OPEN

A Multiregion Analysis of Shale Drilling Activity and Rates of Sexually Transmitted Infections in the United States

Nicholaus P. Johnson, MPH, Joshua L. Warren, PhD,† Elise G. Elliott, PhD,‡§ Linda M. Niccolai, PhD,¶ and Nicole C. Deziel, PhD**

Background: Fossil fuel extraction from deep shale rock formations using new drilling technologies such as hydraulic fracturing has rapidly increased in the Unites States over the past decade. Increases in nonlocal, specialized workers to meet the demands of this complex industry have been suggested to influence the rates of sexually transmitted infections (STIs) in counties with shale drilling activity; these associations may vary geographically. In this multiregion analysis, we examine the associations between shale drilling activity and rates of 3 reportable STIs in Colorado, North Dakota, and Texas, states with active shale drilling.

Methods: We obtained annual reported rates of chlamydia, gonorrhea, and syphilis from the Centers for Disease Control and Prevention, number of active shale wells from Enverus (formerly known as DrillingInfo), and sociodemographic covariates from the US Census Bureau. We used multivariable mixed-effects Poisson regression modeling to estimate rate ratios (RR) with 95% confidence intervals (CIs) adjusted for potential confounders and secular trends.

Results: In Texas, county-years with high drilling activity had 10% increased rates of chlamydia (RR, 1.10; 95% CI, 1.04–1.17) and 15% increased rates of gonorrhea (RR, 1.15; 95% CI, 1.04–1.28), compared with county-years with no drilling. No statistically significant associations were reported for syphilis or for any STIs in Colorado or North Dakota.

Conclusions: Associations between shale drilling and chlamydia and gonorrhea in Texas may reflect increased risk in areas with higher drilling activity and a greater number of major metropolitan areas. Interstate differences highlight the need for local epidemiology to prioritize community health policies.

The extraction of oil and natural gas from unconventional sources such as deep shale rock formations using techniques including horizontal drilling and high-volume hydraulic fracturing has helped position the United States as the leading global producer of both crude oil and natural gas.[1,2] In 2018, horizontal drilling was responsible for approximately 60% of both oil and natural gas production in the United States.[3] The accelerated industrial expansion, particularly in rural areas, has been suggested to increase local employment and stimulate the local economy through increased patronage of hospitality businesses and royalty payments to residents.[4] Conversely, others have found that economic benefits, particularly that of local job creation, may have been overstated and that these potential benefits have come at a cost to the health of host communities in the form of impacted air and water quality, transportation infrastructure, and noise levels.[5,6]

Unconventional oil and gas (UOG) operations are complex, multiphase processes often carried out by regional or national companies using specialized workers who commute across counties or states.[7] The largest boost in employment, and thus the largest influx of these nonlocal workers, likely occurs within the initial phases of development due to the need for construction of the well site, transport of materials and water, and operation of drilling rigs.[8] Few health studies of the UOG industry have examined the potential for indirect morbidities occurring at the community-level from increased labor migration.

An influx of nonlocal laborers has been associated with increases in sexually transmitted infections (STIs), including HIV, in numerous prior settings, including areas of resource extraction.[9–12] Migration increases mixing between population groups, creating more opportunities for sexual transmission of infections.[13] The introduction and growth of the UOG industry, which is 80% male, leads to an increase in young, male workers often living in temporary workcamps characterized by a masculinized culture, separated from their usual social milieu and long-term sexual partners, and potentially with available access to sex workers.[9,13,14] This reliance of the UOG industry on transient labor from other states may impact population mixing patterns, including sexual networks in host communities.[15]

Three previous studies have observed an association between UOG development and an increase in certain STIs, all conducted in the eastern United States. One study focused on counties in New York, Ohio, Pennsylvania, and West Virginia that overlaid the Marcellus Shale formation, one of the highest producing shale resources in the United States. This study found that counties experiencing a "fracking boom" (≥50 hydraulic fracturing wells drilled in a year) experienced a 20% increase in gonorrhea compared with counties not experiencing a "fracking boom."[16] A second study of all counties in Ohio found that counties with high shale gas activity (>10 shale gas wells permitted in a year) experienced a 21% increased rate of chlamydia and a 19% increased rate of gonorrhea compared with counties with no such activity.[17] A third study found that Pennsylvania counties with UOG activity experienced a 7.8% increased rate of gonorrhea and a 2.6% increased rate of chlamydia, relative to the average state rates.[18]

Although these studies contribute important information on the potential community health impacts related to UOG development, they focus exclusively on communities in the Marcellus Shale region of the eastern United States, despite the fact that the midwestern and western United States also host high-producing

From the Departments of *Environmental Health Sciences and †Biostatistics, Yale School of Public Health, New Haven, CT; ‡Department of Environmental Health, Harvard T.H. Chan School of Public Health; §Department of Medicine, Brigham and Women's Hospital, and Channing Division of Network Medicine, Harvard Medical School, Boston, MA; and ¶Department of Epidemiology of Microbial Diseases, Yale School of Public Health, New Haven, CT

Elise G. Elliott is funded by a National Institutes of Health T32 ES007069 training grant.

The other authors declare no sources of funding or conflicts of interest.

Correspondence: Nicole Deziel, PhD, Yale School of Public Health, 60 College St, New Haven, CT 06520. E-mail: nicole.deziel@yale.edu.

Received for publication August 27, 2019, and accepted December 21, 2019.

DOI: 10.1097/OLQ.0000000000001127

shale formations. Therefore, the objective of our study was to examine the relationship between shale drilling activity and reported rates of chlamydia, gonorrhea, and syphilis in Colorado, North Dakota, and Texas from 2000 to 2016. We focus exclusively on the rapidly growing UOG industry (and not conventional drilling activity) because the majority of the labor force will likely continue to be concentrated in the UOG industry. The intent of this multistate, multiregion analysis was to evaluate the relationship between shale drilling activity and STIs in different regions to assess whether previously observed relationships were place-based phenomena or could be observed consistently across multiple geographic areas with UOG development.

MATERIALS AND METHODS

Study Design

We conducted an ecologic study that used annual shale drilling data, sociodemographic data, and reported STI rates for all counties in Colorado (n = 64), North Dakota (n = 53), and Texas (n = 254) for the years 2000 to 2016. We selected this period to allow for the modeling of STI rates before the start of shale drilling activity, which occurred in either 2005 or 2006 in each state. Because our time-dependent data varied across each county and year, the unit of analysis was county-year. The ecological study design allowed us to study health indicators that may follow from industrial changes at policy-relevant geographical scales.

STI Data Acquisition

We obtained the annual rates (cases per 100,000 population) of chlamydia, gonorrhea, and primary and secondary syphilis using the Centers for Disease Control and Prevention's (CDC's) AtlasPlus tool.[19] Case data used to calculate these rates are confirmed diagnoses reported to the CDC by county and state health departments, and population denominators are based on calendar year estimates from the US Census Bureau.

Sociodemographic Data Acquisition

We obtained time-varying data for numerous established sociodemographic risk factors for STI from the Decennial Census and American Community Survey (ACS) provided by the US Census Bureau.[20,21] Because the US Census queries people at their "usual residence" and not a temporary one, we included these variables to control for potential confounding due to differences in background demographic characteristics of county residents (not the shifting demographics due to the presence of temporary workers, which are not likely to be detected by these Census surveys). Variables included sex (percent population female), age (percent population 15–29 years of age), race (percent population identifying as white, black or African American, American Indian or Alaska Native, and Asian), ethnicity (percent population identifying as Hispanic or Latino), educational attainment (percent population 25 years and older who graduated high school and percent population 25 years and older with a bachelor's degree), income (median household income in US dollars per year), poverty (percent population who experienced poverty within the last 12 months), and health insurance coverage (percent population with health insurance). Population density was calculated by dividing the 2010 population estimates used by the CDC in formulating STI rates, by county area (in miles squared) as reported by the US Census Bureau in 2010.

Because the availability of sociodemographic data availability varied across the study period, decision rules were applied to assign values to each county-year. Specifically, because ACS data first became available for 2005 to 2009, data from the 2000 Decennial Census were applied to the years 2000 to 2004. Data from the 2005 to 2009 ACS 5-year estimates were applied to the years 2005 to 2009. The ACS 5-year estimates ending in the given year were applied to the years 2010 to 2016 (e.g., the 2011–2015 ACS 5-year estimates were applied to the year 2015). Because the variable percent population with health insurance did not become available until the 2008 to 2012 ACS, the values from the 2008 to 2012 ACS 5-year estimates were assigned to the years 2000 to 2012; the ACS 5-year estimates ending in the given year were then applied to the years 2013 to 2016 for subsequent years, consistent with the assignments of the other covariates.

Shale Drilling Data Acquisition

We used data pertaining to county-level shale drilling activity from Enverus—a commercially available data set of drilling activity across the United States—to construct a metric for the number of new shale wells drilled or "spudded" per county per year, considering all active wells with a spud date between January 1, 2000, and December 31, 2016.[22]

To focus the analysis on UOG development, we only included oil and gas wells targeting a shale formation. A well was identified as targeting a shale formation if the name of the target formation was identified as a major shale play by the US Energy Information Administration or if the target formation contained the term "shale."[23] Among the wells meeting our inclusion criteria in Colorado (n = 6543), 96% targeted the Niobrara formation, followed by the Baxter-Mancos (3%), and the Pierre (1%) formations. Among wells meeting our inclusion criteria in North Dakota (n = 12,642), 65% targeted the Bakken formation and 35% targeted the Three Forks formation. Of the wells included in Texas (n = 32,998), 48% targeted the Eagle Ford formation and 44% targeted the Barnett formation followed by the Haynesville-Bossier (3%), Bone Spring (2%), Delaware (2%), and Spraberry (1%) formations.

Based on a visual inspection of the distribution of nonzero values for spuds targeting a shale formation per county-year across all 3 states, we identified 50 shale spuds as a natural cut-point in the distribution and therefore an appropriate delineator of high and low shale drilling activity. Each county-year was classified according to its shale drilling activity: none (0 spuds targeting shale), low (1–49 spuds targeting shale), and high (≥50 spuds targeting shale) for the study period 2000 to 2016.

Statistical Analysis

In univariable analyses, we examined whether there were differences in the distribution of individual sociodemographic variables or reported STI rates within county-years with 0, 1–49, and ≥50 spuds targeting shale for Colorado, North Dakota, and Texas (2000–2016) using analysis of variance.

In multivariable models constructed separately for each state, rate ratios (RRs) with 95% confidence intervals (CIs) were calculated for the association between county-year shale drilling activity and reported cases of chlamydia, gonorrhea, and syphilis, using a mixed-effects Poisson regression model fitted using Proc Glimmix in SAS (SAS Institute, Cary, NC). Each model included a log of county population for each county-year as an offset term to account for the impact that variability in population would have on expected STI counts. A county-level random effect was included to establish a baseline STI rate for each county and to control for the potential correlation of rates across time within each county. An observation-level random effect was included to control for any excess variability in the STI case data that was unexplained by the covariates (i.e., overdispersion). Year was included in each model as a categorical variable to account for secular trends in STI counts over time (i.e., the background increase in STI over the study period), with the earliest year for which STI data were available for that state and disease as the reference. Shale drilling activity was included in all models as the independent variable of interest.

All sociodemographic covariates were initially included in our final models, to control for any potential confounding resulting from differences in background demographic characteristics of county residents. When 2 were highly correlated ($|r_{\text{Spearman}}| \geq 0.7$), 1 was removed from the model to avoid estimation troubles caused by multicollinearity. The final models included all remaining sociodemographic covariates, regardless of their statistical significance in the model to more completely account for potential confounding. Models were kept consistent within each state across the 3 STIs. Before inclusion, all covariates were standardized on a state-by-state basis to improve stability during model fitting, and the results were back-transformed to the appropriate scale for interpretation. In sensitivity analyses, we constructed more parsimonious models in which we retained only sociodemographic variables that were statistically significant at $P < 0.05$. In addition, we reran our models removing the covariates "population density" and "% population female" to verify we were not inappropriately adjusting for variables on the causal pathway, which could occur if these variables were in fact sensitive to demographic shifts resulting from the influx of male workers (in contrast to our assumption). All results from sensitivity analyses with more parsimonious models were consistent with the primary models; therefore, results from only the more fully adjusted models are presented.

RESULTS

Colorado

In Colorado, shale drilling activity exhibited a bimodal distribution across the study period. The number of active spuds targeting a shale formation increased from 2000 to 2005, declined to a minimum in 2009, then rose to a maximum in 2014. Average annual rates of all reported STI mirrored and usually remained below rising national trends (Fig. 1).

The study period included 1088 county-years (64 counties × 17 years each; Table 1). Of these county-years, 17 (1.6%) experienced high shale drilling activity, 133 (12.2%) experienced low shale drilling activity, and 938 (86.2%) experienced no shale drilling activity. County-years with high shale drilling activity were generally less populated, had a lower percent white population, had lower educational attainment, and had poorer health insurance coverage compared with county-years with low or no shale drilling activity.

No association was observed for the relationship between shale drilling activity and rates of either chlamydia or gonorrhea. An elevated monotonic relationship between shale drilling activity and rates of syphilis was observed in unadjusted models, but did not remain in adjusted models (Table 2).

North Dakota

In North Dakota, shale drilling first commenced in 2005, experienced a slight decrease in 2009, and increased steadily to a maximum number of active shale spuds in 2014. Average annual reported rates of all STI increased throughout the study period and generally remained far below national trends (Fig. 1).

The study period included 901 county-years (53 counties × 17 years each; Table 1). Of these county-years, 43 (4.8%) experienced high shale drilling activity, 61 (6.8%) experienced low shale drilling activity, and 797 (88.5%) experienced no shale drilling activity. County-years with high shale drilling activity had lower population density, lower educational attainment, and higher median household income compared with county-years with low or no shale drilling activity. Population density in all county-years in North Dakota was over an order of magnitude lower than the population densities in Colorado and Texas.

A statistically significant association was observed between high shale drilling activity and rates of both chlamydia and gonorrhea in unadjusted models, but did not remain after adjustment for

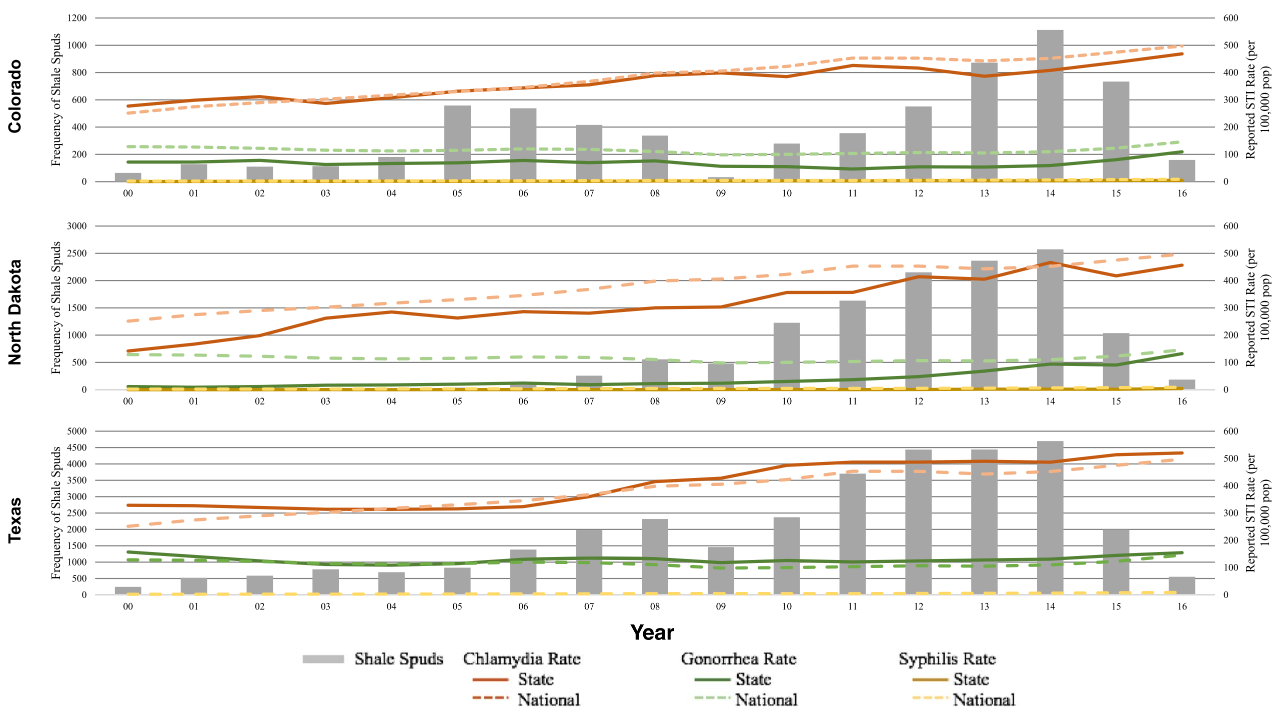

Figure 1. Reported sexually transmitted infection (STI) rates and frequency of shale spuds in Colorado, North Dakota, and Texas (2000–2016).

TABLE 1. Distribution of Exposure, Sociodemographic, and Outcome Variables Among County-Years With 0 Spuds Targeting Shale, 1–49 Spuds Targeting Shale, and ≥50 Spuds Targeting Shale in Colorado, North Dakota, and Texas (2000–2016)

	Colorado County-Years				North Dakota County-Years				Texas County-Years			
Exposure	0 Shale Spuds (n = 938), Mean (SD)	<50 Shale Spuds (n = 133), Mean (SD)	≥50 Shale Spuds (n = 17), Mean (SD)	*P**	0 Shale Spuds (n = 797), Mean (SD)	<50 Shale Spuds (n = 61), Mean (SD)	≥50 Shale Spuds (n = 43), Mean (SD)	*P**	0 Shale Spuds (n = 3,696), Mean (SD)	<50 Shale Spuds (n = 481), Mean (SD)	≥50 Shale Spuds (n = 141), Mean (SD)	*P**
Active shale spuds	0	5.6 (5.9)	340.8 (292.6)	—	0	15.8 (14.2)	271.6 (208.4)	—	0	9.3 (12.0)	202.4 (147.0)	—
Sociodemographic factors												
Population density, ppsm	156.5 (567.9)	54.3 (142.2)	30.2 (32.1)	0.079	9.1 (15.6)	4.6 (6.1)	5.1 (5.2)	0.021	87.1 (251.9)	99.7 (373.3)	291.7 (558.4)	<0.001
% Female	48.2 (3.9)	48.8 (2.6)	50.5 (0.6)	0.015	49.6 (1.4)	49.1 (1.9)	48.0 (1.7)	<0.001	49.7 (3.0)	48.6 (3.9)	48.9 (4.0)	<0.001
% Age 15–29 y	18.8 (4.9)	19.7 (4.0)	19.0 (2.8)	0.088	17.0 (4.9)	16.3 (4.0)	18.6 (3.7)	0.042	19.5 (4.1)	20.3 (4.5)	20.8 (3.7)	<0.001
% White	88.8 (7.4)	90.4 (5.7)	91.7 (3.5)	0.017	91.6 (17.4)	92.5 (8.7)	82.7 (11.6)	0.003	82.5 (9.0)	82.3 (8.8)	82.1 (11.0)	0.808
% Black	1.6 (2.5)	1.6 (2.4)	2.6 (3.9)	0.225	0.8 (1.6)	0.9 (1.6)	0.9 (1.8)	0.843	6.7 (6.9)	6.8 (6.9)	5.3 (5.3)	0.050
% Asian	1.1 (1.3)	0.9 (1.3)	0.6 (0.6)	0.085	0.6 (1.1)	1.1 (1.6)	0.8 (1.1)	0.005	1.1 (1.9)	0.8 (1.6)	1.7 (2.3)	<0.001
% Hispanic	18.1 (15.1)	16.5 (9.9)	21.7 (6.4)	0.268	1.4 (1.6)	1.6 (1.4)	2.6 (1.4)	<0.001	30.1 (22.4)	32.0 (24.4)	37.1 (29.5)	<0.001
% Native	1.5 (2.0)	1.3 (1.3)	0.7 (0.3)	0.106	6.3 (17.2)	5.5 (7.7)	13.2 (10.8)	0.024	0.8 (1.2)	1.4 (3.0)	1.3 (2.4)	<0.001
% High school	27.4 (7.1)	30.6 (5.8)	31.1 (3.7)	<0.001	31.7 (4.0)	32.9 (3.6)	31.6 (2.9)	0.063	31.6 (5.6)	33.7 (6.1)	30.7 (7.5)	<0.001
% Bachelor's degree	19.1 (8.9)	16.0 (6.6)	15.0 (2.7)	<0.001	14.7 (3.7)	15.3 (2.2)	15.5 (2.2)	0.172	11.8 (4.7)	10.6 (4.3)	12.8 (6.3)	<0.001
Median household income, US dollars	47,064.4 (14,799.8)	47,161.0 (10,181.7)	46,249.6 (10,861.8)	0.970	41,356.2 (10,502.8)	50,646.2 (10,493.7)	58,808.6 (11,017.4)	<0.001	40,176.8 (11,010.0)	42,229.4 (10,798.1)	47,712.8 (11,617.3)	<0.001
% Poverty	13.2 (6.1)	12.4 (3.0)	12.2 (1.8)	0.324	12.8 (7.0)	10.6 (2.5)	11.3 (3.1)	0.020	17.5 (6.6)	17.1 (6.9)	16.4 (7.6)	0.083
% Health insurance	83.0 (4.8)	82.6 (4.6)	85.0 (1.4)	0.138	90.1 (5.8)	87.9 (3.7)	86.1 (3.9)	<0.001	78.2 (4.9)	78.2 (4.9)	77.8 (5.4)	0.655
Outcomes												
Chlamydia rate (per 100,000 population)	279.3 (868.4)	321.0 (667.3)	391.8 (497.3)	0.762	45.1 (109.1)	25.1 (45.9)	45.6 (52.7)	0.351	371.4 (1614.2)	419.0 (1935.0)	908.6 (2002.4)	<0.001
Gonorrhea rate (per 100,000 population)	54.8 (208.9)	35.9 (91.3)	33.4 (47.0)	0.541	6.2 (19.9)	2.6 (5.7)	4.7 (6.5)	0.328	117.2 (558.5)	129.3 (658.6)	280.7 (702.4)	0.004
Syphilis rate (per 100,000 population)	1.8 (9.9)	1.5 (4.8)	1.5 (2.2)	0.951	0.1 (0.8)	0.1 (0.4)	0.1 (0.3)	0.884	4.3 (28.4)	4.4 (27.1)	12.2 (36.4)	0.006

**P* values based on analysis of variance.

covariates. The association between shale drilling activity and rates of syphilis was nonmonotonic and null in both unadjusted and adjusted models (Table 2).

Texas

Texas has a longer history of both conventional and UOG development than either Colorado or North Dakota. Shale drilling activity experienced a noticeable increase between 2006 and 2008, which decreased in 2009 before rising again to a maximal number of shale wells in 2014. Meanwhile, reported rates of all STI generally followed and remained higher than national trends throughout the study period (Fig. 1).

The study period included 4318 county-years (254 counties × 17 years each; Table 1). Of these county-years, 141 (3.3%) experienced high shale drilling activity, 481 (11.1%) experienced low shale drilling activity, and 3696 (86%) experienced no shale drilling activity. County-years with high shale drilling activity generally had a much higher population density and a slightly higher Hispanic population compared with county-years with either low or no shale drilling activity. Across the state, Texas county-years were generally more population dense, had higher black and Hispanic populations, and had higher levels of poverty compared with county-years across Colorado and North Dakota.

After adjusting for sociodemographic covariates, county-years with high shale drilling had a 10% increased rate of chlamydia (RR, 1.10; 95% CI, 1.04–1.17) and a 15% (RR, 1.15; 95% CI, 1.04–1.28) increased rate of gonorrhea compared with county-years with no shale drilling activity. No association was observed for the relationship between shale drilling activity and rates of syphilis (Table 2).

DISCUSSION

This work represents the first multistate, multiregion analysis of shale drilling activity and STI rates in the United States. The findings of a positive association between high shale drilling activity and annual county-level rates of gonorrhea and chlamydia in Texas support previous findings from studies of the Marcellus Shale region.[16–18] The lack of associations in Colorado and North Dakota highlights heterogeneity in observed relationships across geographic areas. The null association for syphilis across all 3 states was consistent with prior literature.

Incongruous findings between Texas, Colorado, and North Dakota may be due to a few factors. Although all 3 states experienced a significant increase in shale drilling activity throughout the study period, the increase in Texas was orders of magnitude higher than that observed in either Colorado or North Dakota. This higher intensity of drilling activity may have been associated with a larger influx of workers, which could increase the likelihood of higher STI transmission rates. In addition, the observed association in Texas may be due to its greater number of major metropolitan areas, also referred to as metropolitan statistical areas (MSAs), which have a population equal to or greater than 50,000. Metropolitan statistical areas generally have rates of STI higher than the national average.[24] The out-of-county and out-of-state workers who commute through or visit these MSA could be acquiring STIs in these metropolitan areas, and then introducing the infections in the counties where they are working. In 2010, Texas had 25 MSAs, whereas Colorado had 7 and North Dakota had 3.[25] This hypothesized explanation is also consistent with similar associations previously observed for counties with high shale gas activity in Ohio and Pennsylvania, which both had 16 MSAs in 2010.[17,18,25]

There was no observed association between shale drilling activity and rates of syphilis. This STI occurs most commonly in men who have sex with men, which may compose only a small proportion of the male population in counties with shale drilling activity, thus making the detection of any association particularly difficult.[26]

An increase in rates of chlamydia is concerning because asymptomatic individuals may remain untreated, and an association with gonorrhea is concerning given the recent rise in antibiotic resistant infections.[26] Although these STIs are generally treatable, they have substantial health care costs, and some infections have long-term consequences, such as negative effects on fertility.[27] Future research is needed to further evaluate these associations at the individual level. In addition, an investigation of the transmission dynamics in communities with high shale drilling activity could inform targeted interventions aimed at reducing STI transmission rates among the general population.

Because our analysis is ecologic in nature, results cannot be interpreted at an individual level. However, this ecologic analysis provides an important assessment of community-level health impacts of the UOG industry. Solutions to address potential human health impacts of UOG development or increasing incidence of STIs are likely to be implemented at a community level (e.g., county or state), therefore highlighting the policy relevance of the geographical units studied.[28] Shale drilling is used as the exposure of interest in this study because it is a measurable factor that logically reflects the changes in social forces and dynamics that follow from industrial changes and may facilitate STI transmission. One aspect of this underlying mechanism to examine would be to quantify the number of nonlocal workers migrating to counties with low, medium, or high shale drilling activity, yet there are very limited data on the size and movements of this workforce.

Some important limitations of this study should be noted. Based on our exposure classification, there were fewer county-years in the high shale drilling category for each state, which could have limited statistical power. Also, we did not directly adjust for possible spatially correlated random effects in the data. Other limitations include the reliance on a passive STI surveillance system, which is likely to produce an underestimate of the true STI burden. Although we included year as a categorical variable in our models to account for any secular trends in underlying STI rates, we cannot rule out that the observed elevated STI rates in Texas are due not to a true increase in the community-level burden of STI, but rather to expanded screening, increased use of more sensitive diagnostic tests, or better national reporting.

This study also underscores the need for a better understanding of the UOG worker population and any STI-related health burdens they may be experiencing. Because reported STI rates are aggregated at the county level based on patient's residential address, they may not capture the health burden of the nonlocal UOG workers themselves. To the extent that nonlocal UOG workers are influencing these STI rates, they would likely benefit from improved access to testing and treatment, especially because they may be disconnected from their primary sources of health care. Furthermore, these workers may already be facing numerous other occupational hazards including hazardous respiratory exposures, injuries, and fatalities.[29,30] Future research should focus on improving an understanding of the transmission patterns present between nonlocal workers and community members without further stigmatizing nonlocal UOG workers.[31]

In conclusion, this study provides important information for counties that are either currently or soon to be experiencing shale drilling activity. Associations between shale drilling and chlamydia and gonorrhea in Texas are consistent with the previously observed associations in the Marcellus Shale, and may reflect increased risk in areas with greater drilling activity and increased proximity to major metropolitan areas. Observed differences in relationships between shale drilling and STI rates across states

TABLE 2. Rate Ratios (RRs) and 95% Confidence Intervals (95% CIs) for the Association Between Shale Activity and Reported Sexually Transmitted Infections (STI) in Colorado, North Dakota, and Texas (2000–2016)

	Colorado			North Dakota			Texas		
	County-Years* (n = 1088)	Unadjusted RR† (95% CI)	Adjusted RR§ (95% CI)	County-Years* (n = 901)	Unadjusted RR† (95% CI)	Adjusted RR¶ (95% CI)	County-Years* (n = 4,318)	Unadjusted RR† (95% CI)	Adjusted RR‖ (95% CI)
Chlamydia									
No shale spuds (ref)	880	1.00	1.00	691	1.00	1.00	3696	1.00	1.00
<50 shale spuds	127	1.07 (0.96–1.19)	1.01 (0.94–1.07)	61	1.31 (1.00–1.71)	0.89 (0.72–1.11)	481	1.14 (1.09–1.19)	1.02 (0.99–1.06)
≥50 shale spuds	17	0.86 (0.64–1.15)	0.82 (0.69–0.99)	43	1.88 (1.38–2.55)	0.96 (0.73–1.27)	141	1.36 (1.26–1.47)	1.10 (1.04–1.17)
Gonorrhea									
No shale spuds (ref)	938	1.00	1.00	691	1.00	1.00	3696	1.00	1.00
<50 shale spuds	133	1.00 (0.83–1.20)	1.06 (0.91–1.22)	61	1.31 (0.76–2.27)	1.04 (0.67–1.62)	481	1.02 (0.96–1.08)	1.02 (0.96–1.08)
≥50 shale spuds	17	1.03 (0.64–1.67)	1.01 (0.70–1.45)	43	2.25 (1.21–4.19)	1.12 (0.64–1.95)	141	1.13 (1.02–1.26)	1.15 (1.04–1.28)
Syphilis									
No shale spuds (ref)	938	1.00	1.00	544	1.00	1.00	3696	1.00	1.00
<50 shale spuds	133	1.74 (1.19–2.55)	1.21 (0.93–1.57)	52	2.03 (0.52–7.99)	0.93 (0.14–6.37)	481	1.23 (0.91–1.67)	0.94 (NA–NA) ‡
≥50 shale spuds	17	4.06 (1.61–10.26)	1.33 (0.65–2.73)	40	1.62 (0.38–6.94)	0.63 (0.09–4.25)	141	1.33 (0.79–2.25)	0.88 (NA–NA)‡

*County-years may not sum to total because of missing data.

†Unadjusted models include log(population) offset, county-level random effects, and observation-level random effects.

‡Ninety-five percent CI estimates were not available for adjusted syphilis models in Texas because of model nonconvergence.

§Colorado: adjusted Poisson regression model includes log(population) offset, county-level random effects, observation-level random effects, and adjustment for population density (ppsm), % female, % age 15–29 years, % black, % Hispanic, % high school, % poverty, % health insurance, and year.

¶North Dakota: adjusted Poisson model includes log(population) offset, county-level random effects, observation-level random effects, and adjustment for population density (ppsm), % female, % age 15–29 years, % white, % black, % Hispanic, % American Indian or Alaska Native, % high school, % bachelor's degree, % poverty, % health insurance, median household income (US dollars), and year.

‖Texas: adjusted Poisson regression model includes log(population) offset, county-level random effects, observation-level random effects, and adjustment for population density (ppsm), % female, % age 15–29 years, % white, % black, % Hispanic, % high school, % bachelor's degree, % poverty, % health insurance, median household income (US dollars), and year. Ninety-five percent CI unavailable for syphilis model in Texas.

highlight the need for local epidemiology to better inform an understanding of the underlying transmission dynamics. Future studies, including surveys of the sexual behaviors of workers, sexual behaviors of community members, and sexual mixing patterns, could shed additional light on the possible mechanism underlying observed associations.

REFERENCES

1. Dunn C, Hess T. Today in energy: The United States is now the largest global crude oil producer. Available at: https://www.eia.gov/todayinenergy/detail.php?id=37053#. Published September 12, 2018. Accessed May 10, 2019.
2. United States Energy Information Administration. Today in energy: United States remains the world's top producer of petroleum and natural gas hydrocarbons. Available at: https://www.eia.gov/todayinenergy/detail.php?id=36292. Published May 21, 2018. Accessed May 10, 2019.
3. United States Energy Information Administration. Frequently asked questions. Available at: https://www.eia.gov/tools/faqs/. Updated September 5, 2019. Accessed December 16, 2019.
4. Feyrer J, Mansur ET, Sacerdote B. Geographic dispersion of economic shocks: Evidence from the fracking revolution. Am Econ Rev 2017; 107:1313–1334.
5. Weber JG. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. Energy Econ 2012; 34: 1580–1588.
6. Gorski I, Schwartz BS. Environmental health concerns from unconventional natural gas development. In: Oxford Research Encyclopedia of Global Public Health. Oxford: Oxford University Press, 2019.
7. Wrenn DH, Kelsey TW, Jaenicke EC. Resident vs. nonresident employment associated with Marcellus shale development. J Agr Resour Econ 2015; 44:1–19.
8. Komarek TM. Labor market dynamics and the unconventional natural gas boom: Evidence from the Marcellus region. Resour Energy Econ 2016; 45:1–17.
9. Westwood E, Orenstein M. Does resource development increase community sexually transmitted infections? An environmental scan. Extractive Industries Soc 2016; 3:240–248.
10. Udoh IA, Stammen RM, Mantell JE. Corruption and oil exploration: Expert agreement about the prevention of HIV/AIDS in the Niger Delta of Nigeria. Health Educ Res 2008; 34:670–681.
11. Zuma K, Lurie MN, Williams BG, et al. Risk factors of sexually transmitted infections among migrant and non-migrant sexual partnerships from rural South Africa. Epidemiol Infect 2005; 133:421–428.
12. Baltazar CS, Horth R, Inguane C, et al. HIV prevalence and risk behaviors among Mozambicans working in south African mines. AIDS Behav 2015; 19(Suppl 1):59–67.
13. Shepard M, Betz M, Snyder A. The shale boom and family structure: Oil and gas employment growth relationship to marriage, divorce, and cohabitation. Rural Sociol 2019; 1–35.
14. United States Department of Labor. Labor force statistics from the current population survey. Available at: https://www.bls.gov/cps/cpsaat18.htm. Accessed October 14, 2019.
15. Sangaramoorthy T, Jamison AM, Boyle MD, et al. Place-based perceptions of the impacts of fracking along the Marcellus shale. Soc Sci Med 2016; 151:27–37.
16. Komarek T, Cseh A. Fracking and public health: Evidence from gonorrhea incidence in the Marcellus shale region. J Public Health Policy 2017; 38:464–481.
17. Deziel NC, Humeau Z, Elliott EG, et al. Shale gas activity and increased rates of sexually transmitted infections in Ohio, 2000–2016. PLoS One 2018; 13:e0194203.
18. Beleche T, Cintina I. Fracking and risky behaviors: Evidence from Pennsylvania. Econ Hum Biol 2018; 31:69–82.
19. U.S. Centers for Disease Control and Prevention. National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention (NCHHSTP) AtlasPlus tool. Available at: https://www.cdc.gov/nchhstp/atlas/index.htm. Updated 2017. Accessed May 14, 2019.
20. U.S. Centers for Disease Control and Prevention. CDC health disparities and inequalities report—United States 2013. MMWR Suppl 2013; 62. Available at: https://www.cdc.gov/mmwr/pdf/other/su6203.pdf. Published November 22, 2013. Accessed May 14, 2019.
21. U.S. Census Bureau. Available at: https://data.census.gov/cedsci/. Updated 2019. Accessed May 14, 2019.
22. Enverus. DI application. Available at: https://www.enverus.com/. Updated 2019. Accessed May 14, 2019.
23. U.S. Energy Information Administration. Summary maps: Shale gas and oil plays, lower 48 states. Available at: https://www.eia.gov/maps/maps.htm. Published June 30, 2016. Accessed May 14, 2019.
24. U.S Centers for Disease Control and Prevention. Sexually transmitted disease surveillance 2018. Available at: https://www.cdc.gov/std/stats18/STDSurveillance2018-full-report.pdf. Published October 10, 2018. Accessed July 27, 2019.
25. United State Census Bureau. 2010 Census geographic entity tallies by state and type. Available at: https://www.census.gov/geographies/reference-files/time-series/geo/tallies.html#par_textimage. Accessed July 12, 2019.
26. U.S. Centers for Disease Control and Prevention. Sexually transmitted diseases (STDs). Available at: https://www.cdc.gov/std/default.htm. Published April 2, 2019. Accessed October 16, 2019.
27. Tsevat DG, Wiesenfeld HC, Parks C, et al. Sexually transmitted diseases and infertility. Am J Obstet Gynecol 2017; 216:1–9.
28. Jennings JM, Leifheit KM. Eviction as a social determinant of sexual health outcomes. Sex Transm Dis 2019; 46:69–71.
29. Esswein EJ, Breitenstein M, Snawder J, et al. Occupational exposures to respirable crystalline silica during hydraulic fracturing. J Occup Environ Hyg 2013; 10:347–356.
30. Witter RZ, Tenney L, Clark S, et al. Occupational exposures in the oil and gas extraction industry: State of the science and research recommendations. Am J Ind Med 2014; 57:847–856.
31. Filteau MR. Go back to Texas, gas bastards! How a newcomer population of itinerant energy workers manage dirty work stigma in the marcellus shale region. Soc Nat Resour 2015; 28:1153–1167.