0.615	0.110	0.080	0.060
Producer firm fixed effects	Yes	Yes	Yes	Yes	Yes
Service firm fixed effects	Yes	Yes	Yes	Yes	Yes
Well type fixed effects	Yes	Yes	Yes	Yes	Yes
Basin fixed effects	Yes	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes	Yes

*Notes.* This table decomposes the post-DTSA effect on trade secret use and novelty over distinct six-month periods. Each column represents a distinct regression. The dependent variables are the same as in Table 3: *Trade secret* captures the utilization of trade secrets, *New TS category* signifies the introduction of novel categories of trade secrets, *New TS category* indicates the introduction of a new-to-the-firm category of trade secrets in the well, *New TS category combination* signifies a new combination of trade secret categories used in a well, *Additional TS in category* captures additional trade secrets in a category. The series of post-DTSA variables (columns (1)–(4)) represent the effects in successive six-month periods after the introduction of the DTSA. High-treatment state is the key independent variable of interest in the analysis, and the interaction terms between post and high-treatment state capture the differential effects of the DTSA in high-treatment states over time. Robust standard errors are provided below each coefficient estimate and are clustered at the state level.

Statistical significance levels are denoted as follows: \*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

secret ingredients very rarely. The logic here is that leakage would destroy any secrecy-dependent value associated with future use, and the future value of trade secrets is higher for more productive inputs. Simply put, leakage risk might crowd out the short-term value of use in low-protection regimes. In such cases, trade secret-linked productivity may rise following the passage of the DTSA. In addition, beyond changes to use, firms may respond to increased secrecy protection by experimenting with and developing new ingredients, which may or may not translate into increased productivity, especially over the short term. Collectively, these arguments suggest that the expected effect of the DTSA on the association between trade secrets and productivity is ambiguous. Therefore, we treat it as an empirical question.

To investigate these relationships, we first compare the productivity of wells that have a trade secret ingredient with those without. We use standard industry productivity measures: average daily production in the first 30 days of the well's productive life, also referred to as initial production in the first 30 days (or IP30), measured in barrels for oil and in thousands of cubic feet for gas. Figure 4 shows that, on average, use of trade secret ingredients is associated with a 26% increase in production of oil and 6% in production of gas.<sup>58</sup>

Tables 7 and 8 include regression results for the relationship between use of trade secret fracturing fluid ingredients and well productivity, including DTSA-associated effects. The simple correlations (column (1))

suggest that wells with trade secret ingredients produce roughly an additional 96 barrels of oil and 135,000 cubic feet of gas per day in the first 30 days.<sup>59</sup>

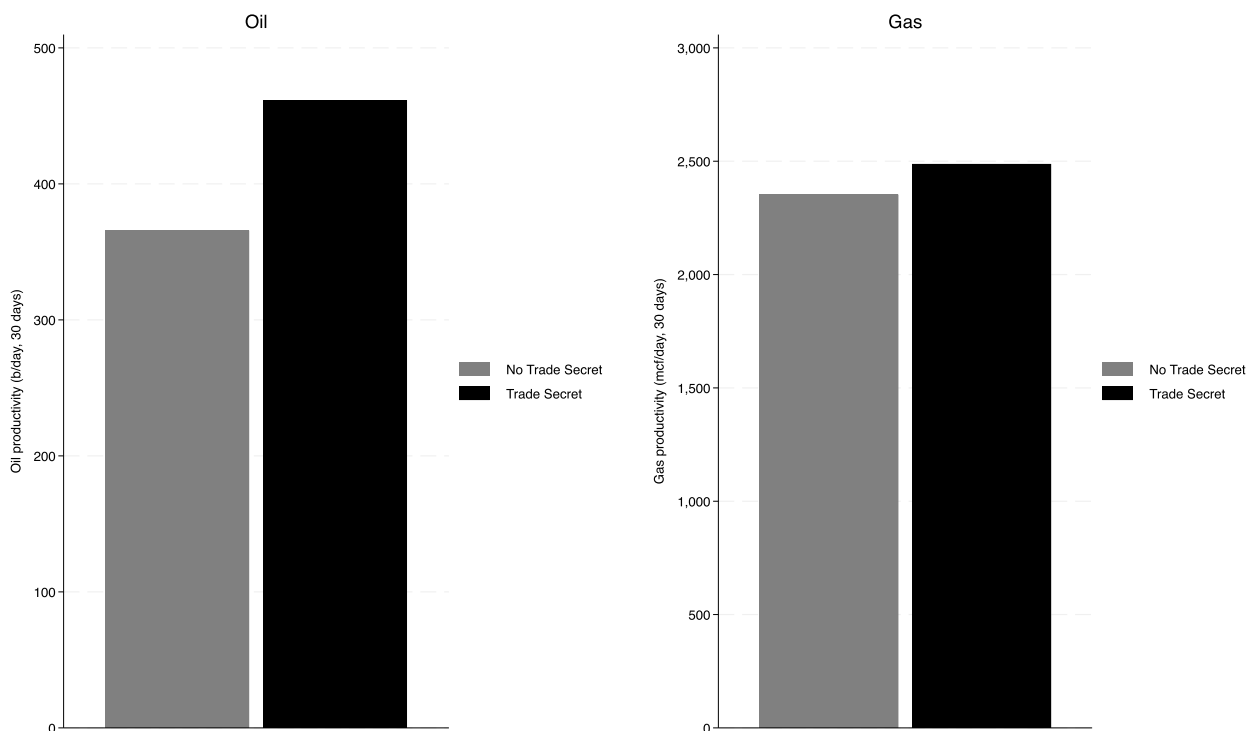
Table 7 includes results for oil productivity. In regressions that include service firm, producer firm, basin, well type, and time fixed effects, the statistical significance of the trade secret-productivity association decreases (column (2)) but it remains positive post-DTSA (column (3)). If we split the post-DTSA period into six-month periods, we find that the surge is largest in the initial period, possibly as firms find the most fruitful opportunities to repurpose their existing trade secrets. The magnitude of the coefficients drops and then rises again toward the end of our observation period, which would be consistent with novel trade secrets (as per Table 6) being introduced into wells successfully. However, the coefficients are not statistically significant.

Table 8 includes results for gas productivity. The raw correlation between the well using a trade secret and gas productivity in the whole sample is positive. Further, we cannot conclude that the DTSA is associated with an increase in trade secret-driven well productivity in gas.<sup>60</sup>

## 8. Discussion and Conclusion

Trade secrets are highly valuable to firms and the economy. Thus, understanding secrecy-protected IP and how different legal protection regimes alter it is important in understanding firm performance and economic

Figure 4. Average Well Productivity (30-Day Output), TS and Non-TS Wells



**Table 7.** Trade Secret Use Post-DTSA and Average Daily Oil Production, bbl (IP30)

	Oil IP30			
	(1)	(2)	(3)	(4)
	No fixed effects	Full fixed effects		
Trade secret	95.821*** (3.932)	12.436*** (3.729)	−0.920 (14.217)	1.928 (14.363)
Post × Trade secret			45.950* (19.723)	
Post 1 × Trade secret				60.620* (27.313)
Post 2 × Trade secret				33.608 (23.912)
Post 3 × Trade secret				15.246 (23.961)
Post 4 × Trade secret				50.940 (30.724)
Observations	42,031	42,025	42,025	42,025
R <sup>2</sup>	0.013	0.494	0.494	0.494
Producer firm fixed effects	No	Yes	Yes	Yes
Service firm fixed effects	No	Yes	Yes	Yes
Well type fixed effects	No	Yes	Yes	Yes
Basin fixed effects	No	Yes	Yes	Yes
Month fixed effects	No	Yes	Yes	Yes

*Notes.* This table investigates the association between trade secret use post-DTSA and well productivity in barrels of oil. We use a standard industry productivity measure, namely, average daily production in the first 30 days of the well's productive life, also referred to as initial production in the first 30 days (IP30 as a shorthand) in barrels of oil. Each column represents a distinct regression. Column (1) includes no fixed effects, columns (2)–(4) include the full suite of fixed effects. The series of post-DTSA variables (columns (1)–(4)) represent the effects in successive six-month periods after the introduction of the DTSA. Robust standard errors are provided below each coefficient estimate and are clustered at the state level in columns (3) and (4) in which DTSA treatment is applied.

Statistical significance levels are denoted as follows: \*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

**Table 8.** Trade Secret Use Post-DTSA and Average Daily Gas Production, mcf (IP30)

	Gas IP30			
	(1)	(2)	(3)	(4)
	No fixed effects	Full fixed effects		
Trade secret	135.259*** (36.974)	53.594* (30.843)	108.260 (138.254)	112.026 (135.045)
Post × Trade secret			−187.361 (216.242)	
Post 1 × Trade secret				−108.817 (129.656)
Post 2 × Trade secret				−329.521 (322.877)
Post 3 × Trade secret				19.430 (94.394)
Post 4 × Trade secret				−462.608 (413.719)
Observations	46,791	46,783	46,783	46,783
R <sup>2</sup>	0.000	0.642	0.642	0.642
Producer firm fixed effects	No	Yes	Yes	Yes
Service firm fixed effects	No	Yes	Yes	Yes
Well type fixed effects	No	Yes	Yes	Yes
Basin fixed effects	No	Yes	Yes	Yes
Month fixed effects	No	Yes	Yes	Yes

*Notes.* This table investigates the association between trade secret use post-DTSA and well productivity in thousands of cubic feet of gas. We use a standard industry productivity measure, namely, average daily production in the first 30 days of the well's productive life, also referred to as initial production in the first 30 days (IP30 as a shorthand) in thousands of cubic feet of gas (mcf). Each column represents a distinct regression. Column (1) includes no fixed effects, columns (2)–(4) include the full suite of fixed effects. The series of post-DTSA variables (columns (1)–(4)) represent the effects in successive six-month periods after the introduction of the DTSA. Robust standard errors are provided below each coefficient estimate and are clustered at the state level in columns (3) and (4) in which DTSA treatment is applied.

Statistical significance levels are denoted as follows: \*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

growth. In this paper, we investigate when firms use this prevalent but understudied mode of IP protection. In the hydraulic fracturing context, we find not only that the use of fracturing fluid ingredient trade secrets is pervasive, as survey-based research suggests (Levin et al. 1987, Cohen et al. 2000, Hussinger 2006, Sofka et al. 2018, Veugelers and Schneider 2018), but also that the use of trade secrets and introduction of novel trade secrets responds to trade secret policy.

Stronger trade secret policies spur an increase in the use of trade secrets both across and within projects (in our setting, wells). Also, firms increase their use of novel trade secret ingredients, which provides some indirect evidence for an increase in secrecy-protected inventive activity. At the same time, firms do not decrease their use of disclosed novel ingredients or their fracturing-related patenting. Hence, this paper augments existing research on the indirect effects of trade secrecy policy on R&D and patenting—which has implied that secrecy protection may lead to fewer disclosed inventive outputs—as well as other innovation-related outcomes such as mergers and acquisitions (Castellaneta et al. 2017; Png 2017a, b; Contigiani et al. 2018). Our findings not only provide a first systematic and detailed empirical analysis of trade secret use but also provide additional nuance to literature focused on patents-as-invention. In particular, the results appear to show that stronger trade secret protection enables experimentation, including novel recipes, broader sourcing, and a higher likelihood of novel (to the firm) disclosed inputs. The last result may suggest mild complementarity between secrecy and disclosure rather than IP substitution, consistent with evidence at the product level (Crass et al. 2019).

We focus our main analyses at the fracturing fluid ingredient level both for pragmatic reasons (i.e., they are the trade secrets we observe) and because fracturing ingredients are important for productivity (Fetter et al. 2018). Our empirical results suggest fracturing fluid recipe composition changes and complexity appears to increase with trade secret protection as well (e.g., Table 5; Online Appendix N). As in other recipes and formulas, fracturing fluid ingredients interact with one another. It is, thus, not surprising that increased use of trade secrets leads to more complex recipes. These findings may also imply more follow-on innovation-related impacts of increased trade secrecy protection; however, we leave full investigation of these relationships to future research.

Our study has several limitations. First, whereas we can see trade secret use and see information about the purpose of the related ingredient, we still are unable to observe what exactly is kept secret. Hence, we must infer new secrecy-protected invention indirectly. Ultimately, without knowing the substance of the secret (which is highly unlikely given that trade secrets enjoy potentially perpetual protection, conditional on nondisclosure) and

without access to the corpus of all trade secrets that predate a given trade secret, such limitations are unavoidable. Second, we are focused on just one industry, and it has features that likely lead to relatively high levels of secrecy use. As such, our findings are likely most generalizable to similar settings with features that support the use of secrecy. These include settings in which the risk of reverse-engineering is relatively low (e.g., algorithms, chemical compounds, perfumes, plastics, production processes), in which the pace of technological change is relatively quick, or in which patenting is not the sole or default IP protection mechanism. Third, even though we can observe trade secret use, we are limited to one type of trade secret, that is, fracturing fluid ingredients. We, therefore, cannot examine the full patterns of secrecy use in hydraulic fracturing (e.g., processes, techniques). Fourth, whereas we find suggestive evidence of an increase in secrecy-protected inventive activity—the use of novel trade secret-protected ingredients—following increased trade secrecy protections, we observe a relatively short period following the change in policy. This short postpolicy window limits our ability to detect any potential decreased knowledge spillovers that may emerge over the longer term as secrecy use increases. Furthermore, we cannot measure spillovers. However, because spillovers are unobservable, even patent measures using citation patterns are indirect and error prone (Arora et al. 2018); moreover, unintended, market-unmediated spillovers are likely overestimated in the literature (Arqué-Castells and Spulber 2022, Fadeev 2023). Last, we focus on the use of trade secrets and secrecy-protected inventive activity. Building on this work, future research may explore substitution or complementarities of secrecy with other IP protection methods, such as patents or trademarks.

In sum, we show that stronger trade secret protection increases firms' secrecy use, and we provide some suggestive evidence that secrecy-protected inventive activity also increases without a measurable decrease in disclosed inventive activity. Our results highlight the importance of studying various forms of intellectual property protection because of their ubiquitous use in and value for organizations.

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## Endnotes

<sup>1</sup> We define appropriability following the definition used by Teece (1986, p. 287) and others (Cohen 2010): “A regime of appropriability refers to the environmental factors... that govern an innovator’s ability to capture the profits generated by an innovation.”

<sup>2</sup> Surveyed firms named secrecy as the most common and effective IP protection tool in oil and gas (or petroleum) and chemical industries as well as in many other U.S. industries: food, textiles, paper, rubber and plastics, mineral products, metals, machine tools, electrical equipment, motors and generators, semiconductors, and search and navigation instruments (Cohen et al. 2000).

<sup>3</sup> The states with disclosure requirements and notable fracturing activity as of 2014 (the beginning of our study period) were Alabama, Arkansas, California, Colorado, Indiana, Louisiana, Michigan, Mississippi, Montana, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, Utah, West Virginia, and Wyoming. Our sample consists of Arkansas, Colorado, Louisiana, Oklahoma, Pennsylvania, Texas, and Wyoming as they also have requirements for claiming trade secrecy.

<sup>4</sup> Note that justification involves attesting that the ingredient is a trade secret and that it is commercially valuable in being held secret among other features (more details in context section). Arkansas, Colorado, Pennsylvania, and Wyoming require both formal submission and chemical family disclosure of the secret to regulators, whereas Louisiana, Oklahoma, and Texas require chemical family disclosure.

<sup>5</sup> Specifically, for each well, we have a list of all ingredients, their category of purpose, and the specific ingredient name (if said ingredient is not a trade secret). For example, well ID 05-077-10201-0000 has 34 listed ingredients: 32 of them are fully disclosed (ingredient name listed as, for example, acetophenone, water), and two of them are trade secret. Notably, we know that both trade secret ingredients are in the friction reducer category. We do not and cannot know the content of the trade secret. We use the category of ingredients to build several of our measures of novel trade secret use.

<sup>6</sup> The primary definition of trade secrets in the U.S. during the period of our study is based on the UTSA (1985): information, including a formula, pattern, compilation, program, device, method, technique, or process that (a) derives independent economic value, actual or potential, from not being generally known to and not being readily ascertainable by proper means by other persons who can obtain economic value from its disclosure or use and (b) is the subject of efforts that are reasonable under the circumstances to maintain its secrecy.

<sup>7</sup> Inventions are novel, uncertain ideas, processes, methods, or objects that satisfy a given need (Kline and Rosenberg 1985, Arthur 2007, Giuri et al. 2007).

<sup>8</sup> The lack of a need for governmental approval of trade secrets also means there is no registry and thereby (unfortunately for researchers) no database of trade secrets.

<sup>9</sup> The current limit on patent monopoly is generally a 20-year term from the filing date of the application. Copyrights are generally

limited to the life of the author plus an additional term. For instance, in the United States and most countries in Europe, the additional term is 70 years.

<sup>10</sup> As per the UTSA, “Trade secret... derives independent *economic value*, actual or potential, *from not being generally known* [emphasis added] to, and not being readily ascertainable by proper means by, other persons who can obtain economic value from its disclosure or use.”

<sup>11</sup> Taken to its extreme, this complementarity may mean that trade secrets are not valuable on their own but only through their use with related resources and/or capabilities. In such cases, leakage of the secret alone may be less material.

<sup>12</sup> An illustrative example: Chocolatier Mars “designs and builds its candy-making equipment within the company so outsiders never see the full process, and it blindfolds outside contractors coming in to make repairs” (Snyder and Almeling 2012, p. 25). Notably, NDAs are used ubiquitously when dealing with trade secrets in the oil and gas industry (Tosto and Nuttall 2012).

<sup>13</sup> See <https://casetext.com/case/wyeth-v-natural-biologies>.

<sup>14</sup> See <https://www.bloomberg.com/news/articles/2023-05-02/samsung-bans-chatgpt-and-other-generative-ai-use-by-staff-after-leak>.

<sup>15</sup> Scholars point to examples suggesting that secrecy is one of the most effective forms of IP protection. Teece (1986) argues that Coca Cola’s secret recipe exemplifies strong IP protected via secrecy.

<sup>16</sup> The Uniform Trade Secrets Act (passed in 1979 and amended in 1985) was intended to introduce a common set of rules for what constitutes trade secrets, their misappropriation, and associated penalties across the United States. States remained free to adopt selected parts of the act and did so to varying degrees and at different times, a fact helpful for identifying effects both in our study and prior research (see Png 2017a, b). Pre-UTSA, trade secrets were governed only by common law, which varied substantially across states.

<sup>17</sup> Monthly import/export data is available (as of March 2025) through the U.S. Energy Information Administration: <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=mtntus2&f=m>.

<sup>18</sup> Based on our literature review, interviews, and manual review of hundreds of disclosure forms, hydraulic fracturing service firms specialize in designing and applying fracturing fluids and are, thus, required to disclose them to the regulators. Our data include a service firm for each well in the sample. The forms are typically filled out by an engineer overseeing chemical compositions of the service provider. In a request for disclosure exemption because of a trade secret, the signer usually must ascertain, under penalties of perjury, that the information provided is true, correct, and complete. Authorities may carry out inspections on site to check that all fluid ingredients used in a well were reported.

<sup>19</sup> Justification typically includes firms attesting to the following: the information has not been disclosed beyond those outside of strict confidentiality, disclosure would cause substantial harm to the competitive position of the company, no federal or state law requires the information to be made public, and the chemical identity is not readily discoverable.

<sup>20</sup> We investigate if there is any evidence of firms using secrecy to conceal harmful behavior using measures of chemical toxicity and find nearly all wells in our sample contain toxic ingredients (98.8%), and the likelihood and amount of toxic ingredients is the same whether the well includes trade secret ingredients or not (details in Online Appendix I).

<sup>21</sup> We use the enactment date of the legislation (May 2016) as it is the relevant date for firm secret activity, after which trade secrets were more likely to be protected. The act was first presented in the House of Representatives and the Senate on July 29, 2015; however, the data suggest little change to trade secret use preenactment.

<sup>22</sup> Notably, federal district court trade secret litigation increased by 30% following the enactment of the DTSA. See Online Appendix P for an account of trade secret–related court cases following the DTSA.

<sup>23</sup> See Online Appendix O for a description of the Png index values used in this paper.

<sup>24</sup> We exploit a uniform federal policy change applied to heterogeneous preexisting state-level policies. This approach is in line with other research that uses the introduction of Medicare to assess how health insurance affects hospital spending across states with varying preexisting coverage (Finkelstein 2007).

<sup>25</sup> Service firms may use their own ingredients (including trade secrets) or ingredients sourced from third-party supplier firms. We include details on externally sourced ingredients and trade secret ingredients in Online Appendix N. We assume the trade-off between value and leakage risk follows the same general logic when using externally sourced ingredients.

<sup>26</sup> Recall that legal trade secret protection is available only if the information is not generally known. Besides the legal repercussions of losing a trade secret, knowledge leakage implies rivals can reach competitive parity with little investment.

<sup>27</sup> The costs of losing a fracturing-related trade secret are potentially quite high (Bell et al. 2025b). For instance, the damages associated with misappropriating fracturing-related secrets were assessed at \$15 million and \$25 million in two recent cases (see Online Appendix Q for details). Such damages include loss of competitive advantages and related R&D expenditure.

<sup>28</sup> Firms protect secrets using both prevention (e.g., contracts, locks, etc.) and retribution (e.g., legal action). The policy change affects the latter directly by making misappropriation more costly and less likely. If prevention is the main mode of protection, the change in law may have limited effect on secrecy use and invention. However, if misappropriation risks matter, the legal change should have detectable effects.

<sup>29</sup> This logic was articulated to us in an interview with the CEO of a hydraulic fracturing firm. Whereas it is predictably difficult to interview firms about their trade secrets, we were able to interview the CEO of one of the service provider companies in our sample. Our reasoning for knowledge leakage considerations is congruent with concerns he raised: “The people, the movement between companies is always an issue. And the other issue is we’re not working in a secure environment. You can go on to a pad and probably obtain a sample of a chemical per se, or the customer may obtain a sample of the chemical and give it to another service provider to say, ‘Hey, can you figure this out? Because we’re paying a lot for this. And if you could find something as good for cheaper, we’ll use that instead.’ And, unfortunately, our customers, they play the game very well. They’re continuously encouraging us to compete against each other whether it’s done on the up and up or not. Right? So, for the most part, our worries are having to report and our customers giving our competitors the information... we tend to avoid the, ‘Hey, we’ll work for this customer for three months.’ Then, when that project’s done, it’s up for grabs because that’s a real potential for everything that we learned from an efficiency perspective, that customer is going to give to the next service provider. And so that’s a real issue. ... whether we like it or not, our trade secrets are constantly getting passed around.”

<sup>30</sup> We observe trade secret use. We do not observe any novel trade secret–protected inventions that go unused. Further, as described in more detail in the empirics, we can only observe novelty as new-to-the-firm categories or types of ingredients.

<sup>31</sup> “Of all the appropriability mechanisms, secrecy entails the clearest suppression of knowledge flows and thus its use may entail the sharpest trade-off between the appropriability incentive effect on

R&D versus the complementarity and efficiency benefits of spillovers, pitting the private incentives of firms most clearly against the innovative performance of an industry as a whole” (Cohen 2010, p. 191).

<sup>32</sup> A senior engineer who files trade secret claim forms with various state authorities for Halliburton, a large service firm, was interviewed about the use of fracturing fluids by a professor at Oklahoma University. When asked about the need to rely on proprietary knowledge, she said, “As in any industry, there are things that each company has that provides them a competitive advantage. That is what is deemed to be proprietary information. The company invests millions and millions of dollars to develop this and to bring this formulation to the operators. It allows them [the service firm] to get a leg up on their competition. If the proprietary information was made available, then the competition [of the service firm] would be able to take that and reverse engineer it. In a very short order, it would negate our investment in all our research and technology development, and it is millions every year. That would stifle our company to bring more innovative products to the marketplace down the road to solve other problems. Because, if we’re losing our competitive advantage, there’s no reason for us to have that.” The interview is available via University of Oklahoma here: <https://www.youtube.com/watch?v=BWw1VVXcH2Q&t=398s>.

<sup>33</sup> Further, we compared Rystad’s data with DrillingInfo (Enverus), a widely used database for well production, and found that Rystad data contained around 98.2% of the number of wells captured by DrillingInfo for the same period in the selected states.

<sup>34</sup> For our measure of new secrets, we use wells from 2013 and 2014 as reference and start our analyses in 2015 (described in more detail in the sections below). Note that 47,500 wells are the sample used in regressions with our full suite of fixed effects (service firm, producer firm, basin, well type, and month) from the full sample of 47,617.

<sup>35</sup> We, unfortunately, cannot observe use of other types of trade secret inputs, which may also change following the policy changes and may also affect well- and firm-level outcomes.

<sup>36</sup> For instance, per our measure, an ingredient listed as “crystalline silica,” which is commonly understood as sand, would not be recorded as secret, but “proprietary” or “trade secret” would be recorded as a secret even if all omitted the CAS number. As such, we are measuring secrets more strictly relative to some previous research. Please see Online Appendix C for a discussion of our measure and analyses using a measure based only on the CAS number, following Korschnik and Dayalu (2016). The results are qualitatively similar using either measure although the CAS number–based results are not significant in certain specifications.

<sup>37</sup> They are detailed in Online Appendix L.

<sup>38</sup> This measure is, therefore, likely undercounting new-to-the-firm trade secrets as we cannot know if secrets in existing categories are new or existing ingredients.

<sup>39</sup> The measure captures new-to-the-firm secret categories. As such, it is a high bar for novelty at the firm level but does not necessarily capture new-to-the-world type inventions (which would be impossible to identify for trade secrets). It also favors firms that a priori had secrets in relatively few categories. For larger firms or firms that had existing trade secrets across many categories, this measure fails to detect novelty. However, given that we cannot see the precise content of trade secret ingredients, exploiting categories at least allows some measure of new-to-the-firm trade secret use, which provides some indirect evidence of secrecy-protected inventive activity.

<sup>40</sup> The DTSA received bipartisan support. One concern may be that firms in our sample (and especially those in high-treatment states) drove the passage of the DTSA, that is, they lobbied the government

into passing the law. We think this concern is minimal for several reasons. First, the DTSA is a federal-level legislation. Second, in the oil and gas industry, the primary lobbying firms are large integrated companies, whereas the bulk of firms we study are specialist oilfield service providers. Third, lobbying expenditure in the industry declined in the years prior to the passage of DTSA (2015 and 2016): <https://www.opensecrets.org/federal-lobbying/industries/summary?id=E01>.

<sup>41</sup> The lower the substantive requirements, the longer the time to take legal action, and the higher the remedies, the higher the score on the Png index. The score is the average across all six dimensions and, hence, bounded between zero and one.

<sup>42</sup> We follow the public algorithm provided by Png (2017a, b) to compute the index value for Texas, which adopted UTSA after the observation period in the Png articles and posted data. For all other states, we used existing Png index values. See Online Appendix O for more details on the index construction.

<sup>43</sup> As per the LexisNexis database, “State courts generally have jurisdiction over trade secret disputes. In determining which state has jurisdiction, courts consider where the alleged misappropriation and damage occurred [emphasis added].” See <https://www.lexisnexis.co.uk/legal/guidance/trade-secrets-usa-q-a-guide>. Also, we interviewed Prof. Mark Schultz, an expert in trade secret law and coauthor of the Organisation for Economic Co-operation and Development Trade Secret Index (Lippoldt and Schultz 2014). In response to a question about the likely location of trade secret lawsuits in our setting, he said, “It’s a fair statement to say that, most of the time, it’s going to be the location of the well.”

<sup>44</sup> In Online Appendix F, we replace month fixed effects with oil price controls to estimate the role of changes to the competitive environment and time trends as an alternative control for the passage of time. The results remain similar.

<sup>45</sup> It is possible that the effect of the DTSA could be very low (or even nonexistent) if other policies or contextual factors lowered knowledge leakage risk so much as to fully alleviate such concerns. We assume no existing policy or situation provides such protection in our context pre-DTSA. We thank a reviewer for pointing this out.

<sup>46</sup> Following the Starr et al. (2021) index, high noncompete protection states are Louisiana, Colorado, Wyoming, and Pennsylvania, whereas low noncompete protection states are Texas, Oklahoma, and Arkansas. We categorize the first four states as high noncompete protection states because they rank closely together and provide a four and three state split for the two groups. There are both high- and low-treatment states in both groups.

<sup>47</sup> In Online Appendix G, we cluster standard errors at the service firm level. In Online Appendix G, we also include wild cluster bootstrap estimated *p*-values for all main coefficients to address concerns regarding relatively few states (clusters). Canay et al. (2021) highlight wild bootstrap as a suitable solution, in particular in cases in which the number of clusters is small but the number of observations per cluster is large, such as ours. Our core results are robust to these different clustering specifications.

<sup>48</sup> We also ran logit (for binary dependent variable) and Poisson (for count dependent variable) models. We also ran firch logit models for the novel trade secret analyses (because the outcome was somewhat rare). The results are qualitatively similar.

<sup>49</sup> Per this operationalization, 191 wells in the sample have new-to-the-firm trade secret ingredients between 2015 and 2018.

<sup>50</sup> Whereas the increase in use of trade secrets is stable post-DTSA (Figure 2), the share of secret ingredients continues to increase (Figure 3). Although speculative, given our other results, which are consistent with secrecy-protected inventive activity ramping up post-DTSA, we interpret these results as reflective of this ramp-up (e.g., novel ingredient use).

<sup>51</sup> We also ran the analyses using a continuous measure for secret protection level as well as by-state analyses and found results consistent with our main tables; see Online Appendix E.

<sup>52</sup> Online Appendix K collapses well-level results and presents similar findings at the firm–state level.

<sup>53</sup> We include split-sample analysis in the main paper for ease of presentation. A version of the results with triple interactions is included in Online Appendix M. The results are consistent with the split-sample results.

<sup>54</sup> The veracity of these submissions may be checked by government officials. Per the legal counsel of a service provider firm in our sample, “It’s important that people know what is going down into the well site to know that, if I’m putting something down there, I have thought through it, and I know what it is, and I disclosed it, and regulators can come and check, test it out, and see that the components and ingredients that we said are the things that are contained in it ... They do that from time to time. It’s not in every well that they do it, but they do samples from time to time.”

<sup>55</sup> We measure new disclosed ingredients using the disclosed chemical identifiers (CAS numbers), noting when an ingredient (CAS) is first used by a service firm in a given category.

<sup>56</sup> Firms source a large portion of their inventions from outside the firm (Arora et al. 2016). To further investigate evidence for invention rather than relabeling, we investigate the sources of ingredients. Additional analyses on the sourcing of trade secret ingredients suggest ingredient recombination in recipes: we find that post-DTSA, service provider firms source more ingredients from third party suppliers and in high-treatment states. See Online Appendix N for details.

<sup>57</sup> A lack of a decrease also provides some support that these increases are policy-driven as they and the DTSA persist over the full period.

<sup>58</sup> These statistics are based on the entire sample of wells without differentiating the predominant type of hydrocarbon produced. Wells may produce oil, gas, or both. We further study these associations in Online Appendix J. The raw associations hold for focused wells and when we control for service firm, producer firm, basin, well type, and time fixed effects.

<sup>59</sup> This is likely a conservative estimation. Another way to specify this regression is considering wells that only produce oil and vice versa for gas. Note that this categorization is only apparent ex post, and thus, we include the full sample in this analysis. If we focus on the different split samples, the association between trade secret use and productivity is substantially higher. See Online Appendix J.

<sup>60</sup> In additional analyses in Online Appendix J, we do not find evidence that the DTSA drove additional increases in productivity in high-treatment states relative to low-treatment states.

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