Who Is Burning Money and Throwing It In the Air?:

A Quantitative Analysis of Disproportionality of Texas Oil and Gas Extraction Facility Venting and Flaring Practices in 2012

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ABSTRACT

While overall air pollution has steadily decreased in the United States since the 1970s, air pollution from the oil and gas extraction industry has dramatically increased rural population's exposure to toxic air emissions since the fracking boom. In fact, venting (i.e., releasing or leaking natural gas into the atmosphere) and flaring (i.e., burning extracted natural gas) by the oil and gas extraction industry is the largest industry source of volatile organic compounds that create air toxins and form smog. While venting and flaring is a growing problem, due to the inaccessibility of public information, little is known about which types of facilities and operators are most responsible for producing these toxic air hazards. Using a sample of 126,862 oil and gas extraction facilities producing in Texas in 2012 and the 4,608 companies that directly operate them, I analyze how venting and flaring at oil and gas extraction facilities is related to the characteristics of facilities, operators, and the political environment in which they are embedded. I overcame data limitations by creating a geodatabase using Texas Railroad Commission, United States Energy Information Administration, and American Community Survey data. Findings suggest that venting and flaring is not a uniform practice of all oil and gas extraction facilities. Instead, only 5% of facilities and 10% of operators engage in venting or flaring. A two-part hurdle regression model shows venting and flaring practices are consistently associated with facilities with new drilling, few nearby wells, large oil production, and permitting, and operators that produce more oil. Findings suggests economic incentives and state policy are key factors contributing to the environmental decisions of organizations. I suggest political will be applied to enact economic incentives and state policy to reduce the pollution and waste caused by venting and flaring.

Keywords: privileged access, oil and gas extraction, rural air pollution, disproportionality

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1. INTRODUCTION

While overall air pollution has steadily decreased in the United States since the 1970s, some rural populations have experienced dramatic increases in exposure to air pollution produced by increased oil and gas extraction industry development stimulated by the fracking boom. The primary oil and gas extraction industry source of air pollution is venting (i.e., releasing natural gas into the air), and flaring (i.e., burning extracted natural gas). Venting and flaring emits air toxins such as methane, carbon dioxide (CO_2), and volatile organic compounds. In fact, venting and flaring is the largest industrial source of volatile organic compounds which create smog, and it is the largest source of methane emissions by the oil and gas industry (EPA 2017). Children exposed to volatile organic compounds produced by flaring have reported increased hematological, breathing and skin problems (Effiong and Etowa 2012). Heat from flaring at oil and gas extraction facilities also affects other species. The number of species surrounding facilities that flare is significantly smaller and less diverse (Isichei and Sanford 1976). Furthermore, venting primarily releases methane gas into the atmosphere, which is a potent greenhouse gas contributing to global climate change. In other words, due to oil and gas development spurred by the fracking boom, venting and flaring is increasingly exposing rural communities to air pollutants that have negative health and environmental effects.

In addition to producing environmental and health hazards, venting and flaring also wastes a finite natural resource- natural gas. Prior to the start of the fracking boom in 2005, the

United States Energy Information Administration (2017a) estimated 96,408 million cubic feet of natural gas worth nearly $836 million was flared or vented[2] at extraction sites across the United States; by 2015, the amount tripled to 289,545 million cubic feet worth over $1,233 million. A large amount of that gas has been increasingly flared in Texas, which is the largest producer of oil and gas in the United States. As described in *Figure 1*, while prior to the shale oil boom in 2005, 7,743 million cubic feet of natural gas worth nearly $57 million was wasted by flaring or venting at extraction sites in Texas; by 2015 the amount grew over tenfold to 100,388 million cubic feet worth over $427 million. According to the United States Energy Information Administration (2017b), Texas residents consumed 211,379 million cubic feet of gas in 2015. So in 2015, the amount of gas wasted from venting and flaring in Texas could have provided nearly half of the natural gas consumed by its residents.

While venting and flaring by the oil and gas extraction industry is a growing problem, it is unlikely that all oil and gas extraction facilities pose the same risk. Freudenberg's research on the "double diversion" (2005) shows environmental degradation is supported by unquestioned false narratives that all industrial facilities pose equal toxic risks and environmental destruction is economically necessary. However, there is extreme disproportionality in the production of environmental hazards; most pollution is produced by a few high-risk facilities with privileged access to pollute the environment (Freudenberg 2006). Drawing upon this concept, disproportionality researchers claim environmental hazards could be dramatically reduced with minimal economic impact by targeting these few types of high-risk facilities (Grant, Jorgenson, and Longhofer 2013).

Among the few quantitative disproportionality studies explaining heavy pollution in the United States, researchers find that the characteristics of facilities, the companies that own them, and their surrounding political environment are related to extreme pollution. In a series of studies on the toxic emissions of United States chemical production plants, disproportionality research shows a significant positive relationship between toxic emissions and plant size (Grant, Bergesen, and Jones 2002), subsidiary status (Grant and Jones 2003), and the social vulnerability of residents surrounding the facility (Grant, Jones, and Trautner 2004). In another series of studies on electric power plants and the companies that ultimately own them (i.e., parent companies), disproportionality research on environmental pollution in the United States finds a significant positive relationship between carbon emissions and facility age (Touché 2011), parent company size (Prechel and Zheng 2012), parent company organizational complexity (Prechel and Istvan 2016; Touché 2011), parent company resource dependence (Prechel and Zheng 2012; Prechel and Touché 2014; Prechel and Istvan 2016; Touché 2011), parent company age (Prechel and Zheng 2012), and the weakness of the environmental regulations in the state in which the parent company is located (Prechel and Zheng 2012; Prechel and Touché 2014; Prechel and Istvan 2016). Also, in a study of all facilities reporting to the Environmental Protection Agency's Toxic Release Inventory, "double disproportionality" research shows that poor and minority residents are disproportionately exposed to the most toxic hazards, and facilities responsible for the most pollution are primarily located in poor and minority neighborhoods (Collins, Munoz, and JaJa 2016).

However, disproportionality research primarily focuses on pollution produced in urban areas and has yet to examine pollution produced by the oil and gas extraction industry, which is primarily located in rural locations. Although pollution by the oil and gas extraction industry is a growing concern, research has yet to address the issue due to data limitations. Quantitative studies on extreme pollution in the United States have primarily relied upon information from the

Environmental Protection Agency, which has limited information on the oil and gas industry because, due to intense lobbying efforts, the oil and gas extraction industry is exempt from reporting to the Environmental Protection Agency's Toxic Release Inventory. Additionally, although the oil and gas extraction industry is required to report to the Environmental Protection Agency's Greenhouse Gas Reporting Program, reporting is required only at the shale-level for those producing 25,000 metric tons or more of (CO_2 equivalent) greenhouse gases. Since shales span across multiple counties, this information cannot be used to consider how local and facility context plays a role in extreme pollution by the oil and gas extraction industry. This research overcomes these limitations to examine extreme venting and flaring by using electronically metered venting and flaring records and other information maintained by the Texas Railroad Commission (TRC), the state agency responsible for regulating the greatest portion of oil and gas produced in the United States.

This paper draws upon open-systems organizational theory to examine how the characteristics of oil and gas extraction facilities, the companies that own them, and local and state political context are related to extreme venting and flaring in 2012. However, point-based maps of production, venting, and flaring volumes are not readily available. In order to overcome this issue, I link several Texas Railroad Commission datasets to map venting and flaring rates in 2012 and develop measures of facility, operator, local political, and infrastructure context. The purpose of this study is threefold: (1) to map Texas oil and gas extraction facility venting and flaring rates, (2) to determine how Texas oil and gas venting and flaring practices are related to facility political context, and (3) determine which types of facilities and operators are most responsible for engaging in heavy venting and flaring. By identifying the characteristics of the types of facilities and operators disproportionately responsible for venting and flaring extracted natural gas, state regulators can better target high-risk facilities and reduce the waste and pollution caused by venting and flaring from the oil and gas extraction industry.

2. AN OPEN SYSTEMS APPROACH TO DISPROPORTIONALITY

Disproportionality research emerges out of Freudenberg's "double diversion" framework (2005). From this perspective, extreme pollution is supported by a double diversion. The first part of the diversion is disproportionality, which is the diversion of resources to privileged groups, or "privileged access" to pollute. The second part of the diversion is the hegemonic narrative, or "privileged accounts" that the pollution created is necessary for economic production. Freudenberg (2005) argues that important insights on the relationship between humans and the natural environment can be obtained by examining privileged access and privileged accounts of the natural environment. Drawing upon open systems theories (Scott 2003) on the environmental behavior of capitalist organizations, disproportionality research attempts to alleviate the harmful impact of humans on the environment by exposing what types of organizations have privileged access to pollute (Grant and Jones 2003; Grant et al. 2002; Grant et al. 2004; Prechel and Zheng 2012; Prechel and Touché 2014; Prechel and Istvan 2016).

According to the resource dependence perspective of organizational behavior, organizational outcomes are constrained by access to critical resources not controlled by the organization (Pfeffer and Salancik 1978). Drawing from resource dependence theory, disproportionality research shows a significant positive relationship between extreme pollution and resource constraints facing organizations. For example, since organizations facing increased resource constraints have less time and resources to invest in green technologies, ecologically inefficient organizations are more likely to have lower profits and more debt (Prechel and Zheng

2012). Likewise, oil and gas extraction companies are faced with economic and time constraints. Since it costs time and resources to build pipeline to newly drilled wells in less densely developed areas, I expect: (H1) facilities further from established pipeline engage in more venting and flaring practices than facilities nearer to established pipeline, (H2) those with few nearby wells engage in significantly more venting and flaring practices than facilities with more wells nearby, and (H3) facilities with newly drilled wells engage in more venting and flaring practices than those without new drilling activity.

Organizational behavior is constrained by the past tendencies of the organization. This propensity of organizations to stay the same over time is called structural inertia. According to Hannan and Freeman (1984:149):

> Some of the factors that generate structural inertia are internal to organizations: these include sunk costs in plant, equipment, and personnel, the dynamics of political coalitions, and the tendency for precedents to become normative standards. Others are external. There are legal and other barriers to entry and exit from realms of activity. Exchange relations with other organizations constitute an investment that is not written off lightly. Finally, attempting radical structural change often threatens legitimacy; the loss of institutional support may be devastating.

Structural inertia increases the costs to adopt new green technologies and equipment. Drawing from population ecology perspectives of organizational behavior, disproportionality research shows a significant positive relationship between extreme pollution and the size of organizations. For example, since there are more costs to adopt new green technologies and equipment, disproportionality research shows ecologically inefficient organizations are larger (Grant et al. 2002). In this context, I expect (H4) facilities and operators that produce more engage in more venting and flaring practices than facilities and operators that produce less.

In addition to characteristics internal to the organization, decision making within formal organizations is also related to the regulatory context in which the organization is embedded. For example, research shows that organizations located in states and countries with few regulatory controls have higher pollution emissions (Prechel and Zheng 2012; Grant et al. 2018). Texas oil and gas extraction industry venting and flaring practices are primarily regulated by Texas Statewide Rule 32. While in the 1940s, Texas regulators shut down wells that unnecessarily vented or flared, Texas Statewide Rule 32 and amendments to it in the 1990s created new legal opportunities for wells to legally vent or flare by easily obtaining a permit. Because facilities are embedded within these legal requirements, I expect that (H5) facilities with venting and flaring permits engage in more venting and flaring practices than facilities without a permit, and (H6) facilities with more venting and flaring violations engage in more venting and flaring practices than facilities with less venting and flaring violations.

Environmental justice research suggests that low income and minority communities are disproportionately exposed to environmental harms (Mohai and Saha 2006; Mohai et al. 2009). Because politically disenfranchised communities are less resistant to exposure, heavy polluting facilities are primarily located in communities with less social and economic capital (Collins, Munoz, and JaJa 2016). In this context, I expect (H7) facilities located in minority neighborhoods engage in more venting and flaring practices than facilities in white neighborhoods, (H8) facilities located in low income engage in more venting and flaring practices than facilities in high income neighborhoods, and (H9) facilities located in less populated neighborhoods engage in more venting and flaring practices than facilities located in more populated neighborhoods.

3. METHODS

3.1. Study Design and Subjects

I conduct a cross sectional two-part hurdle regression analysis of all producing oil and gas extraction facilities in Texas in 2012, and the companies directly responsible for operating them. I consider oil and gas extraction facilities as the one or more well surface locations drilled on land within a single mineral lease. A mineral lease is a legal contract providing the operator with rights to drill for minerals on a plot of land. In 2012, there were 126,862 producing oil and gas extraction facilities operating on-shore in Texas, and they were controlled by 4,608 different operators. Among these facilities and operators, 6,651 facilities engaged in venting and flaring, and these facilities were controlled by 455 different operators. All 126,862 facilities and 4,608 operators were included in the first part of my analysis. All 6,651 facilities and 455 operators that engaged in venting and flaring were included in the second part of my analysis. The year of analysis was chosen because 2012 is when the fracking boom became visibly impactful in Texas.

3.2. Data Sources

3.2.1. Texas Railroad Commission databases (TRC)

The Texas Railroad Commission is the primary agency regulating the Texas oil and gas industry. Various Texas Railroad Commission datasets were used to match facility and operator characteristics (such as venting and flaring and production volumes) to geographic points. A map of how various Texas Railroad Commission datasets were connected is described in *Figure 2*.

I started to connect venting and flaring rates to facility points by parsing out records from the Production Data Query Dump, Full Wellbore Query Data, and Drilling Permit Master and Trailer Plus Longitudes and Latitudes Dataset. Then, I connected 2012 monthly venting and flaring volume records with production records in the Production Data Query Dump using a unique operator-lease identifier made up of the oil/gas code, district number, lease number, operator number, month, and year. Next, I connected the Production Data Query Dump information with the Full Wellbore Query data using the aforementioned unique operator-lease identifier. Prior to connecting the datasets, I removed all wellbores in the Full Wellbore Query data that were not active in 2012. Then, using the API number available in the Full Wellbore Query, I connected wells to the Drilling Permit Master and Trailer Plus Longitudes and Latitudes Dataset. Finally, I was able to obtain a 100% match between 2012 production and disposition records and wellbore surface location longitude and latitude coordinates using the Texas Railroad Commission Digital Map and API Data.

3.2.2. United States Energy Information Administration natural gas pipeline shapefile (EIA)

A shapefile of the natural gas interstate and intrastate pipelines as of January 1, 2012 was obtained from the United States Energy Information Administration (EIA) and collected by the Federal Energy Regulatory Commission. This dataset provides an extensive and comprehensive map of all interstate and intrastate natural gas pipelines in the continental United States.

4.2.3. American Community Survey, 2010-2014, Geodatabase Format (ACS)

The 2010-2014 American Community Survey (ACS) five-year population estimates geodatabase was used to obtain residential community information. The geodatabase format of the American Community Survey brings together geography from the Census Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line Shapefiles and the ACS five-year estimates in a Geographic Information System (GIS). The five-year population sample files were used over single year estimates because they are recommended when examining small areas with populations lower than 20,000 (Census Bureau 2015), which characterizes most populations surrounding well sites.

3.3. Variables

3.3.1. Dependent Variable

Two dependent variables are used in this research. The first dependent variable is a dichotomous variable representing whether a facility participated in venting and flaring practices in 2012. As described in *Table 1*, facilities that did not report any venting and flaring volumes were given the null category “0”, and facilities that reported at least 1 thousand cubic feet (mcf) of gas was vented or flared were categorized as “1.” The second dependent variable is a count variable representing the percent of the gas produced at the facility that was vented or flared in 2012. A map of Texas oil and gas extraction facility venting and flaring rates is shown in *Figure 3*.

3.3.2. Independent Variables

The independent variables and measures for analyses are described in *Table 1*. A comparison of the summary statistics for all facilities to those that vent and flare are described in *Table 2*.

Oil and gas infrastructure is measured in two ways. First, I measure pipeline development as the number of feet between the lease and pipeline established by January 1, 2012. Second, I measure extraction development as the square root of the number of wells drilled within one mile. This information was obtained from EIA pipeline information and TRC well records.

I measure new drilling as a dichotomous variable representing whether a facility filed a drilling permit in 2012. As described in Table 1, facilities that did not file a drilling permit were given the null category “0”, and facilities that filed a drilling permit were categorized as “1.”

I measure size at the facility and operator level using electronically metered oil and gas production and disposition records obtained from TRC. Facility gas production size is measured as the square root of the amount of gas produced at the facility in thousand cubic feet (mcf). Likewise, operator gas production size is measured as the square root of the amount of gas produced by the operator in mcf. Facility oil production size is measured as the square root of the amount of oil produced at the facility in barrels. Operator oil production size is measured as the square root of the amount of oil produced by the operator in barrels.

I measure state regulatory context in two ways. First, I measure the number of violations the facility received for illegally venting and flaring in 2012. Second, I measure if the facility had a permit to legally vent venting or flare in 2012. These measures were obtained using TRC records.

Finally, I examine community context using four measures. Drawing upon established distance-based methods (Mohai and Saha 2006), all measures operationalize communities as U.S. census block groups within one mile. Census block groups are used over tracts, zip codes, and counties, because Census block groups represent smaller geographic areas. First, I measure the portion of residents living in block groups within one mile of the facility that are non-Hispanic black. Second, I measure the portion of residents living in block groups within one mile of the facility that are Hispanic. Third, I measure the median household income category of households living in block groups within one mile of the facility. Fourth, I measure the number of people per square mile living in block groups within one mile of the facility. This information was obtained from ACS and TRC records.

3.4. Creating the Geographic Information System

Datasets were matched within a Geographic Information System (GIS), using the following steps. First, all geographic data (wellbore longitude/latitude coordinates, the pipeline shapefile, and the ACS geodatabase) were added to the map and projected to North American Dam NAD83 State Plan Texas Central FIPS 4203 Coordinate System. Wellbore coordinate points were then grouped for each operator's lease, representing numerous wellbore surface locations drilled on the same lease. Next, using the ArcGIS Near Analysis tool, I determined the nearest distance between lease points and gas pipelines by applying geodesic methods, meaning it accounts for the actual ellipsoid shape of the earth. Then, a one-mile buffer was drawn around lease multi-points using geodesic methods and I overlaid it with the ACS block group boundary file. ACS estimate tables were then connected to the block group-lease buffer overlay file using the block group number (i.e., geoid). Once the datasets were connected within the GIS, community data was summed up for the population living in block groups within one mile of the facility. Finally, ACS block group shapefiles and lease venting and flaring volume points were symbolized and added to an online map created using ArcGIS Enterprise. The GIS created is available in a mobile friendly format at http://tinyurl.com/vf12map. The code used to manage secondary datasets and create the GIS is available at http://tinyurl.com/vf12code.

3.5. Analytical Strategy

This research uses a two-part model (Duan et al. 1983) in order to determine correlations between facility and operator characteristics and both (1) whether, among all producing oil and gas extraction facilities, the facility vented or flared (i.e., participation), and (2) the percent of gas vented or flared among facilities that vented or flared (i.e., magnitude). A two-part model is used when a zero inflated dependent variable is genuinely zero and the components contributing to the participation and magnitude may differ (Min and Agresti 2002; Humphreys 2013).

The first part of the model (i.e., the participation model) investigates the direct effects of lease and operator characteristics on whether the lease vents or flares using the following logit regression model equation:

$$\log\left(\frac{\varphi_{1j}}{1-\varphi 1_j}\right) = \gamma_0 + \sum_{k=1}^{K} \beta_k\left(M_{kj} - \overline{M_{kJ}}\right) + \; e_j, \text{ where } e_{itj} \approx \mathrm{N}(0,\sigma_e^2)$$

In the full participation model above, φ_{1j} denotes the probability that lease j vented or flared; γ_0 denotes the average log odds that a lease will vent or flare; β_k is the corresponding coefficient that represents the direction and strength of the explanatory variable (k is the number of variables at the lease-level); M_{kj} is the observation of the explanatory variable k for lease j, and $\overline{M_k}$ is the mean of the explanatory variable k; e_j represents the random error, which is assumed to be normally distributed with a mean of 0 and variance of σ_e^2. A logit is used because our dependent variable is dichotomous. The model assumes homoskedasticity, linearity of parameters, and independent variables are not strongly collinear. I use Huber's (1967) formula to produce consistent standard errors, even though the data is clustered by facility operator. Parameters were transformed to meet linearity assumptions. Also, uncentered variance inflation factors were examined to ensure strongly correlated independent variables are not skewing results.

The second part of the model (i.e., the magnitude model) investigates the direct effects of lease and operator characteristics on the venting or flaring rate for leases that vented or flared gas using the following negative binomial regression model equation:

$$\mu_{\boldsymbol{i}}, = \exp(\ln(t_{\boldsymbol{i}}) + \beta_1 x_{1\boldsymbol{i}} + \beta_2 x_{2\boldsymbol{i}} + \beta_3 x_{3\boldsymbol{i}} + \ldots + \beta_k x_{k\boldsymbol{i}},$$

$$\Pr(Y=\boldsymbol{y_i} \mid \mu_i,\alpha)=\frac{\Gamma(\boldsymbol{y_i} + \alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y_i + \mathbf{1})} \left(\frac{\mathbf{1}}{\mathbf{1} + \alpha\mu_i}\right)^{\alpha^{-\mathbf{1}}} \left(\frac{\alpha\mu_i}{\mathbf{1} + \alpha\mu_i}\right)^{\boldsymbol{y_i}},$$

In the full magnitude model above, $\mu_{\boldsymbol{i}}$ denotes the mean incidence rate of y per unit of exposure t (i.e., risk of new occurrence during period t). β_1 is the intercept. β_2, β_3, …, β_k are the estimated unknown regression parameters. Γ is a gamma noise variable which has a mean of 1 and a scale of v. α is 1 / v, and the model is estimated using maximum likelihood estimation techniques. A negative binomial model is used because our dependent variable is over dispersed count data. The model assumes linearity of parameters and independent variables are not strongly collinear. Negative binomial regression models have a Poisson regression mean structure and an extra parameter to model over-dispersion, so homoskedasticity is not assumed.

4. FINDINGS

Results show extreme disproportionality in facility venting and flaring practices. As described in Table 2, only 5.2% of producing facilities engaged in venting and flaring. Furthermore, among facilities that engaged in the practice, while on average facilities vented or flared 26% of the gas they produced through the year, a few facilities vented or flared all of the gas they produced. In addition to disproportionality at the facility level, results also show extreme disproportionality at the level of the operator. As shown in Table 3, while 4,608 different operators controlled producing oil and gas extraction facilities, only 455 (~10%) engaged in the practice. These findings align with Freudenberg's (2005) disproportionality hypothesis that natural resources are diverted to groups with privileged access to pollute.

As shown in Table 3, as predicted, venting and flaring practices have a consistent significant positive relationship with new drilling and a consistent significant negative relationship with development density. Holding all other independent variables constant, facilities where new drilling occurred have an expected 2.26 increase in the odds that the facility vented and flared, and this relationship is statistically significant. Among facilities that vented or flared, holding all other independent variables constant, facilities with new drilling compared to facilities without new drilling the expected percent of gas vented or flared increases by a rate of 2.018, and this relationship is statistically significant. Holding all other independent variables constant, each increase in the square root of the number of wells drilled within a mile is associated with an expected odds that the facility vented or flared decreases by a factor of .89 and this relationship is statistically significant. Among facilities that vented or flared, if a facility were to increase the square root of the number of wells drilled within a mile by one, the expected percent of gas vented or flared decreases by a factor of .918, while holding all other independent variables in the model constant, and this relationship is statistically significant. However, there is no significant relationship between facility venting and flaring practices and the nearness of established pipeline. These findings show that economic incentives have a significant effect on organizations as they decide whether to invest in green completion equipment.

As predicted, there is a consistent significant relationship between facility and operator oil production and venting and flaring practices. Holding all other independent variables constant, each unit increase in facility oil production (i.e., square root of the barrels of oil produced by the facility) is associated with an expected .4.63 x 10^{-4} increase in the log odds that the facility vented and flared, and this relationship is statistically significant. Among facilities that vented or flared, each unit increase in facility oil production increases the expected log count of the percent of gas vented or flared by .002, holding all other independent variables constant, and this relationship is statistically significant. Additionally, holding all other independent variables constant, each unit increase in operator oil production (i.e., square root of the barrels of oil produced by the operator) is associated with an expected 2.697 x 10^{-4} increase in the log odds that the facility vented and flared, and this relationship is statistically significant. Also, among facilities that vented or flared, each unit increase in operator oil production increases the expected log count of the percent of gas vented or flared by 2.697×10^{-4}, holding all other independent variables constant, and this relationship is statistically significant. Consistent with Grant's findings (2002), this research suggests, because large organizations are more powerful and less prone to change, they are less ecologically efficient.

The effect of facility and operator gas production on venting and flaring practices is less consistent. While facilities that produce more are more likely to engage in venting and flaring, among facilities that vent and flare, facilities that produce more and those owned by companies that produce more vent and flare at a lower rate than facilities that produce less. Holding all other independent variables constant, each unit increase in facility gas production (i.e., square root of the mcf of gas produced at the facility) is associated with an expected .001 increase in the log odds that the facility vented and flared, and this relationship is statistically significant. However, among facilities that vented or flared, each unit increase in facility gas production decreases the expected log count of the percent of gas vented or flared by .002, holding all other independent variables constant, and this relationship is statistically significant. Additionally, among operators that vented or flared, unit increase in operator gas production (i.e., square root of the mcf of gas produced by the operator) decreases the expected log count of the percent of gas vented or flared by -3.008×10^{-4}, holding all other independent variables constant, and this relationship is statistically significant. There is no significant relationship with operator gas production and whether a facility vented or flared. This suggests that because facilities and operators that produce a large amount of natural gas have and more long-term interests in the natural gas industry and greater economic incentives to invest in the technology and infrastructure to capture natural gas (and perhaps move mobile green equipment between operators), large gas production size is negatively associated with extreme venting and flaring.

As predicted, facility regulatory context is related to facility venting and flaring practices. Facilities with permits to legally vent or flare gas are more likely to vent and flare and vent and flare at a higher rate. Holding all other independent variables constant, facilities with a permit to legally vent or flare have an expected 11.55 increase in the odds that the facility vented and flared, and this relationship is statistically significant. Among facilities that vented or flared, holding all other independent variables constant, facilities with a permit to vent and flare compared to facilities without a venting and flaring permit are expected to have a rate 3.889 times greater for the percent of gas vented or flared, and this relationship is statistically significant. Also, holding all other independent variables constant, each violation for venting and flaring is associated with an expected 1.79 increase in the odds that the facility vented and flared, and this relationship is statistically significant. While facilities that vent or flare are more likely to obtain a venting and flaring violation in comparison to those that do not flare, there is no relationship between venting and flaring violations and venting and flaring rates. In other words, in general, facilities with higher venting and flaring rates do not receive significantly more violations than facilities with lower venting and flaring rates. These findings correspond to previous open systems approaches to disproportionality (Prechel and Zheng 2012; Grant, Jorgenson, Longhofer 2018). Environmental outcomes are related to the regulatory context in which the facility is embedded. Few political checks and balances in the form of permitting and inadequate policing is positively associated with extreme venting and flaring practices.

While the surrounding community political environment is related to whether a facility engages in venting and flaring, there is no significant relationship between the extent to which the facility vents or flares and the community in which it is embedded. The portion of the community that is Hispanic and community household incomes have a significant positive relationship with engagement in venting and flaring. Holding all other independent variables constant, each increase in the portion of Hispanic residents in block groups within a mile is associated with an expected 1.024 increased odds that the facility vented or flared, and this relationship is statistically significant. Additionally, holding all other independent variables constant, each increase in the mean income category of households in block groups within a mile of the facility is associated with a 1.086 increased odds that the facility vented or flared, and this relationship is statically significant. There is no significant relationship between the portion of the surrounding community that is black and whether a facility vented or flared, and there is no significant relationship between the population density of the surrounding community and whether a facility vented or flared. Additionally, among venting and flaring facilities, there is no significant relationship between any community variables (i.e., portion black, portion Hispanic, population density, and household income) and the percent of gas vented or flared. This suggests that because communities have little recourse to resist venting and flaring, community variables have less of an effect on extreme venting and flaring than facility variables.

5. CONCLUSION

This research quantified the relationship between Texas oil and gas venting and flaring magnitudes and the characteristics of facilities, operators, and the political context in which they are embedded. By doing so, this research enhanced our understanding of the types of facilities and operators responsible for wasting natural resources and emitting air pollutants by venting and flaring most of the gas they produce. I created a mobile friendly online map of oil and gas venting and flaring rates, natural gas pipeline infrastructures, and community class, race, and other demographic patterns using Texas Railroad Commission databases, United States Energy Information Administration shapefiles, and the American Community Survey geodatabase. I used mapped data and two-part hurdle regression to find venting and flaring practices are consistently associated with new drilling (positive relationship), development density (negative relationship), facility oil production (positive relationship), oil production (positive relationship), and permitting (positive relationship). These findings suggest that economic incentives and legal opportunities to vent and flare are associated with extreme venting and flaring.

This research alludes extreme environmental degradation could be reduced by transforming the economic incentives and legal opportunities to vent and flare. This could be done in several ways:

1. *Increase accessibility of Texas Railroad Commission venting/flaring data.* Prior to this research, a point map of where venting and flaring most occurs in Texas was not available to the public. Furthermore, in order to obtain point-based estimates of facility venting and flaring volumes, several thousand dollars was required to purchase comprehensive raw data, and advanced geoprocessing and data management was required to transform raw data into maps. For communities and shareholders to resist the dirty production practices of companies, they must be aware of where and how much it occurs. To increase transparency, Texas legislature should require the Texas Railroad Commission keep updated venting and flaring maps available to the public and require the Texas Railroad Commission waive all Public Information Act request fees for academic researchers using data for nonprofit purposes that are in the public interest.
2. *Amend Texas Statewide Rule 32 Section f.2.D.* In the 1940s Texas state regulators minimized venting and flaring practicing by enacting “no flare” policies, which shut down production at wells that engaged in unnecessary flaring. However, amendments

to Statewide Rule 32 in 1990 created new legal opportunities for companies to vent and flare for the purpose of economic expediency. These legal opportunities should be eliminated by amending Texas Statewide Rule 32 Section f.2.D to only allow companies to vent or flare for emergencies, cleanings, and repairs, and eliminating the provision to allow it when there is the "unavailability of a pipeline or other marketing facility, or other legal uses."

3. *Increase funding to the Texas Railroad Commission.* Once legal loop holes are eliminated, the Texas Railroad Commission must be empowered with the administrative capacity to identify and target heavy polluters. As such, the Texas legislature must increase the funding for Texas Railroad Commission inspectors and data specialists.
4. *Increase financial incentives for green investments*. The Texas Legislature can also create fiscal incentives for companies to build the technology and infrastructure necessary to eliminate routine flaring. This could be done by providing tax breaks for companies that purchase or rent green equipment to minimize flaring.

In addition to contributing to policy recommendations, this research also makes several contributions to the study of natural resources:

1. *Describes data management and GIS methods to understand the oil and gas industry*. In this paper I describe how state-level data can be used to map oil and gas extraction facilities and the companies that directly own them. As such, researchers can use these methods and other external business, community, and health datasets to better understand the oil and gas industry and its effects.

2. *Provides innovative two-part modeling methods to advance our understanding of the types of organizations prone to extreme pollution*. While prior research primarily explains variation in magnitude (Grant et al. 2002; Grant and Jones 2003; Grant et al. 2004; Prechel and Zheng 2012; Prechel and Touché 2014; Prechel and Istvan 2016; Touché 2011), this research explains both participation in and magnitude of extreme pollution practices. By leaving out organizations that do not engage in heavy enough pollution practices to be required to report to the Environmental Protection Agency's Toxic Release Inventory, a significant portion of the population is left out of the analysis. This research advances our understanding by including all facilities and organizations in the analysis and introducing a clustered two-part modeling method to better explain the types of organizations disproportionately responsible for industrial pollution.
3. *Establishes an open systems theoretical approach to understand variations in the production of environmental hazards by the natural resource extraction industry*. Using an open systems approach to disproportionality, this research shows variations in environmental decision making are related to internal organizational factors of the facility and operator, as well as external factors related to the political environment in which the facility and operator is embedded. The open systems theoretical approach advanced in this paper can be applied to other examinations of variations in the production of environmental hazards by the mineral extraction industry.

In short, this study's GIS multi-level open systems approach can also be extended to future studies of the types of organizations that have disproportionate impact on the natural environment. By extending this approach, future research will be able to further expose the types of facilities and operators that produce most environmental hazards. In doing so, we will be able to employ evidence-based methods to better target extreme polluters and reduce the environmental impact of the production process.

REFERENCES

ADI Analytics. 2015. "Options to Reduce Flaring." Retrieved August 9, 2016 (http://adi-analytics.com/2015/03/10/options-to-reduce-flaring/).

Bullard, Robert D. 1990. *Dumping in Dixie : Race, Class, and Environmental Quality.* Boulder, CO: Westview Press.

Census Bureau. 2015. "When to Use 1-year, 3-year, or 5-year Estimates." Retrieved July 11, 2016 (https://www.census.gov/programs-surveys/acs/guidance/estimates.html).

Collins, Mary. 2011. "Risk-Based Targeting: Identifying Disproportionalities in the Sources and Effects of Industrial Pollution." *American Journal of Public Health* 101:S231-237.

Collins, Mary, Ian Munoz, and Joseph JaJa. 2016. "Linking Toxic Outliers' to Environmental Justice Communities Across the United States." *Environmental Research Letters* 11.

Cutter, Susan, Bryan Boruf and W. Lynn Shirley. 2003. "Social Vulnerability to Environmental Hazards." *Social Science Quarterly* 84(2): 242-261.

Duan, Naihua, Willard Manning, Carl Morris, and Joseph Newhouse. 1983. "A Comparison of Alternative Models for the Demand for Medical Care." *Journal of Business and Economic Statistics* 1(2): 115-126.

de Palma, André, Kiarash Motamedi, Nathalie Picard, and Paul Waddell. 2007. "Accessibility and Environmental Quality: Inequality in the Paris Housing Market." *European Transport* 36. 47-74.

Downey, Liam, and Brian Hawkins. 2008. "Race, Income, and Environmental Inequality in the United States." *Sociological Perspectives* 51: 759-781.

Ehrlich, Paul, and John Holdren. 1971. "Impact of Population Growth." *Science* 171(3977): 1212-1217.

EPA. 2017a. “Basic Information about Oil and Natural Gas Air Pollution Standards.” Retrieved December 20, 2017 [https://www.epa.gov/controlling-air-pollution-oil-and-natural-gas-industry/basic-information-about-oil-and-natural-gas].

______. 2017b. “Natural Gas Extraction – Hydraulic Fracturing.” Retrieved January 10, 2018 [https://www.epa.gov/hydraulicfracturing].

Freudenburg, William. 2005. “Privileged Access, Privileged Accounts: Toward a Socially Structured Theory of Resources and Discourses.” *Social Forces* 84(1): 89-114.

______. 2006. “Environmental Degradation, Disproportionality, and the Double Diversion: Reaching Out, Reaching Ahead, and Reaching Beyond.” *Rural Sociology* 71(1):3-32.

Freudenburg, William R. and Wilson, Lisa, J. 2002. “Mining the Data: Analyzing the Economic Implications of Mining for Nonmetropolitan Regions.” *Sociological Inquiry* 72(4): 549-575.

Grant, Don, Andrew Jorgenson, and Wesley Longhofer. 2018. “Pathways to Carbon Pollution: The Interactive Effects of Global, Political, and Organizaitonal Factors on Power Plants' CO_2 Emissions

Grant, Don, Andrew Jorgenson, and Welsley Longhofer. 2013. “Targeting Extreme Polluters: An Alternative Approach to Reducing Energy-Related CO_2 Emissions.” *Journal of Environmental Studies and Sciences* 3(4): 376-380.

Grant, Don, Mary Nell Trautner, Liam Downey and Lisa Thiebaud. 2010. “Bringing the Polluters Back In: Environmental Inequality and the Organization of Chemical Production.” *American Sociological Review* 75(4): 479-504.

Grant, Don, Andrew Jones, and Mary Nell Trautner. 2004. “Do Facilities with Distant Headquarter Pollute More?: How Civic Engagement Conditions the Environmental Performance of Absentee Managed Plants.” *Social Forces* 83(1): 189-224.

Grant, Don and Andrew Jones. 2004. “Do Foreign Owned Plants Polluter More?: New Evidence from the EPA’s Toxic Release Inventory.” *Society and Natural Resources* 17(2):171-179.

______. 2003. “Are Subsidiaries More Prone to Pollute?” *Social Science Quarterly* 84(1):162-173.

Grant, Don, Andrew Jones and Albert Bergesen. 2002. “Organizational Size and Pollution: The Case of the U.S. Chemical Industry.” *American Sociological Review* 67(3) 389-408.

Hamilton, James. 1995. “Testing for Environmental Racism: Prejudice, Profits, Political Power?” *Journal of Policy Analysis and Management* 14: 107-132.

Hernandez, Maricarmen, Timothy Collins, Sara Grineski. 2015. “Immigration, Mobility, and Environmental Injustice: A Comparative Study of Hispanic People’s Residential Decision Making and Exposure to Hazardous Air Pollutants in Greater Houston, Texas.” *Geoforum* 60:83-94.

Howarth, Robert, Renee Santoro, and Anthony Ingraffea. 2011. “Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations.” *Climate Change* 106:679.

Humphreys, Brad. 2013. “Dealing with Zeros in Economic Data.” Retrieved August 22, 2017 (https://sites.ualberta.ca/~bhumphre/class/zeros_v1.pdf).

IPIECA. 2013. “Green Completions.” Retrieved July 29, 2016 (http://www.ipieca.org/energyefficiency/solutions/78161).

Mohai, Paul, and Bunyan Bryant. 1992. “Environmental Racism: Reviewing the Evidence.” PP. 163-176 in *Race and the Incidence of Environmental Hazards: A Time for Discourse,* edited by Buyan Bryant and Paul Mohai. Boulder, CO: Westview Press.

Min, Yongyi, and Alan Agresti. 2002. “Modeling Nonnegative Data with Clumping at Zero: A Survey.” *JIRSS* 1(1-2): 7-33.

Pais, Jeremy, Kyle Crowder and Liam Downey. 2014. "Unequal Trajectories: Racial and Class Differences in Residential Exposure to Industrial Hazard." *Social Forces*:1189.

Pastor, Manuel, Jim Sadd, and John Hipp. 2001. “Which Came First? Toxic Facilities, Minority Move-in and Environmental Justice.” *Journal of Urban Affairs* 23:1-21.

Pellow, David. 2000. “Environmental Inequality Formation: Toward a Theory of Environmental Injustice.” *American Behavioral Scientist* 43(4):581-601.

Pellow, David N., Adam Weinberg and Allan Schnaiberg. 2001. "The Environmental Justice Movement: Equitable Allocation of the Costs and Benefits of Environmental Management Outcomes." *Social Justice Research* 14:423-39.

Prechel, Harland, and Alesha Istvan. 2016. “Disproportionality of Corporations’ Environmental Pollution in the Electrical Energy Industry.” *Sociological Perspectives* 59(3): 505-527.

Prechel, Harland, and George Touche. 2013. "The Effects of Organizational Characteristics and State Environmental Policies on Sulfur-Dioxide Pollution in U.S. Electrical Energy Corporations." *Social Science Quarterly* 95: 76-96.

Prechel, Harland, and Lu Zheng. 2012. “Corporate Characteristics, Political Embeddedness and Environmental Pollution by Large U.S. Corporations.” *Social Forces* 90:1-24.

Princen, Thomas. 1997. “The Shading and Distancing of Commerce.” *Ecological Economics* 20: 235-253.

Prindle, D. 1981. *Petroleum Politics and TRC*. Austin, TX: University of Austin Press.

Pulido, Laura. 2000. "Rethinking Environmental Racism: White Privilege and Urban Development in Southern California." *Annuals of the Association of American Geographers* 90(1):12-40.

Rinquist, Evan. 2005. "Assessing Evidence of Environmental Inequalities: A Meta-Analysis." *Journal of Policy Analysis and Management* 24(2):223-247.

Saha, Robin, and Paul Mohai. 2005. "Historical Context and Hazardous Waste Facility Siting: Understanding Temporal Patterns in Michigan." *Social Problems* 52(4): 618-648.

Tedesco, John and Jennifer Hiller. 2014a. "Flares in Eagle Ford Shale Wasting Natural Gas." *San Antonio Express-News*. Retrieved May 19, 2016 (http://www.expressnews.com/business/eagleford/item/Up-in-Flames-Day-1-Flares-in-Eagle-Ford-Shale-32626.php%E2%80%9DUp%20in%20Flames).

______. 2014b. "Flares Emitting More Pollution than Refineries." *San Antonio Express-News.* Retrieved June 29, 2016 (http://www.expressnews.com/business/eagleford/item/Up-in-Flames-Day-2-Flares-emitting-more-32640.php).

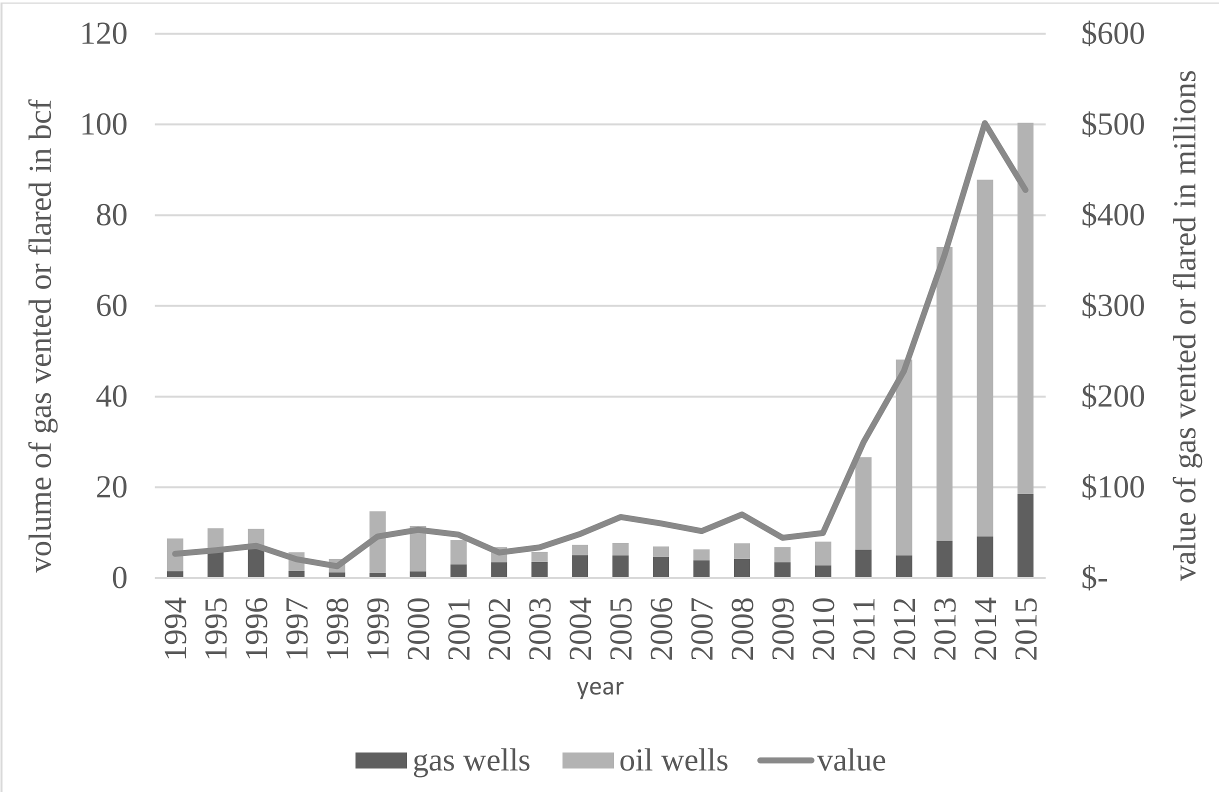
Texas Register. 1978. "Gas Well Gas Shall Be Utilized for Legal Purposes 051.02.02." March 21. 3 (21): 1020.

______. 1990b. "16 TAC 3.32." Oct. 2. 15: 5804-5805.

Wilson, Sacoby, Herb Fraser-Rahim, Edith Williams, Hongmei Zhang, LaShanta Rice, Erik Svedsen, and Winston Abara. 2012. "Assessment of the Distribution of Toxic Release Inventory Facilities in Metropolitan Charleston: An Environmental Justice Case Study." *American Journal of Public Health* 102: 1974-1980.

FIGURES

Figure 1: Estimated Waste from Flaring and Venting at Extraction Sites in Texas, 1994-2015



Source: Texas Railroad Commission Production Data Query Dump, 2016

Figure 2: Texas Railroad Commission Dataset Connections

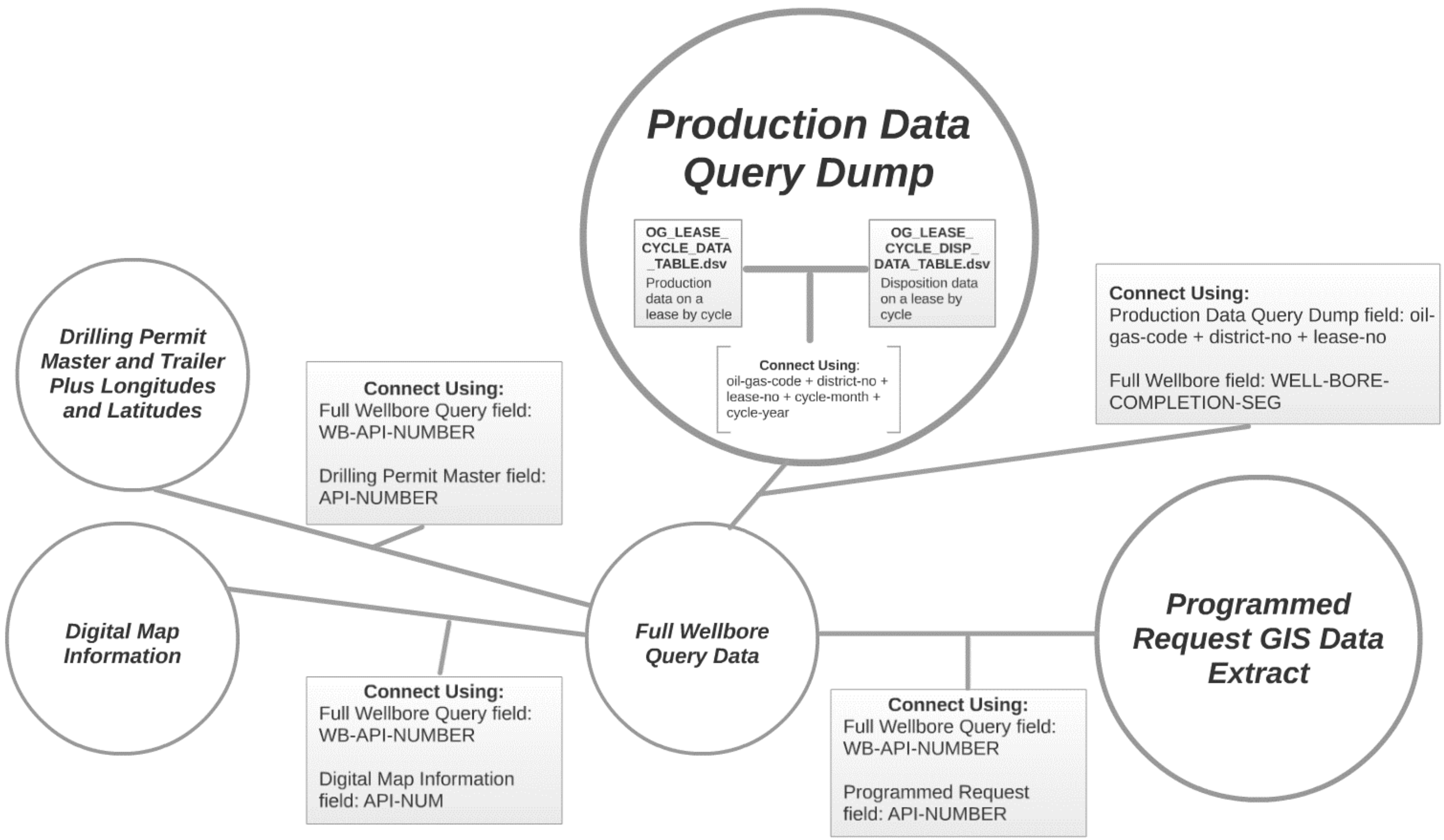
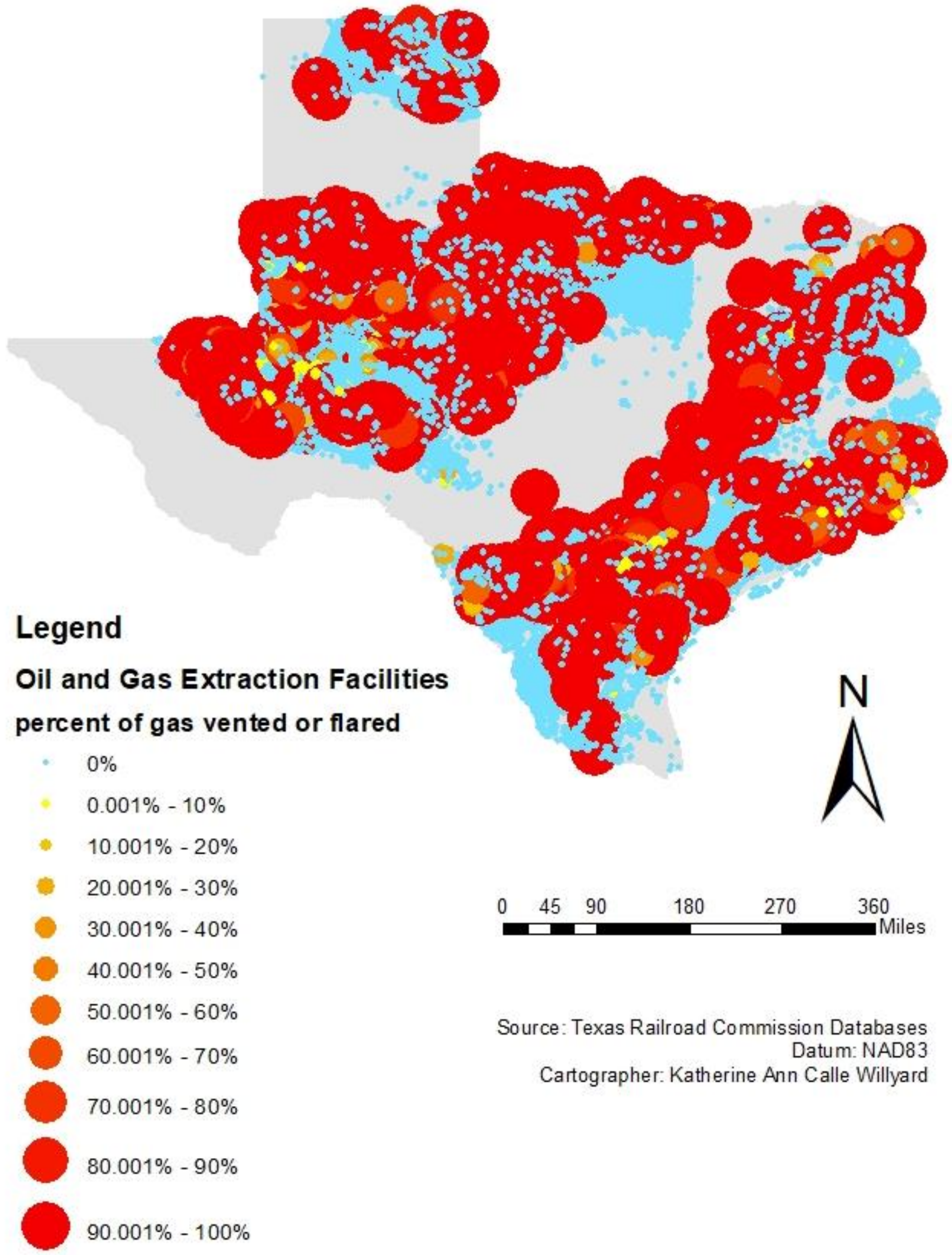


Figure 3: Texas Oil and Gas Extraction Facility Venting and Flaring Rates in 2012



TABLES

Table 1: Variable Measures and Descriptive Statistics for All Facilities

Variable	Measure	Source	N	Mean	Sd	Min	Max
Dependent Variable							
Venting/Flaring Facility	1- Facility vented or flared 0-Not	TRC	126,862	.052	.222	0	1
Venting/Flaring Percent	100 * Vented or flared / Produced	TRC	126,862	1.385	10.611	0	100
Economic Variables							
Nearest Pipeline	Feet to nearest established gas pipeline	EIA	126,862	9,399	17,563	0	176658
New Drilling	1- New wells were drilled in 2012 0-Not	TRC	126,862	.043	.203	0	1
Development Density	Sqrt(number of wells drilled within a mile)	TRC	126,862	4.611	4.721	0	1,403.169
Size Variables							
Facility Oil Production	Sqrt(barrels of oil produced at facility)	TRC	126,862	32.027	65.946	0	3,256.343
Facility Gas Production	Sqrt(mcf of gas produced at facility)	TRC	126,862	138.22	160.47	0	5,600.897
Operator Oil Production	Sqrt(barrels of oil produced by operator)	TRC	126,862	1,045	1,294	0	6,531.994
Operator Gas Production	Sqrt(mcf of gas produced by facility)	TRC	126,862	6,482	8,350	0	27,591.14
State Regulation Variables							
Venting/Flaring Permit	1- Received permit to vent or flare 0-Not	TRC	126,862	.004	.066	0	1
Venting/Flaring Violations	Venting or flaring violations	TRC	126,862	.002	.068	0	9
Community Variables							
Portion Black	Portion individuals living in block groups within a mile that are Non-Hispanic black	ACS	126,862	4.211	7.436	0	88.075
Portion Hispanic	Portion individuals living in block groups within a mile that are Hispanic	ACS	126,862	25.703	23.533	0	100
Population Density	People per square mile in block groups within a mile	ACS	126,862	38.905	156.71	.007	6,707.434
Household Income	Median household income category of households in block groups within a mile	ACS	126,862	9.652	1.944	1	15

Table 2: Comparison of Descriptive Statistics for All Facilities and Those That Vent or Flare

	All Producing Facilities					Facilities that Vented or Flared				
Variable	**N**	**Mean**	**Sd**	**Min**	**Max**	**N**	**Mean**	**Sd**	**Min**	**Max**
Dependent Variable										
Venting/Flaring Facility	126,862	.052	.222	0	1	6,651	1	0	1	1
Venting/Flaring Percent	126,862	1.385	10.611	0	100	6,651	26.417	38.557	.0000893	100
Economic Variables										
Nearest Pipeline	126,862	9,399	17,563	0	176658	6,651	8,850	14,612	0	148,172
New Drilling	126,862	.043	.203	0	1	6,651	.180424	.385	0	1
Development Density	126,862	4.611	4.721	0	1,403	6,651	4.104607	2.809	0	33.615
Size Variables										
Facility Oil Production	126,862	32.027	65.946	0	3,256	6,651	121.147	146.457	0	3,085
Facility Gas Production	126,862	138.22	160.47	0	5,600	6,651	219.408	233.572	1	4,730
Operator Oil Production	126,862	1,045	1,294	0	6,531	6,651	2,234.341	1,822.442	0	6,531
Operator Gas Production	126,862	6,482	8,350	0	27,591	6,651	5,067.858	3,715.916	1	27,591
State Regulation Variables										
Venting/Flaring Permit	126,862	.004	.066	0	1	6,651	.063	.242	0	1
Venting/Flaring Violations	126,862	.002	.068	0	9	6,651	.01	.17	0	8
Community Variables										
Portion Black	126,862	4.211	7.436	0	88.075	6,651	2.480	5.473	0	88.075
Portion Hispanic	126,862	25.703	23.533	0	100	6,651	41.834	25.689	0	99.614
Population Density	126,862	38.905	156.71	.007	6,707	6,651	15.68	96.823	.007	2,075
Household Income	126,862	9.652	1.944	1	15	6,651	9.4	2.124	2	14

Table 3: Regression Estimates of Venting and Flaring Rates

	Participation Model- Logit Model Predicting Venting or Flaring Facilities			**Magnitude Model- Negative Binomial Model Predicting Percent Gas Vented or Flared**		
	Coefficient	*Odds Ratio*	*Robust Standard Error*	*Coefficient*	*Incidence Rate Ratio*	*Robust Standard Error*
Economic Variables						
Nearest Pipeline	$-.1.51x10^{-6}$	1.00	$3.41x10^{-6}$	$3.59x10^{-6}$	1.00	$2.40x10^{-6}$
New Drilling	.816***	2.26	.254	.702*	2.018	.315
Development Density	-.117*	.89	.045	-.086***	.918	.019
Size Variables						
Facility Oil	.005**	1.00	.001	.002**	1.00	.001
Facility Gas	.001*	1.00	.000409	-.004***	.997	.001
Operator Oil	$4.6x10^{-4}$***	1.00	$1.505x10^{-4}$	$2.697x10^{-4}$**	1.00	$1.188x10^{-4}$
Operator Gas	$-7.8x10^{-5}$	1.00	$4.23x10^{-5}$	$-3.008x10^{-4}$***	1.00	$8.04x10^{-5}$
State Regulation Variables						
Permit	2.45***	11.55	.303	1.358***	3.889	.380
Violations	.58***	1.79	.160	.134	1.143	.078
Community Variables						
Portion Black	-.005	1.00	.021	.005	1.005	.013
Portion Hispanic	.02***	1.02	.006	-.003	.997	.005
Population Density	-.001	.999	.002	$-2.306x10^{-4}$	1.00	$4.201x10^{-4}$
Household Income	.08**	1.086	.032	-.055	.946	.035
Constant	-4.7***	.009	.553	4.683***	108.045	.341
Ln Alpha				.630		.120
Alpha				1.878		.225
n	126,862			6,651		
clusters	4,608			455		
Adjusted R^2	.236			.070		
AIC * n	39,850.491			46,939.773		

*** $p<0.001$ ** $p<0.01$ * $p<0.05$ (two-tailed significance tests)