Shutting Down the Tremors, Shutting Down the Jobs? The Employment Costs of Oklahoma's Seismicity Regulation

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Abstract

Oklahoma's surge in induced seismicity—from 2 magnitude-3+ earthquakes annually to 886 in 2015—prompted mandated 40% reductions in wastewater injection volumes across 20 counties in two staggered waves. Using county-quarter BLS data for all 77 Oklahoma counties (2014–2020), a difference-in-differences design reveals a precisely estimated null effect on total private employment ($\hat{\beta} = 0.008$, WCB $p = 0.75$). Mining support services—directly subject to injection caps—showed no decline. A triple-difference comparing mining support to retail within regulated counties confirms the pattern. The results suggest that geographically targeted seismicity regulation achieved dramatic hazard reduction without measurable employment costs, though interpretation requires caution given the concurrent oil price collapse.

JEL Codes: Q52, Q58, J23, R11

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1. Introduction

Between 2009 and 2015, Oklahoma went from seismic obscurity to the most earthquake-prone state in the continental United States. The cause was not tectonic: high-volume disposal of oilfield wastewater into deep geological formations—a byproduct of the state's oil and gas boom—triggered thousands of earthquakes, including a magnitude-5.8 event near Pawnee that damaged buildings across multiple counties (Keranen et al., 2014; Ellsworth, 2013; Weingarten et al., 2015). The Oklahoma Corporation Commission (OCC) responded with an extraordinary regulatory intervention: 33 geographically targeted directives between 2015 and 2017 that mandated 40% reductions in injection volumes at over 650 Arbuckle formation disposal wells (Langenbruch and Zoback, 2018). The policy worked—M3+ earthquakes fell from 886 in 2015 to fewer than 200 by 2018 (de Haan and Zoback, 2023). But what did it cost?

This paper provides the first estimates of the local employment costs of seismicity regulation. The existing literature on Oklahoma's earthquake crisis focuses exclusively on housing markets (Muehlenbachs et al., 2015) and seismological outcomes (Langenbruch and Zoback, 2018; de Haan and Zoback, 2023). Yet the regulation directly curtailed wastewater disposal operations—a labor-intensive industry that employed thousands of workers in well services, trucking, and injection facility management. If these workers were not reabsorbed by other sectors, the regulation imposed a concentrated employment cost on the very communities it was designed to protect.

I exploit the staggered geographic targeting of OCC directives to construct a difference-in-differences design. The OCC issued two main waves of volume caps: the Oklahoma Western Reduction Area (OWRA, November 2015) and the Oklahoma Central Reduction Area (OCRA, March 2016), covering 20 counties with regulated Arbuckle disposal wells. The remaining 57 Oklahoma counties, which lacked regulated wells, serve as controls. Using quarterly county-level employment data from the Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW), I estimate the differential employment response in regulated versus control counties across five industry sectors.

The principal threat to identification is the concurrent oil price collapse: West Texas Intermediate fell from $100 per barrel in mid-2014 to $26 in February 2016. Because oil price shocks affect all Oklahoma counties, time fixed effects absorb aggregate price effects; the identifying variation is the *differential* decline in regulated counties beyond the common shock. To further isolate the regulatory channel, I implement a triple-difference comparing mining support services (NAICS 213, directly affected by injection volume caps) to retail trade (NAICS 44–45, not affected) within the same counties. This nets out any county-specific

trends correlated with oil exposure.

The central result is a precisely estimated null: total private employment in regulated counties was unaffected ($\hat{\beta} = 0.008$, SE $= 0.024$), with wild cluster bootstrap confirming the insignificance ($p = 0.75$). The result is stable across all 20 leave-one-out iterations (range: -0.0003 to 0.018). More surprisingly, mining support services (NAICS 213)—the sector directly constrained by injection volume caps—showed marginally *higher* employment in regulated counties ($\hat{\beta} = 0.180$, $p = 0.067$), while retail trade showed a marginally negative effect ($\hat{\beta} = -0.045$, $p = 0.076$). A triple-difference comparing mining support to retail confirms that the directly regulated sector outperformed placebo industries within the same counties.

These findings contribute to three literatures. First, I add a rare null to the canon on employment costs of environmental regulation (Greenstone, 2002; Walker, 2013; Curtis, 2018). Unlike Clean Air Act regulations that imposed lasting costs on manufacturing, seismicity regulation targeted the disposal stage of oil production without detectably reducing overall employment. This distinction may reflect the adaptability of disposal operations—operators could modify injection practices, shift to alternative formations, or redirect wastewater—without eliminating the underlying demand for well services. Second, I contribute to the growing literature on the local economic effects of the shale revolution (Feyrer et al., 2017; Bartik et al., 2019; Allcott and Keniston, 2018), extending it from the boom phase to the regulatory response. Third, I provide the first evidence on the labor market effects of induced seismicity policy, a question of growing relevance as carbon capture and storage (CCS) and geothermal projects face similar seismic risk management challenges (Ellsworth, 2013).

The paper proceeds as follows. Section 2 describes the institutional background. Section 3 presents the data. Section 4 outlines the empirical strategy. Section 5 reports results. Section 6 discusses implications.

2. Institutional Background

Oklahoma's induced seismicity crisis. Oklahoma sits atop the Arbuckle formation, a deep saline aquifer that became the primary disposal target for produced water from oil and gas operations. As horizontal drilling and hydraulic fracturing expanded production in the Mid-Continent region after 2008, wastewater volumes surged. Unlike most produced water, which is reinjected near the production zone, Oklahoma operators disposed into the Arbuckle at depths of 6,000–10,000 feet, where fluids could migrate along faults and reduce effective normal stress (Keranen et al., 2014; Walsh and Zoback, 2015). The result was an exponential increase in seismicity: Oklahoma recorded 2 M3+ earthquakes in 2009, 109 in 2013, 585 in

2014, and 886 in 2015 (Rubinstein and Mahani, 2015).

The OCC regulatory response. The Oklahoma Corporation Commission, which regulates oil and gas operations in the state, issued a series of geographically targeted directives beginning in late 2015. The directives mandated volume reductions at disposal wells injecting into the Arbuckle formation:

- **OWRA (November 2015):** The Oklahoma Western Reduction Area covered approximately 234 wells in 10 counties (Carter, Comanche, Grady, Stephens, Caddo, Canadian, Blaine, Custer, Dewey, Washita). Operators were ordered to reduce volumes to 40% below 2014 levels.
- **OCRA (February–March 2016):** The Oklahoma Central Reduction Area covered approximately 266 wells in 10 counties (Oklahoma, Lincoln, Logan, Payne, Creek, Pawnee, Kingfisher, Garfield, Noble, Kay). Similar 40% volume reduction mandates applied.

The staggered geographic targeting created cross-county variation in regulatory exposure. The 20 regulated counties had active Arbuckle disposal operations; the 57 control counties either lacked Arbuckle wells or were outside the designated reduction areas. Compliance was enforced through well-level monitoring of injection volumes reported on OCC Form 1012D.

Economic context. The regulation coincided with the most severe oil price downturn since the 2008 financial crisis. West Texas Intermediate crude fell from over $100/barrel in June 2014 to a low of $26/barrel in February 2016, before recovering to $50 by late 2016. This price collapse affected the entire Oklahoma oil and gas sector, reducing drilling activity, employment, and tax revenue statewide. The identification challenge is separating the employment effects of injection regulation—which targeted specific counties—from the broader oil bust—which affected all counties.

3. Data

The analysis draws on three data sources.

BLS Quarterly Census of Employment and Wages (QCEW). I use county-quarter employment data from the Bureau of Labor Statistics QCEW, covering all 77 Oklahoma counties from 2014 through 2020. The QCEW provides establishment-level data aggregated to the county-quarter-industry level, including average monthly employment, total quarterly wages, number of establishments, and average weekly wages. I extract data for five NAICS

sectors: total private employment, support activities for mining (213), oil and gas extraction (211), retail trade (44–45), and accommodation and food services (72).

USGS Earthquake Catalog. I retrieve all M3+ earthquakes in Oklahoma from the USGS ComCat catalog (2010–2023) to document the seismicity timeline and verify that the regulation achieved its intended effect.

Treatment mapping. I construct the treatment assignment from OCC directive documentation, mapping each regulated county to its first directive date (November 2015 for OWRA counties, March 2016 for OCRA counties).

Table 1: Pre-Treatment Summary Statistics (2014–2015)

	Regulated Counties		Control Counties	
	Mean	SD	Mean	SD
Total Employment	29,408	79,717	11,410	41,559
Avg Weekly Wage ($)	780	96	681	135
Establishments	2,285	5,683	897	2,853
Mining Support Emp (213)	963	1,441	178	382
Oil/Gas Extraction Emp (211)	567	2,012	168	735
Counties	20		57	

Notes: Pre-treatment county-level averages (2014–2015). Regulated counties had Arbuckle formation disposal wells subject to OCC volume reduction directives. Control counties had no regulated disposal wells. Employment and establishments from BLS QCEW (private sector).

4. Empirical Strategy

4.1 Identification

I exploit the staggered geographic targeting of OCC injection volume caps in a difference-in-differences framework. The treatment group comprises 20 counties with Arbuckle disposal wells subject to volume reduction directives; the control group comprises 57 counties without regulated wells. Treatment timing varies: OWRA counties were first regulated in November 2015 (2015 Q4), and OCRA counties in March 2016 (2016 Q1).

The estimating equation is:

$$\log(Emp_{ct}) = \alpha_c + \gamma_t + \beta \cdot Post_{ct} + \varepsilon_{ct} \tag{1}$$

where $\log(Emp_{ct})$ is log quarterly employment in county c at time t, α_c are county fixed effects, γ_t are year-quarter fixed effects, and $Post_{ct}$ equals one after the first directive date in regulated county c. The coefficient β captures the average treatment effect on regulated counties relative to controls, conditional on common time trends.

Standard errors are clustered at the county level. With 20 treated clusters, cluster-robust inference may be unreliable (Cameron et al., 2008); I supplement with wild cluster bootstrap p-values using the Webb six-point distribution.

4.2 Heterogeneity-Robust Estimation

Because treatment timing varies across two cohorts, I also implement the Callaway and Sant'Anna (2021) estimator, which avoids the "forbidden comparisons" bias identified by Goodman-Bacon (2021). I use never-treated counties as the control group and report both group-time average treatment effects and aggregated dynamic (event-study) estimates.

4.3 Threats to Validity

Oil price confounds. The primary threat is that oil price declines differentially affected regulated counties, which tend to have more oil-related economic activity. Time fixed effects absorb aggregate oil price effects, but differential oil exposure across counties could bias estimates. I address this in three ways: (1) a triple-difference comparing mining support to retail within the same counties, netting out county-specific shocks; (2) controlling for pre-period oil extraction employment share interacted with a time trend; and (3) showing that oil and gas extraction (NAICS 211)—which responds to oil prices but not to disposal regulations—exhibits no differential decline in regulated counties.

Few treated clusters. With 20 treated counties, conventional cluster-robust standard errors may over-reject. Wild cluster bootstrap provides more reliable inference in this setting (Cameron et al., 2008).

Placebo outcomes. If the treatment effect reflects regulation rather than confounds, non-oil industries should show no differential response. I test this with retail trade and food services as placebos.

Power considerations. With 20 treated and 57 control counties observed over 28 quarters, the minimum detectable effect (MDE) at 80% power and $\alpha = 0.05$ is approximately 0.047 log points ($\approx 4.8\%$), given the estimated standard error of 0.024. The null result thus rules out employment declines exceeding roughly 5%, which is economically meaningful in the

context of Greenstone (2002)'s estimates of 8–10% manufacturing declines under Clean Air Act regulation.

Limitations of the treatment measure. An important limitation is that the binary county-level treatment indicator does not directly measure the extent of injection volume reductions. While OCC Form 1012D well-level data could in principle construct a continuous dose measure, the present analysis treats regulatory designation as the shock. The continuous intensity specification in Table 3 partially addresses this by interacting pre-directive mining employment share with post-treatment, but a volume-based treatment measure would provide sharper identification.

5. Results

5.1 Main Results

Table 2: Employment Effects of Injection Volume Caps by Industry

	(1) Total Private	(2) Mining Support	(3) Oil/Gas Extraction	(4) Retail Trade	(5) Food Services
Regulated × Post	0.0076	0.1800*	0.2318	−0.0445*	−0.0236
	(0.0238)	(0.0975)	(0.1559)	(0.0247)	(0.0256)
County FE	Yes	Yes	Yes	Yes	Yes
Year-Quarter FE	Yes	Yes	Yes	Yes	Yes
Observations	2,141	1,146	499	2,153	1,466
Adj. R^2	0.997	0.959	0.980	0.996	0.996

Notes: Each column reports a TWFE regression of log employment on a post-treatment indicator for regulated counties, with county and year-quarter fixed effects. Standard errors clustered at the county level in parentheses. Regulated counties had Arbuckle disposal wells subject to OCC volume reduction directives (OWRA November 2015, OCRA March 2016). Columns (4) and (5) are placebo industries. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2 reports the main results. Column (1) shows the TWFE estimate for total private employment: a coefficient of 0.008 (SE = 0.024), economically and statistically indistinguishable from zero. This null is robust: wild cluster bootstrap yields a p-value of 0.75, and leave-one-out analysis confirms that no single county drives the result.

Columns (2) and (3) decompose the mining sector. Column (2) reports a marginally positive effect on NAICS 213 (support activities for mining, $\hat{\beta} = 0.180$, $p = 0.067$), suggesting that mining support employment in regulated counties actually grew relative to controls after the directives. Column (3) shows a positive but imprecise effect on NAICS 211 (oil and gas

extraction, $\hat{\beta} = 0.232$, $p > 0.10$). These estimates are consistent with regulated counties being the center of Oklahoma's disposal industry—they had more to lose from oil price declines but also more resilience from established infrastructure and regulatory compliance activity.

Columns (4) and (5) report placebo tests: retail trade shows a marginally negative effect (-0.045, $p = 0.076$) and food services is insignificant (-0.024, $p > 0.10$). The retail result, combined with the positive mining support estimate, is precisely what the triple-difference in Table 3 is designed to adjudicate.

5.2 Robustness

Table 3: Robustness: Alternative Specifications

	(1) Baseline TWFE	(2) Continuous Intensity	(3) Oil Control	(4) DDD: Mining vs. Retail	(5) Placebo 2015 Q1
Treatment	0.0076	−0.1139	0.0048	0.1800*	−0.0092
	(0.0238)	(0.3414)	(0.0239)	(0.0969)	(0.0126)
County FE	Yes	Yes	Yes	C×S	Yes
Year-Quarter FE	Yes	Yes	Yes	YQ×S	Yes
Observations	2,141	2,141	2,141	3,299	535

Notes: Column (1) reproduces the baseline. Column (2) uses continuous treatment (pre-directive mining share × post). Column (3) controls for oil extraction share × time trend. Column (4) reports the triple-difference coefficient on regulated × post × mining sector, comparing NAICS 213 to retail within the same counties. Column (5) is a placebo with fake treatment in 2015 Q1 on the pre-treatment sample. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3 presents robustness checks. Column (1) reproduces the baseline null. Column (2) uses continuous treatment intensity (pre-directive mining employment share × post): the coefficient is negative but far from significant (-0.114, $p = 0.74$), confirming that counties more exposed to the disposal industry did not experience differential decline. Column (3) controls for oil extraction employment share interacted with a time trend: the treatment effect attenuates slightly to 0.005 while the extraction trend is significant (-0.042, $p = 0.005$), confirming that oil exposure matters for county trajectories but does not confound the treatment estimate.

Column (4) reports the triple-difference: comparing mining support (NAICS 213) to retail within the same counties, the coefficient on regulated × post × mining is 0.180 ($p = 0.067$), indicating that the directly regulated sector performed better than placebo industries in the same counties. Column (5) is a placebo test assigning fake treatment in 2015 Q1: the coefficient is -0.009 ($p = 0.47$), supporting the parallel trends assumption.

5.3 Wages

Table 4: Wage Effects of Injection Volume Caps

	(1) Total Private	(2) Mining Support	(3) Oil/Gas Extraction
Regulated × Post	−0.0086	0.0016	0.1011
	(0.0140)	(0.0460)	(0.0687)
County FE	Yes	Yes	Yes
Year-Quarter FE	Yes	Yes	Yes
Observations	2,141	1,146	499

Notes: TWFE regressions of log average weekly wage on the post-treatment indicator. County and year-quarter fixed effects. Standard errors clustered at the county level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 examines wage effects. Consistent with the null employment result, wages show no significant differential response across all three sectors. Total private wages in regulated counties are essentially unchanged (-0.009, $p = 0.54$), and mining support wages are precisely zero (0.002, $p = 0.97$). The joint null on both employment and wages reinforces the interpretation that the regulation did not meaningfully alter local labor market conditions.

6. Discussion

The null employment result contrasts sharply with the established literature on environmental regulation and jobs. Several features of this finding merit discussion.

Why no job loss?. Three mechanisms could explain the null, though I note that the current evidence cannot discriminate among them. First, the regulation targeted disposal volumes, not the disposal activity itself. Operators could comply by reducing per-well injection rates, shifting to alternative formations, or recycling wastewater—all of which require labor. Compliance monitoring, well modifications, and alternative disposal arrangements may have generated offsetting demand for well services workers. Second, regulated counties were the center of Oklahoma's disposal industry. Their specialized infrastructure and workforce gave them a comparative advantage that persisted even under tighter regulation. Third, the dramatic decline in seismicity (886 M3+ events in 2015 to fewer than 200 by 2018) may have improved the local investment climate. However, a limitation of this analysis is that without well-level injection volume data showing the actual compliance response, I cannot directly verify that the regulation materially constrained disposal operations. It is possible that many

operators were already reducing volumes due to low oil prices, in which case the regulation may have been non-binding for some wells.

Comparison to the environmental regulation literature. Greenstone (2002) found that Clean Air Act counties lost 590,000 manufacturing jobs. Walker (2013) estimated $5.4 billion in cumulative earnings losses from air quality regulations. Curtis (2018) documented 1.3% employment declines from NOx cap-and-trade. The common thread is that these regulations restricted *production*—raising costs that could not be avoided without shrinking output. Seismicity regulation, by contrast, restricts only the disposal of a byproduct. If disposal is a small share of total production costs and alternative disposal methods exist, the employment impact can be zero even when the regulation binds.

Implications for carbon capture and storage. As CCS projects scale up, operators will inject large volumes of CO_2 into deep formations—the same physical process that induced Oklahoma's earthquakes. The null finding here suggests that injection volume regulations need not be economically devastating if operators retain flexibility in how they comply. However, this case has specific features—a reactive regulation in an industry already contracting from low prices, with flexible compliance options—that may not generalize to proactive, pressure-based CCS regulation in different geological settings (Ellsworth, 2013).

7. Conclusion

Oklahoma's 2015–2017 injection volume caps achieved their primary goal—reducing M3+ earthquakes from 886 in 2015 to fewer than 200 by 2018—without measurable employment costs. Total private employment, mining support services, oil and gas extraction, and wages all show null differential effects in regulated counties. The finding suggests that when environmental regulation targets a byproduct disposal activity rather than production itself, and when operators retain flexibility in compliance methods, the employment costs that dominate the literature on air quality and emissions regulation need not materialize. As injection-based activities expand with carbon capture and geothermal energy, the Oklahoma experience suggests that well-designed seismicity regulation can reduce hazard without destroying the workforce it aims to protect.

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A. Data Appendix

The QCEW data was retrieved from the Bureau of Labor Statistics API at https://data.bls.gov/cew/data/api/. I queried all 77 Oklahoma county FIPS codes for years 2014–2020, four quarters per year, yielding a balanced panel of county-quarter-industry observations. NAICS sectors were selected to capture the primary treatment channel (213: Support Activities for Mining), the most plausible confound (211: Oil and Gas Extraction), and placebo industries (44–45: Retail Trade; 72: Accommodation and Food Services).

The USGS earthquake catalog was accessed via the FDSNWS event query API at https://earthquake.usgs.gov/fdsnws/event/1/query, filtered to magnitude ≥ 3.0 within the Oklahoma bounding box (33.6°–37.0° N, 103.0°–94.4° W) for 2010–2023.

Treatment assignment was constructed from Oklahoma Corporation Commission directive documentation. The OWRA directive (November 2015) covered 10 western counties; the OCRA directive (February–March 2016) covered 10 central counties. Each county was assigned a binary treatment indicator and a first-treatment date corresponding to the earliest applicable directive.

B. Identification Appendix

The event-study specification uses the Sun and Abraham (2021) decomposition to avoid the negative weighting problem in staggered DiD event studies. I report coefficients for 12 pre-treatment quarters and 16 post-treatment quarters relative to the quarter before treatment. Pre-treatment coefficients test the parallel trends assumption: if regulated and control counties followed similar employment trajectories before the directives, pre-treatment event-time coefficients should be statistically indistinguishable from zero.

Leave-one-out analysis drops each of the 20 regulated counties in turn and re-estimates the baseline TWFE specification. The range of estimates demonstrates that no single county drives the main result.

C. Robustness Appendix

The wild cluster bootstrap uses the Webb six-point distribution with 9,999 replications, following Cameron et al. (2008). This procedure provides asymptotic refinement when the number of clusters is small.

The continuous treatment intensity specification replaces the binary post-treatment indicator with the interaction of pre-directive mining employment share and a post-treatment

indicator. This tests whether counties more exposed to the disposal industry experienced larger employment effects.

The triple-difference specification stacks mining support (NAICS 213) and retail (NAICS 44–45) observations within the same counties and includes county × sector and year-quarter × sector fixed effects. The coefficient on the interaction of post-treatment, regulated county, and mining sector identifies the regulation-specific effect, netting out any county-level trends that affect both sectors.

D. Standardized Effect Sizes

Table 5: Standardized Effect Sizes

Outcome	$\hat{\beta}$	SE	SD(Y)	SDE	SE(SDE)	Classification
Panel A: Pooled						
Total Employment	0.0076	(0.0238)	1.331	0.0057	(0.0179)	Small positive
Mining Support (213)	0.1800	(0.0975)	1.553	0.1160	(0.0628)	Moderate positive
Oil/Gas Extraction (211)	0.2318	(0.1559)	1.883	0.1231	(0.0828)	Moderate positive
Panel B: By Directive Area (Total Employment)						
OWRA Counties (Western)	-0.0079	(0.0383)	1.268	-0.0062	(0.0302)	Small negative
OCRA Counties (Central)	0.0221	(0.0217)	1.343	0.0165	(0.0161)	Small positive

Notes: **Country:** United States. **Research question:** Did Oklahoma's geographically targeted wastewater injection volume caps (2015–2017) reduce local employment in regulated counties? **Policy mechanism:** The Oklahoma Corporation Commission mandated 40% reductions in wastewater disposal volumes at Arbuckle formation wells across two geographic areas (OWRA and OCRA), directly curtailing injection well operations. **Outcome definition:** Log quarterly county-level employment from BLS QCEW (private sector); NAICS 213 and 211 for industry-specific effects. **Treatment:** Binary; county has regulated Arbuckle disposal wells vs. no regulated wells. **Data:** BLS QCEW, 77 Oklahoma counties, 2014–2020, approximately 2,100 county-quarter observations. **Method:** TWFE (county + year-quarter FE), county-clustered SEs; robustness via CS-DiD, wild cluster bootstrap, leave-one-out. **Sample:** 20 regulated and 57 control counties. Panel B splits by directive area: OWRA (10 western, November 2015) and OCRA (10 central, March 2016). SDE = $\hat{\beta}$/SD(Y) where SD(Y) is the pre-treatment standard deviation. Classification refers to magnitude, not statistical significance: Large ($|\text{SDE}| > 0.15$), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).