Appendices

A. Additional Institutional Background

A.1 More on the Rule of Capture

The Texas Supreme Court ultimately chose the rule of capture based on two public policy considerations. First, "Because the existence, origin, movement and course of such waters, and the causes which govern and direct their movements, are so secret, occult and concealed that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would therefore be practically impossible." Second, "Because any such recognition of correlative rights would interfere, to the material detriment of the commonwealth, with drainage of agriculture, mining, the construction of highways and railroads, with sanitary regulations, building, and the general progress of improvement in works of embellishment and utility" (Potter 2004). However, for more than a century the Texas Supreme Court had not made an official decision on whether a landowner owns not only the water that emerges from the ground, but the water in place underground as well (i.e., ownership before the water is produced). Finally, on February 24, 2012 in *Edwards Aquifer Authority v. Day*, the Supreme Court announced for the first time that under Texas law the ownership of the groundwater in place also belongs to the owner of the property and is subject to takings (when property owners require compensation for having their withdrawals capped or reduced). This is similar to mineral rights associated with oil and gas resources, yet it is still unclear what is considered effective groundwater management and regulatory takings (McCarthy and Jackson, Sjoberg, McCarthy and Townsend LLP 2012 and Texas Water Code Section 36.002).

A.2 Priority Groundwater Management Areas

SB1 moved to treat the state as a whole by setting up regional planning groups and providing data collection to close data gaps. Priority Groundwater Management Areas (PGMAs) are identified by the TCEQ as areas that currently have no GCD and will potentially have "critical problems" within the next 50 years.[1] They were created to enable effective management of groundwater resources in areas of the state where critical groundwater problems exist or may exist in the future.[1] As of January 2017, seven PGMAs have been designated in Texas and cover all or part of 35 counties (TCEQ and TWDB 2017).[2] Once a decision to designate an area as a PGMA has been made, the affected counties must take one of several actions within two years: (1) join an existing GCD, (2) create one or more GCDs, (3) or a combination of (1) and (2) depending on the hydrogeology. If affected counties do not take steps in creating a GCD, the TCEQ will step in and create one or more districts under Chapter 36 of the Texas Water Code.

A.3 Water Life Cycle in Hydraulic Fracturing

Freshwater consumption is water that, following its use, is removed from the local hydrologic cycle and is therefore unavailable to other potential users (U.S. EPA 2016b). Hydraulic fracturing operations can consume water in a variety of ways, such as through evaporation from storage ponds (used to store water near the well pad before stimulation occurs), retention of water in the geologic formation, or disposal of wastewater in Underground Injection Control (UIC) Class II injection wells (U.S. EPA 2016b). Although the successful stimulation of wells has become more resilient to the use of various water types,[3] historically, the majority of hydraulic fracturing operations have used freshwater because it requires minimal testing and treatment (U.S. EPA 2016b), and therefore is usually the least cost water option. U.S. EPA (2016a)

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[1] Source: https://www.tceq.texas.gov/groundwater/pgma.html.

[2] A map of Texas PGMAs is available at http://hayscountyroundup.blogspot.com/2009/11/tceq-report-looks-at-options-to-plug.html, and an (outdated) shape file is available at http://www.twdb.texas.gov/mapping/gisdata.asp.

[3] Mentioned in a phone conversation with Gabriel Collins, an attorney in Houston, Texas. https://www.bakerinstitute.org/experts/gabe-collins/.

outlines five stages in the hydraulic fracturing water cycle, where each stage is defined by an activity involving water that supports hydraulic fracturing (Appendix Table A.1).

Appendix Table A.1. The stages and activities in the hydraulic fracturing water cycle.

Stage	Activity
Water Acquisition	The withdrawal of groundwater or surface water to make hydraulic fracturing fluids.
Chemical Mixing	The mixing of a base fluid, sand or proppant, and additives at the well site to create hydraulic fracturing fluids.
Well Injection	The injection and movement of hydraulic fracturing fluids through the oil and gas production well and in the targeted rock formation.
Wastewater Handling	The on-site collection and handling of water that returns to the surface after hydraulic fracturing stimulation and the transportation of that water for disposal or reuse.
Wastewater Disposal and Reuse	The disposal and reuse of hydraulic fracturing wastewater.

Source: U.S. EPA (2016a).

A.4 Water Sourcing and Disposal

The amount of water needed for a hydraulic fracturing stimulation depends on the geology of the region and many other factors (see Appendix A.5), and is needed within a short period of time to ensure sufficient pressure can be applied to stimulate the well and meet production expectations, as designed by the completion engineer. Although the Texas Railroad Commission is the primary authority regulating the oil and gas industry, it has no statutory authority to regulate water use in the industry,[4] and operators currently can use any amount of water in development activity. Since water is over allocated in Texas, operators obtain water by purchasing water from owners of water rights, or land or water rights themselves. Due to industry water needs, lucrative markets for water have developed in regions with hydraulic fracturing activity. In fact, since the revenue from selling water is so large, some landowners will not sign an oil and gas lease unless the terms specify that the operator must purchase its water from a supply well located on their property (Goldenberg 2013; Scanlon et al. 2014; and Hiller 2018). For surface owners with severed mineral rights, selling freshwater provides the sole revenue stream from the industry that compensates for not receiving royalty payments (Scanlon et al. 2014). Further, most ranchers would rather have an operator drill a new freshwater well on their land because after the oil and gas well is completed, they have a useful new freshwater well.

In areas with relatively low water availability, large water withdrawals occurring over a short period can abruptly reduce water availability. Anecdotal evidence of such impacts has come in the form of drying domestic wells; cattle wells running dry on larges ranches in west Texas (Dallas News 2014); and stream capture decline, which has caused private stock dams to run dry in western North Dakota (Kusnetz 2012). Aside from the direct impacts on groundwater availability, there is a fear of displacement of local homeowners as water scarcity increases. Kusnetz (2012) documents this fear amongst residents in western North Dakota, where several cases of fruitless drilling of new water wells occurred, as well as reports of residents that had to haul water for domestic and livestock use from out of town.

Further, in Barnhart, Texas, a small town in the western part of the state located on the eastern fringe of the Permian Basin, Goldenberg (2013) reported that the "town well ran dry." However, precluding this were "warning signs," where residents reported seeing sand in toilet bowls, sputters of air in faucets, and water pumps that worked overtime but produced no water. While much of the town's water supply was

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[4] Source: http://www.rrc.state.tx.us/about-us/resource-center/faqs/oil-gas-faqs/faq-water-use-in-association-with-oil-and-gas-activities/.

being used for oil and gas development (one rancher reported 104 water supply wells were drilled on his leased land), residents complained of water rationing restrictions. The article also reported that many local ranchers sold off much of their herds, and cotton farmers lost significant yields, as it became increasingly difficult (or prohibitively expensive—new wells can cost tens of thousands of dollars) to provide feed and water under conditions of drought combined with the new water demands of the industry.[5]

The collective depletion of aquifers therefore can necessitate users to invest in new (and larger) water wells or pumps, which effectively must be drilled deeper in order to access the available groundwater. Since these wells are also pumping water from deeper depths, the costs associated with pumping water increase.[6] In this case, large spatial externalities exist since the pumping of water by one or many users affects other nearby water users, and these externalities are potentially important causes of welfare losses (Pfeiffer and Lin 2012). Careful management of water can therefore be needed at the local level, such as in regions with significant hydraulic fracturing activity (or those that supply the industry with water), as it is local water availability that is the most sensitive in terms of social welfare.

Wastewater, which includes both the initial flowback and the produced water, is pumped throughout the life of a well along with oil and gas, and contains many of the salts, minerals, and other petroleum residues that naturally exist in the formation. The quantity of wastewater produced is large and poses an expensive logistical challenge for operators. For example, in the Permian Basin, six to eight barrels (252 to 336 gallons) of wastewater are produced per barrel (42 gallons) of oil (Carr 2017), although the volumes of both produced water and oil decline at relatively the same rate as the well ages (Kondash and Vengosh 2015). Operators must dispose, treat, or reuse this wastewater in a safe and responsible manner. In Texas, operators have typically opted to dispose wastewater via injection into UIC Class II injection wells since it is less expensive to dispose of the wastewater and purchase new freshwater, as opposed to treating and reusing recycling wastewater (Texas Railroad Commission Undated and Collins 2017). Disposal of produced water in injection wells, however, has been connected to seismic activity in certain areas, particularly in north Texas and Oklahoma (Ellsworth 2013; Walsh and Zoback 2015). If total wastewater volumes continue to increase, as is projected to happen due to increasing hydraulic fracturing activity and longer horizontal wellbores that use more water, the wastewater disposal problem may become even more pronounced due to limited disposal well capacities. In attempt to circumvent both the water supply and disposal issues, several companies have recently started developing cheaper ways to recycle wastewater.[7] However, efforts to recycle can be limited if landowner agreements require operators to utilize their water resources, a common obstacle to recycling in Texas (Hiller 2018).

A.5 Factors Affecting Total Water Use in a Well

There are many factors and operator decisions that affect the volume of water needed to stimulate a well, including the measured depth, or the total length of pipe used in a well, which is a function of the true vertical depth and the lateral (or horizontal) length. The measured depth of a well relates to total water use, as some shale formations lie deeper than others and therefore require more water to fill the vertical space in the wellbore. Similarly, the horizontal length component of measured depth has a direct correlation to the amount of water used. As the lateral wellbore length increases, more water is needed to fill space in the horizontal portion of the wellbore, maintain pressure, and carry water and sand into a larger fracture network during the stimulation stages.

After the well is drilled and the casing and cement are in place (sealing the wellbore from the hydrocarbon-producing formation), perforating guns containing explosive charges are pulled into the wellbore and

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[5] This is an example of the "stock" externality (Provencher and Burt 1993), where water used today is not available tomorrow, and users must find other sources of due to the decline in water availability brought on by the pumping decisions of other users.

[6] This is an example of the "pumping cost" externality (Provencher and Burt 1993).

[7] Apache Corporation has built five water-recycling facilities in Balmorhea (West Texas) that can store around 126 million gallons of wastewater (Hiller 2018).

detonate to "punch" perforations (or holes) through the casing and cement and into the formation.[8] The holes reconnect the formation to the wellbore and provide a path for the fracturing fluid to be forced into the formation. The choice of perforation design has an immediate influence on the well's total water use and productivity as it dictates the number of holes punched into the target formation (more holes mean more water is needed). Accordingly, the charges used in perforation treatments can be of different sizes, although they are constrained by the amount of space in the wellbore. Some are designed to create longer or shorter perforation lengths extending into the formation (ranging from 6" to 48"); and others are designed to create perforation holes of various sizes (ranging from .23" to .72" by diameter).[9],[10],[11]

Learning in the industry has also occurred on other dimensions that contribute to the amount of water used per well. As exploration and drilling have generated significant amounts of new information on local geology, operators have become more adept at choosing optimal completion inputs and stimulation techniques to free more of the oil and gas trapped within, such as by drilling wells with longer horizontal lengths and stimulating them in multiple discrete stages (or intervals).[12] The latter has significantly increased production per well as it creates a larger fracture network that reaches more of the producing formation around each interval, and enables the entire length of the wellbore to be stimulated more thoroughly. Over time, operators have also increased the number of stages used to stimulate a wellbore, which directly affects total water use.[13] With more stages, and possibly a larger number of perforations in each stage, more water is needed to stimulate and enter a larger number of fractures.

In addition to its contribution to well productivity, the stimulation of multiple stages can take place iteratively or all at once before production, potentially offering operators more freedom to pace extraction with other decisions or market conditions (Vissing 2018). Similarly, refracturing a well one or more times over its life is another important determinant of total water use. Refracturing has become more common in the industry as it provides a relatively low-cost means of maintaining total output by increasing production rates from older wells as opposed to drilling new ones.[14] It can also be an effective way to revive production from wells where the initial stimulation was poor and did not offer good returns.[15] The caveat is that each refracture requires an additional volume of water, but usually less than the initial stimulation.

Lastly, the composition of the hydraulic fracturing fluid used, and the geology of the formation are other important factors affecting total water use. The hydraulic fracturing fluid composition is an especially important determinant as the industry has begun to use more sand per lateral foot, which requires additional water to carry sand particles deeper into the fractures. The proportions of each water type (e.g., freshwater, brackish or saltwater, and recycled wastewater) in a fracture fluid can affect water needs due to their respective densities (and the desirably lower viscosity of hydraulic fracturing fluids), and the use of alterna-

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[8] An example of a perforating gun is available at http://www.halliburton.com/en-US/ps/wireline-perforating/wireline-and-perforating/perforating-services/high-pressure-gun-systems/default.page.

[9] More in-depth discussions and visuals of the perforation process are available at https://www.epa.gov/sites/production/files/documents/casingperforatedoverview.pdf and https://info.drillinginfo.com/well-completion-101-part-2-well-perforation/.

[10] It is true that significant heterogeneity exists in firm beliefs over optimal perforation lengths and hole-size, but after conversations with Bob Kleinberg, a former employee at Schlumberger (https://www.bu.edu/ise/profile/robert-kleinberg/), it appears that the geology of the formation usually dictates these choices.

[11] DrillingInfo also describes how too large of a perforation hole or too long of a perforation length can lead to excess debris from the explosions, which can cause blockage in the wellbore and therefore reduce well productivity. Similarly, too small of a perforation hole diameter and or too short of a perforation length can affect well productivity since less "damage" to the formation is created. To circumvent these concerns, various perforation patterns have been used in attempt to maximize wellbore exposure to the producing formation without jeopardizing well productivity, and there are usually four to eight holes perforated per foot, where the most common patterns create holes in three, four, or six directions across a given perforated interval or stage. Source: https://info.drillinginfo.com/well-completion-101-part-2-well-perforation/.

[12] A more in-depth discussion and a visual for the concept of multi-stage stimulation is available at https://www.researchgate.net/publication/270340648_Integrated_Shale_Gas_Reservoir_Modeling/figures?lo=1.

[13] Mentioned in conversations with Bob Kleinberg, formerly of Schlumberger.

[14] Source: https://info.drillinginfo.com/makes-successful-refrac/.

[15] Conversations with DrillingInfo indicate that, for a variety of reasons, operators are not usually able to stimulate fractures in all perforations along a horizontal wellbore, meaning that reserves are commonly left behind during the initial stimulation. This feature has created the refracture market, and firms commonly use downhole technology such as a flowmeter to detect intervals along the wellbore that were not fractured and provide potential refracture targets.

tive water types reduces freshwater needs. Other fracture fluids can contain non-aqueous substances such as liquid-gas mixtures of nitrogen or carbon dioxide, both of which reduce the amount of water needed to stimulate a well. Geologic characteristics such as the type of formation (e.g., such as shales, tight sands, and coalbeds), affect the perforation choices mentioned above, but they also influence the amount of water used per well as some formations are harder and require more water pressure to stimulate fractures than others. Some formations also have more cracks and associated natural leakage, and are therefore more conducive to other unintended losses, which increases water use (U.S. EPA 2015).

A.6 Impacts of Water Use

In a county-level analysis of water use (or consumption) and availability, U.S. EPA (2016b) found that large volumes of water used in hydraulic fracturing alone do not necessarily result in impacts to drinking water resources. Where water availability is low, compared to use, withdrawals for hydraulic fracturing are more likely to affect drinking water resources or require curtailments. For example, in Pennsylvania, a water-rich state, water withdrawals have been restricted during summer and drought conditions in the Susquehanna River Basin (SRBC 2015). Furthermore, groundwater withdrawals exceeding natural recharge rates may lower the water level in aquifers (particularly for confined aquifers, i.e., those with no connection to surface recharge), potentially mobilizing contaminants or increasing their concentration. These results suggest that the potential for impacts exists, and that more studies are needed to understand where impacts will occur at the local scale.

B Background on Hydraulic Fracturing Regions in Texas

B.1 Major Unconventional Oil and Gas Formations and Water Sources

There are five major unconventional oil and gas formations in Texas.[16] Each is located in an area with different geological characteristics, implying that water use for an average well is likely to be different across space (Nicot et al. 2012). Similarly, these formations are located in areas with different levels of water availability, implying that water supplies for hydraulic fracturing operations come from a variety sources. Nicot et al. (2012) provide an outline of these and estimate the majority are surface and groundwater (including fresh and brackish or salt water). Other sources include recycled or reused wastewater from previous completions or from other industries or municipalities. In some areas, they also report that some operators have experimented with gel-based fracturing fluids, which reduce water needs.

Barnett Shale

The Barnett Shale is a large onshore natural gas field (home to the original shale gas boom), where operators initially began using hydraulic fracturing techniques to enable production from unconventional sources (Nicot et al. 2012). The productive part of the formation is estimated to cover 5,000 square miles and at least 18 counties in the Dallas area, and contributes significantly to total U.S. natural gas production.[17] Water supply for hydraulic fracturing in this region comes from both surface and ground sources, and is estimated to be in equal 50% and 50% proportions (Nicot et al. 2014).

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[16] Source: http://www.rrc.state.tx.us/oil-gas/major-oil-and-gas-formations/.

[17] Source: http://www.rrc.state.tx.us/oil-gas/major-oil-and-gas-formations/barnett-shale-information/.

Eagle Ford Shale

The Eagle Ford Shale is significant due to its capability of producing large amounts of both natural gas and oil.[18] It sits below all or part of 27 counties in the southeast part of Texas, trending in a northeast direction from the Mexican border. It is roughly 50 miles wide and 400 miles long with an average thickness of 250 feet, and lies at a depth of between 4,000 and 12,000 feet. The play has been important to Texas, as it was where the majority of unconventional oil production first occurred in the state over 2010–2011, following the unconventional oil boom in North Dakota in 2008. Water supply for hydraulic fracturing in this region predominantly comes from groundwater sources (90%), although a small portion (10%) comes from surface sources (Nicot et al. 2012).

Granite Wash

The Granite Wash is a tight sand play within the Anadarko Basin, encompassing a number of oil and gas producing formations, and lying below 26 counties in the panhandle of Texas and others in western Oklahoma.[19] Its spatial extent is approximately 160 miles long and 30 miles wide, and varies in depth from 11,000 to 15,400 feet and is 3000 feet thick on average. It is significant for both oil and gas production and, although the formation is predominantly composed of sand, has been a beneficiary of horizontal drilling methods developed for shale plays. Water supply for hydraulic fracturing in this region comes from groundwater sources (80%), and a small portion (20%) from surface sources (Nicot et al. 2012).

Haynesville Shale

The Haynesville shale is a gas-producing formation, which lies below 10 counties in East Texas and others in Western Louisiana.[20] The productive portion of the formation is deep and lies over 10,000 feet below the surface. Nicot et al. (2012) jointly estimate portions of water supply for hydraulic fracturing in the Haynesville shale, and what they refer to as the East Texas Basin, which includes other smaller plays in the area. They estimate that 70% comes from groundwater and 30% from surface sources in this region.

Permian Basin

The Permian Basin in west Texas has become the one of the largest and most important hydrocarbon-producing regions in the U.S. It covers an area approximately 250 miles wide and 300 miles long and is composed of more than 7,000 fields.[21] Much of the area sits over cake-layered formations, where large amounts of oil and natural gas are produced from depths ranging from a few hundred feet to five miles below the surface. Importantly, it is located in a primarily semi-arid to arid environment (making it prone to drought), and sits under the Ogallala Aquifer in the northern part of the basin and under the Edwards-Trinity Aquifer in the southern part of the basin. Nicot et al. (2012) estimate that 100% of water use in hydraulic fracturing comes from groundwater sources in this region, and Cook and Webber (2016) note that landowners selling freshwater to operators typically pump it from the two aforementioned aquifers.

B.2 Understanding the Potential for Water Scarcity

Although part of this paper concerns the general question of whether water use in hydraulic fracturing is large enough to affect local water availability, it is also important to understand *where* the largest effects are most likely to occur. The regions in Texas with the most hydraulic fracturing activity are the Permian and Eagle Ford Basins, which are located in areas with low and relatively low rainfall and groundwater recharge. Given their water-scarce nature, it is reasonable to assume that water withdrawals are more likely to have a larger effect on local water availability in these areas, especially during times of drought. In the Permian Basin, water use in roughly 10 counties with significant hydraulic fracturing activity is not

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[18] Source: http://www.rrc.state.tx.us/oil-gas/major-oil-and-gas-formations/eagle-ford-shale-information/.

[19] Source: http://www.rrc.state.tx.us/oil-gas/major-oil-and-gas-formations/granite-wash-information/.

[20] Source: http://www.rrc.state.tx.us/oil-gas/major-oil-and-gas-formations/haynesvillebossier-shale-information/.

[21] Source: http://www.rrc.state.tx.us/oil-gas/major-oil-and-gas-formations/permian-basin-information/.

currently managed by a GCD; but Midland, Reagan, and Upton counties are identified as PGMAs. Similarly, in the Eagle Ford Basin, water use in roughly eight counties is not managed by a GCD. As shown in Nicot et al. (2012), water use in hydraulic fracturing in these areas increased between 2008 and 2012. Since then, many new wells have been completed and water use per well has continued to rise, in GCD and non-GCD areas.

Although the topic has been studied previously, and no study has shown a causal link between water of the industry and local availability,[22,23,24] water availability can be important in order for operators to keep completion costs low, particularly during times of low oil prices when profit margins are smaller. For example, during times of low water availability, operators may have to obtain water from more distant areas where it is plentiful, which can increase water-related expenditures in several ways. First, water prices should theoretically rise with scarcity, along with increasing competition over limited water supplies. Second, since operator demand for water may be inelastic (at least after a well is drilled),[25] water might be sourced from greater-than-average distances. In these cases, water expenditures can be higher since transportation distance increases (transportation is the largest water-related cost) or if are export fees are associated with the area from which the water is obtained from.[26]

B.3 Sourcewater

Due to plausible future water constraints such as having to haul water greater distances and therefore facing higher water costs, *sourcewater.com* was developed to be the largest online water source, reuse, and disposal database in the upstream energy industry. The platform aims to complement (or even replace) traditional sourcing methods used in the industry, which often involve operators sourcing water from the same water supplier or "friend" in a particular area, or cold calling, and not finding the nearest water source. Not obtaining water from the nearest source means operators are not minimizing total water costs, which makes it more difficult for alternatives to freshwater to be competitive when purchasing water. Hence, by using its online platform with over 100,000 water sources, Sourcewater advertises that operators can significantly cut down on total water costs by obtaining water from nearer sources.[27]

C Data

C.1 Additional Descriptive Statistics

An interesting trend in Appendix Table C.1.1 is that the number of wells in the Permian basin in non-GCD areas is significantly greater than the number stimulated in GCD areas until 2015. This trend also holds across both drilling orientations. Although this could be due to better geology or other factors making non-GCD areas preferred in this sample period, it also potentially suggests that an easier access to water, and therefore plausibly lower water costs, could play a role in an operator's decision on where to drill.

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[22] Scanlon et al. (2014) study whether water scarcity in will affect hydraulic fracturing activity in the Eagle Ford Basin. They find that with appropriate management, such as by increasing the use of brackish groundwater and produced water, water availability should not physically limit future shale energy production.

[23] Stevens and Torell (2018) posit that water availability affects the amount of water used in hydraulic fracturing stimulations, among other drilling decisions and development outcomes. During times of drought, they show evidence that smaller wells are completed, which could collectively be due to a number of reasons.

[24] Freyman (2014), as part of a Ceres report, analyzes increasing water demand in hydraulic fracturing in water-stressed regions, and provides recommendations to stakeholders and operators for mitigating exposure to water sourcing risks.

[25] A completion engineer designs wells, but I am not sure how much cohesion there is between completion engineers and water managers (those responsible for ensuring sufficient water supplies are gathered for completions). Hence, after a horizontal well is drilled, I have reason to believe that few onsite decisions can be made to change the amount of water specified by the completion engineer. However, this warrants further study.

[26] One company was fined for using water from a source that was banned for use in hydraulic fracturing. Source: https://fuelfix.com/blog/2011/10/06/parched-texans-impose-water-use-limits-for-fracking-gas-wells/.

[27] Although this seems like an opportunistic way to obtain water prices, phone conversations with Ben Reed and Josh Adler of Sourcewater have indicated a reluctance of operators to transact on their platform. Operators instead opt for phoning the suppliers found in Sourcewater search results.

Appendix Table C.1.1. Descriptive statistics. Number of wells in GCD and non-GCD areas in the Permian Basin (27,978 Observations).

		2012	**2013**	**2014**	**2015**	**2016**	**Through May 2017**
Number of Horizontal and Directionally Drilled Wells	GCD Areas	358	678	1,067	1,027	891	380
	Non-GCD Areas	650	803	1,297	1,309	992	317
Number of Vertically Drilled Wells	GCD Areas	2,567	2,495	2,019	596	234	82
	Non-GCD Areas	3,101	3,144	2,611	859	342	159

Source: data from Primary Vision.

Appendix Table C.1.2. Summary statistics. Wells completed in Texas over February 2012 through May 2017.

	Unique Operators	# Wells	Mean # Wells Per Operator	HFFM?	Any Info. on Water Type?	Hor/ Dir Wells	Mean Water Use Per Well
Operators in GCD and Non-GCD Areas	255	47,521	186	95.29%	78.84%	58.65%	4,130,954
Operators in GCD Areas Only	253	4,348	17	97.31%	73.71%	66.7%	4,719,932
Operators in Non-GCD Areas Only	148	1,313	9	99.92%	90.48%	19.04%	1,089,263

Source: data from Primary Vision.

C.2 Additional Data

There are several other variables I would like to consider in future research, including an indicator for whether a well was completed near the expiration date of the primary term on its associated lease. The primary term specifies the maximum number of years within which an operator must drill and produce from at least one well, otherwise it will lose the lease. Herrnstadt et al. (2019) show that these expiration dates have a significant impact on drilling decisions, and a large share of wells are completed just prior to expiration. Controlling for this characteristic would be important if reporting for these wells is systematically worse. Additionally, given variation in the time taken to submit a completion report to FracFocus, this variable could be important if it is correlated with reporting less detailed information.

D. Robustness Checks

D.1 Analysis of Reporting

Appendix Table D.1.1. Logit model results for reporting metric 1. Outcome: hydraulic fracturing fluid mass calculated (0 or 1)? Each model was estimated using wells in Texas over February 2012 through May 2017, but ***omitting*** *observations for operators who did not have wells in both GCD and non-GCD areas.*

	(1)	(2)	(3)	(4)
GCD (0 or 1)	-0.6521***	-0.4201**	-0.3920**	-0.3883**
	(0.23310)	(0.17543)	(0.19775)	(0.19773)
Well Orientation (0 or 1)		-1.1573***	-1.0736***	-1.0626***
		(0.18880)	(0.19280)	(0.18665)
TWV (One Unit = 100k Gallons)		-0.00547***	-0.00551***	-0.00544***
		(0.001092)	(0.001175)	(0.001153)
Refrac (0 or 1)		0.3354	0.3951	0.3885
		(0.32464)	(0.32987)	(0.32606)
#Wells by Operator in County-Month			-0.0078	-0.0064
			(0.01228)	(0.01248)
Operator's 1st Well			-0.2534	-0.2989
			(0.70965)	(0.70212)
Operator's 1st Well in County			0.2981	0.2985
			(0.20153)	(0.19807)
Cumulative #Wells in County	No	No	Yes	Yes
Cumulative #Wells by Largest 5 in County	No	No	Yes	Yes
Cumulative #Wells by Operator in County	No	No	Yes	Yes
#Wells by Largest 5 in County-Month	No	No	Yes	Yes
Total #Wells by Operator in County	No	No	Yes	Yes
Drought Controls	No	No	No	Yes
Constant	Yes	Yes	Yes	Yes
N	37455	37455	37455	37455
Pseudo-R-Squared	0.374	0.395	0.398	0.400
Operator FEs	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on county. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Appendix Table D.1.2. Logit model results for reporting metric 2. Outcome: ***any*** *information on water type in completion report (0 or 1)? Each model was estimated using wells in Texas over February 2012 through May 2017, but* ***omitting*** *observations for operators who did not have wells in both GCD and non-GCD areas.*

	(1)	(2)	(3)	(4)
GCD (0 or 1)	-0.3629***	-0.3761***	-0.4244***	-0.3986**
	(0.12950)	(0.13561)	(0.15918)	(0.15815)
Well Orientation (0 or 1)	-0.5892***	-0.7775***	-0.8116***	-0.8173***
	(0.15272)	(0.18209)	(0.14608)	(0.14439)
TWV (One Unit = 100k Gallons)		0.00554***	0.00511***	0.00513***
		(0.001621)	(0.001820)	(0.001809)
Refrac (0 or 1)		0.0223	0.0038	0.0047
		(0.16734)	(0.16721)	(0.16663)
#Wells by Operator in County-Month			0.0472	0.0472
			(0.03085)	(0.03082)
Operator's 1st Well			-0.5514**	-0.5530**
			(0.24142)	(0.24266)
Operator's 1st Well in County			0.2158*	0.2162*
			(0.12421)	(0.12493)
Cumulative #Wells in County	No	No	Yes	Yes
Cumulative #Wells by Largest 5 in County	No	No	Yes	Yes
Cumulative #Wells by Operator in County	No	No	Yes	Yes
#Wells by Largest 5 in County-Month	No	No	Yes	Yes
Total #Wells by Operator in County	No	No	Yes	Yes
Drought Controls	No	No	No	Yes
Constant	Yes	Yes	Yes	Yes
N	45502	45502	45502	45502
Pseudo-R-Squared	0.367	0.369	0.380	0.380
Operator FEs	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on county. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

D.2 Analysis of Hydraulic Fracturing and Groundwater Levels

D.2.A Various Specifications of Equation (2)

Appendix Table D.2.1. Fixed effects model results for water use in hydraulic fracturing across space. Outcome: distance to groundwater level (feet).

	(1)	(2)	(3)
TWV10 (Unit = 100BBLs)	0.00027	0.00027	0.00100***
	(0.000219)	(0.000220)	(0.000138)
TWV (10–15 Miles)	0.00010	0.00009	0.00064***
	(0.000127)	(0.000129)	(0.000082)
TWV (15–20 Miles)	0.00001	0.00001	0.00007
	(0.000056)	(0.000053)	(0.000107)
TWV (20–25 Miles)	0.00007	0.00007	0.00024
	(0.000052)	(0.000053)	(0.000142)
TWV (25–30 Miles)	0.00003	0.00003	0.00015
	(0.000034)	(0.000033)	(0.000180)
TWV (30–35 Miles)	0.00011*	0.00010	0.00029
	(0.000060)	(0.000060)	(0.000205)
TWV (35–40 Miles)	0.00000	-0.00000	0.00007
	(0.000024)	(0.000024)	(0.000050)
TWV (40–45 Miles)	0.00007*	0.00007*	0.00006
	(0.000040)	(0.000040)	(0.000055)
TWV (45–50 Miles)	0.00008	0.00008	0.00016
	(0.000050)	(0.000049)	(0.000100)
Drought Index	Yes	Yes	Yes
Rain	Yes	Yes	Yes
Temp	No	No	Yes
Wind	No	No	Yes
Population	No	Yes	Yes
Total Corn Acres	No	Yes	Yes
Irrigated Corn Acres	No	Yes	Yes
Total Cotton Acres	No	Yes	Yes
Cotton Acres Irrigated	No	Yes	Yes
Total Sorghum Acres	No	Yes	Yes
Sorghum Acres Irrigated	No	Yes	Yes
Total Wheat Acres	No	Yes	Yes
Wheat Acres Irrigated	No	Yes	Yes
Total Rice Acres	No	Yes	Yes
Constant	Yes	Yes	Yes
N	15014	15014	5805
# Stations	267	267	106
R-Squared	0.135	0.144	0.224
Station FEs	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

D.2.B Treatment Effect Dynamics

Appendix Table D.2.2. Fixed effects model results with lags and leads. Lags indicated by (-) and leads indicated by (+). Outcome: distance to groundwater level (feet).

	(1)	(2)	(3)	(4)
TWV10 (-6)	0.000189	0.000189*	0.000184	0.000179
	(0.0001141)	(0.0001128)	(0.0001133)	(0.0001144)
TWV10 (-5)	0.000137***	0.000142***	0.000137***	0.000134***
	(0.0000463)	(0.0000489)	(0.0000483)	(0.0000496)
TWV10 (-4)	0.000119***	0.000124***	0.000117***	0.000113***
	(0.0000349)	(0.0000364)	(0.0000349)	(0.0000351)
TWV10 (-3)	0.000088***	0.000091***	0.000086***	0.000085***
	(0.0000311)	(0.0000306)	(0.0000284)	(0.0000281)
TWV10 (-2)	0.000079*	0.000085*	0.000080*	0.000079*
	(0.0000462)	(0.0000453)	(0.0000455)	(0.0000454)
TWV10 (-1)	0.000067*	0.000075*	0.000068*	0.000070*
	(0.0000404)	(0.0000404)	(0.0000405)	(0.0000407)
TWV10	0.000062	0.000066	0.000062	0.000063
	(0.0000433)	(0.0000451)	(0.0000434)	(0.0000435)
TWV10 (+1)	0.000020	0.000025	0.000018	0.000018
	(0.0000181)	(0.0000184)	(0.0000182)	(0.0000189)
TWV10 (+2)	0.000001	-0.000005	-0.000009	-0.000009
	(0.0000150)	(0.0000196)	(0.0000180)	(0.0000177)
TWV10 (+3)	-0.000009	-0.000013	-0.000015	-0.000015
	(0.0000144)	(0.0000174)	(0.0000147)	(0.0000145)
TWV10 (+4)	-0.000028	-0.000029	-0.000028	-0.000029
	(0.0000262)	(0.0000288)	(0.0000257)	(0.0000249)
TWV10 (+5)	-0.000015	-0.000017	-0.000016	-0.000019
	(0.0000299)	(0.0000301)	(0.0000277)	(0.0000274)
TWV10 (+6)	-0.000025	-0.000024	-0.000020	-0.000023
	(0.0000363)	(0.0000357)	(0.0000287)	(0.0000270)
Drought Index	No	Yes	Yes	Yes
Drought Index Lags - 6	No	No	Yes	Yes
Rain	No	Yes	Yes	Yes
Rain Lags - 6	No	No	No	Yes
Population	No	No	Yes	Yes
Total Corn Acres	No	No	Yes	Yes
Irrigated Corn Acres	No	No	Yes	Yes
Total Cotton Acres	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	Yes	Yes
Total Sorghum Acres	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	Yes	Yes
Total Wheat Acres	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	Yes	Yes

Total Rice Acres	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes
N	13437	13176	13176	13082
# Stations	254	254	254	250
R-Squared	0.122	0.136	0.160	0.162
Station and Year-Month FEs	Yes	Yes	Yes	Yes

D.2.C Leave-One-Out Tests

Appendix Table D.2.3. Fixed effects model results leaving out monitoring stations in the ***Permian Basin****. Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)	(5)
TWV10 (Unit = 100BBLs)	0.00080*	0.00081*	0.00157***	0.00081*	
	(0.000469)	(0.000469)	(0.000134)	(0.000467)	
TWV10 x Eagle Ford					0.00110**
					(0.000486)
Drought Index	No	Yes	Yes	Yes	Yes
Rain	No	Yes	Yes	Yes	Yes
Temp	No	No	Yes	No	No
Wind	No	No	Yes	No	No
Population	No	No	No	Yes	Yes
Total Corn Acres	No	No	No	Yes	Yes
Irrigated Corn Acres	No	No	No	Yes	Yes
Total Cotton Acres	No	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	No	Yes	Yes
Total Sorghum Acres	No	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	No	Yes	Yes
Total Wheat Acres	No	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	No	Yes	Yes
Total Rice Acres	No	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
N	12904	12617	4371	12617	12617
# Stations	219	219	73	219	219
R-Squared	0.133	0.146	0.213	0.155	0.159
Station FEs	Yes	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Appendix Table D.2.4. Fixed effects model results leaving out monitoring stations in the ***Eagle Ford Shale****. Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)	(5)
TWV10 (Unit = 100BBLs)	0.00009*	0.00011**	0.00062**	0.00009**	
	(0.000048)	(0.000050)	(0.000294)	(0.000045)	
TWV10 x Permian					0.00013***
					(0.000040)
Drought Index	No	Yes	Yes	Yes	Yes
Rain	No	Yes	Yes	Yes	Yes
Temp	No	No	Yes	No	No
Wind	No	No	Yes	No	No
Population	No	No	No	Yes	Yes
Total Corn Acres	No	No	No	Yes	Yes
Irrigated Corn Acres	No	No	No	Yes	Yes
Total Cotton Acres	No	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	No	Yes	Yes
Total Sorghum Acres	No	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	No	Yes	Yes
Total Wheat Acres	No	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	No	Yes	Yes
Total Rice Acres	No	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
N	14565	14278	5732	14278	14278
# Stations	256	256	105	256	256
R-Squared	0.116	0.128	0.169	0.138	0.138
Station FEs	Yes	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Appendix Table D.2.5. Fixed effects model results with lags and leaving out monitoring stations in the ***Permian Basin****. Lags indicated by (-). Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)	(5)
TWV10 (Unit = 100BBLs)	0.00009	0.00009	0.00026**	0.00009	0.00009
	(0.000128)	(0.000138)	(0.000094)	(0.000129)	(0.000127)
TWV10 (-1)	0.00010	0.00012	0.00027***	0.00011	0.00011
	(0.000107)	(0.000101)	(0.000041)	(0.000102)	(0.000102)
TWV10 (-2)	0.00014	0.00015	0.00035***	0.00014	0.00014
	(0.000117)	(0.000114)	(0.000056)	(0.000112)	(0.000113)
TWV10 (-3)	0.00016**	0.00016***	0.00019**	0.00016***	0.00016***
	(0.000065)	(0.000061)	(0.000070)	(0.000055)	(0.000056)
TWV10 (-4)	0.00019***	0.00020***	0.00026***	0.00020***	0.00019***
	(0.000050)	(0.000048)	(0.000037)	(0.000041)	(0.000041)
TWV10 (-5)	0.00021***	0.00022***	0.00036***	0.00022***	0.00022***
	(0.000070)	(0.000080)	(0.000043)	(0.000070)	(0.000070)
TWV10 (-6)	0.00024	0.00024	0.00054***	0.00024	0.00024
	(0.000153)	(0.000153)	(0.000089)	(0.000150)	(0.000150)
Drought Index	No	Yes	Yes	Yes	Yes
Drought Index Lags - 6	No	No	No	Yes	Yes
Rain	No	Yes	Yes	Yes	Yes
Rain Lags - 6	No	No	No	No	Yes
Temp	No	No	Yes	No	No
Wind	No	No	Yes	No	No
Population	No	No	No	Yes	Yes
Total Corn Acres	No	No	No	Yes	Yes
Irrigated Corn Acres	No	No	No	Yes	Yes
Total Cotton Acres	No	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	No	Yes	Yes
Total Sorghum Acres	No	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	No	Yes	Yes
Total Wheat Acres	No	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	No	Yes	Yes
Total Rice Acres	No	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
N	11592	11331	3933	11331	11235
# Stations	212	212	72	212	208
R-Squared	0.136	0.152	0.230	0.179	0.180
Station FEs	Yes	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Appendix Table D.2.6. Fixed effects model results with lags and leaving out monitoring stations in the ***Eagle Ford Shale****. Lags indicated by (-). Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)	(5)
TWV10 (Unit = 100BBLs)	0.00002	0.00002	0.00048**	0.00002	0.00002
	(0.000024)	(0.000024)	(0.000230)	(0.000021)	(0.000020)
TWV10 (-1)	0.00003	0.00004*	0.00048**	0.00003	0.00003
	(0.000022)	(0.000023)	(0.000228)	(0.000020)	(0.000020)
TWV10 (-2)	0.00004	0.00005**	0.00052**	0.00004*	0.00004*
	(0.000022)	(0.000022)	(0.000216)	(0.000021)	(0.000021)
TWV10 (-3)	0.00005***	0.00005***	0.00030***	0.00005***	0.00005***
	(0.000018)	(0.000015)	(0.000103)	(0.000015)	(0.000016)
TWV10 (-4)	0.00005***	0.00006***	0.00026**	0.00005***	0.00005***
	(0.000017)	(0.000017)	(0.000118)	(0.000015)	(0.000016)
TWV10 (-5)	0.00006**	0.00006**	0.00020	0.00006***	0.00005***
	(0.000023)	(0.000026)	(0.000164)	(0.000021)	(0.000020)
TWV10 (-6)	0.00003	0.00003	0.00029	0.00003	0.00002
	(0.000034)	(0.000037)	(0.000287)	(0.000034)	(0.000035)
Drought Index	No	Yes	Yes	Yes	Yes
Drought Index Lags - 6	No	No	No	Yes	Yes
Rain	No	Yes	Yes	Yes	Yes
Rain Lags - 6	No	No	No	No	Yes
Temp	No	No	Yes	No	No
Wind	No	No	Yes	No	No
Population	No	No	No	Yes	Yes
Total Corn Acres	No	No	No	Yes	Yes
Irrigated Corn Acres	No	No	No	Yes	Yes
Total Cotton Acres	No	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	No	Yes	Yes
Total Sorghum Acres	No	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	No	Yes	Yes
Total Wheat Acres	No	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	No	Yes	Yes
Total Rice Acres	No	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
N	13036	12775	5107	12775	12679
# Stations	247	247	102	247	243
R-Squared	0.117	0.131	0.181	0.155	0.157
Station FEs	Yes	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

D.2.D Leave-Many-Out Tests

Appendix Table D.2.7. Fixed effects model results leaving out monitoring stations in the ***Permian Basin*** *and* ***Eagle Ford Shale****. Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)
TWV10 (Unit = 100BBLs)	-0.00028	-0.00026	-0.00021	-0.00021
	(0.000184)	(0.000175)	(0.000144)	(0.000144)
Drought Index	No	Yes	Yes	Yes
Rain	No	Yes	Yes	Yes
Population	No	No	Yes	Yes
Total Corn Acres	No	No	Yes	Yes
Irrigated Corn Acres	No	No	Yes	Yes
Total Cotton Acres	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	Yes	Yes
Total Sorghum Acres	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	Yes	Yes
Total Wheat Acres	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	Yes	Yes
Total Rice Acres	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes
N	12168	11881	11881	11881
# Stations	208	208	208	208
R-Squared	0.129	0.144	0.152	0.152
Station FEs	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Appendix Table D.2.8. Fixed effects model results with lags and leaving out monitoring stations in the ***Permian Basin*** *and* ***Eagle Ford Shale****. Lags indicated by (-). Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)	(5)
TWV10 (Unit = 100BBLs)	-0.00008	-0.00007	0.00085**	-0.00005	-0.00003
	(0.000088)	(0.000092)	(0.000315)	(0.000087)	(0.000088)
TWV10 (-1)	-0.00012	-0.00006	0.00089***	-0.00007	-0.00005
	(0.000086)	(0.000071)	(0.000248)	(0.000076)	(0.000077)
TWV10 (-2)	-0.00009	-0.00003	0.00098***	-0.00002	-0.00003
	(0.000082)	(0.000070)	(0.000190)	(0.000069)	(0.000069)
TWV10 (-3)	-0.00005	-0.00003	0.00048	-0.00001	-0.00001
	(0.000066)	(0.000052)	(0.000280)	(0.000051)	(0.000052)
TWV10 (-4)	-0.00005	-0.00005	0.00053*	-0.00002	-0.00003
	(0.000065)	(0.000061)	(0.000284)	(0.000053)	(0.000051)
TWV10 (-5)	-0.00007	-0.00011	0.00046	-0.00007	-0.00007
	(0.000085)	(0.000104)	(0.000275)	(0.000079)	(0.000075)
TWV10 (-6)	-0.00010	-0.00013	0.00034	-0.00009	-0.00010
	(0.000102)	(0.000112)	(0.000312)	(0.000095)	(0.000097)
Drought Index	No	Yes	Yes	Yes	Yes
Drought Index Lags - 6	No	No	No	Yes	Yes
Rain	No	Yes	Yes	Yes	Yes
Rain Lags - 6	No	No	No	No	Yes
Temp	No	No	Yes	No	No
Wind	No	No	Yes	No	No
Population	No	No	No	Yes	Yes
Total Corn Acres	No	No	No	Yes	Yes
Irrigated Corn Acres	No	No	No	Yes	Yes
Total Cotton Acres	No	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	No	Yes	Yes
Total Sorghum Acres	No	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	No	Yes	Yes
Total Wheat Acres	No	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	No	Yes	Yes
Total Rice Acres	No	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
N	10922	10661	3866	10661	10565
# Stations	201	201	71	201	197
R-Squared	0.132	0.149	0.213	0.173	0.174
Station FEs	Yes	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * p<0.10, ** p<0.05, *** p<0.01

D.2.E Leave-2011-and-2012-Out Tests

Appendix Table D.2.9. Fixed effects model results with lags and leaving out observations from ***2011*** *and* ***2012*** *during the major Texas drought. Lags indicated by (–). Outcome: distance to groundwater level (feet).*

	(1)	(2)	(3)	(4)	(5)
TWV10 (Unit = 100BBLs)	0.00006	0.00007	0.00025***	0.00006	0.00007
	(0.000046)	(0.000049)	(0.000068)	(0.000049)	(0.000049)
TWV10 (-1)	0.00007*	0.00008**	0.00022***	0.00007*	0.00007*
	(0.000038)	(0.000039)	(0.000024)	(0.000042)	(0.000043)
TWV10 (-2)	0.00006**	0.00007**	0.00019***	0.00007**	0.00007**
	(0.000029)	(0.000029)	(0.000040)	(0.000032)	(0.000032)
TWV10 (-3)	0.00008***	0.00008***	0.00010**	0.00008***	0.00008***
	(0.000027)	(0.000027)	(0.000038)	(0.000026)	(0.000026)
TWV10 (-4)	0.00009***	0.00010***	0.00011***	0.00009***	0.00009***
	(0.000034)	(0.000035)	(0.000029)	(0.000035)	(0.000034)
TWV10 (-5)	0.00009**	0.00010***	0.00015***	0.00010***	0.00010***
	(0.000034)	(0.000037)	(0.000036)	(0.000035)	(0.000034)
TWV10 (-6)	0.00009	0.00009	0.00021***	0.00011	0.00010
	(0.000073)	(0.000073)	(0.000057)	(0.000074)	(0.000073)
Drought Index	No	Yes	Yes	Yes	Yes
Drought Index Lags - 6	No	No	No	Yes	Yes
Rain	No	Yes	Yes	Yes	Yes
Rain Lags - 6	No	No	No	No	Yes
Temp	No	No	Yes	No	No
Wind	No	No	Yes	No	No
Population	No	No	No	Yes	Yes
Total Corn Acres	No	No	No	Yes	Yes
Irrigated Corn Acres	No	No	No	Yes	Yes
Total Cotton Acres	No	No	No	Yes	Yes
Cotton Acres Irrigated	No	No	No	Yes	Yes
Total Sorghum Acres	No	No	No	Yes	Yes
Sorghum Acres Irrigated	No	No	No	Yes	Yes
Total Wheat Acres	No	No	No	Yes	Yes
Wheat Acres Irrigated	No	No	No	Yes	Yes
Total Rice Acres	No	No	No	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
N	10454	10248	3811	10248	10170
# Stations	248	248	99	248	244
R-Squared	0.127	0.148	0.216	0.187	0.188
Station FEs	Yes	Yes	Yes	Yes	Yes
Year-Month FEs	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses. Clustered on monitoring station. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

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