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Abstract
This paper looks at the variables that determine the location of hydraulic fracturing wells. Using cross-sectional data on Texas counties, we test whether county income level and the percentage of the population that is minority are significant indicators of well location. This study mirrors other studies that focus on the location of undesirable land uses such as landfills. Our study finds that income level and the size of the minority population are not statistically significant indicators of hydraulic fracturing well location.

Keywords
fracking, oil well, hydraulic fracturing, household income, minority populations

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I. Introduction

The method of hydraulic fracturing used in the oil and gas industry has been utilized for many years. More recently in the natural gas industry, the method of hydraulic fracturing, commonly known as fracking, has been combined with horizontal drilling in order to access more gas from each well. The well not only extends vertically into the deep shale basins, but also horizontally from the kickoff point up to 10,500 feet outwards (*Hydraulic Fracturing*). This new technique as well as the discovery of Marcellus shale along the east coast has brought fracking to the attention of the public at large. The potential environmental and health impacts of fracking wells on the surrounding area will be discussed later in the paper and are widely debated. The question of interest for this paper, however, is how great is the impact of local income levels and other demographic measures as indicators of where natural gas wells are located.

The question this paper focuses on is interesting because it investigates one example of externalities resulting from natural resource extraction. The difficulty of these externalities is balancing the need for the service with the unaccounted for cost of accessing it. To explore this a bit further, consider that natural gas could be the solution to the United States' dependence on foreign oil because the country has many large shale deposits, the rock formation that holds the natural gas. Natural gas would also boost the economy as a new area of development. It burns cleaner than other widely used fossil fuels so it could help solve problems with greenhouse gas emissions. The downside of this venture is the externalities that come from drilling natural gas wells. Research is just beginning to emerge on the health impacts of hydraulic fracturing wells for people and the environment. This makes it difficult to form a strong argument for the existence of this particular negative externality. Instead, this paper will simply look at where these wells are being located.

The initial motivation for this paper is the current debate on Marcellus shale. Watching the documentary *Gasland* serves as further inspiration because the families that seem to be dealing with the problems associated with natural gas wells appear to have lower incomes. The idea for the model used in this paper is inspired by the models set up by Boer et al. and Pastor et al. These two articles investigate the claims of environmental racism with regard to the location of treatment, storage, and disposal facilities (TSDF). The research in this paper applies a similar model to the location of natural gas wells, which will be discussed further in the literature review section. Texas counties are the focus of this analysis because data is most easily accessible for this area on all of the variables included in the model.

Assuming that there is some negative externality from natural gas wells, whether it is the loss in land aesthetics or water contamination, our interest is in the equality of the distribution of this externality. Economists are interested in the location of sites that result in some negative externality, such as hazardous waste facilities and landfills, to see whether they are disproportionately located near a certain portion of the population. This new area of interest has culminated as the environmental justice movement. Environmental justice "is the principle that all people and communities are entitled to equal protection of environmental and public health laws and regulations" (Brulle 2006). Is there environmental justice in the location of natural gas wells? Similar questions have been asked by other researchers but we have not found another paper on the application to the natural gas industry.

There are three economic theories that have been developed that pertain to the issues highlighted by the environmental justice movement: discrimination, the Coase theorem, and the theory of collective action (Hamilton 1993). Discrimination and the theory of collective action are the main points made by researchers in support of the environmental justice movement. The results of Hamilton's study indicate "that firms processing hazardous waste, when deciding where to expand capacity, do take into account variations in the potential for collective action to raise their costs" (Hamilton 1993). This is just one specific, illustrative example of the theory of collective action. Discrimination is very similar to this but references specific demographic characteristics as the distinguishing factor in firms' decision-making with respect to the location of undesirable land uses.

The Coase theorem alternatively states that "even in the presence of externalities an economy can always reach an efficient solution provided that the costs of making a deal are sufficiently low" (Krugman et al. 2007). Applying this to the location of fracking wells, a well should be located where the benefit from the wells exceeds the costs. One can argue this theory does not hold true because the health impact of the drilling exceeds the benefits to the economy. This is an especially poignant argument today with the recent statement released by the Environmental Protection Agency (EPA). The EPA stated, in response to water contamination complaints from the community of Pavillion, Wyoming, that "the explanation best fitting the data…is that constituents associated with hydraulic fracturing have been released into the Wind River drinking water aquifer" (Llanos

2011). In the past, EPA studies have supported the findings of the natural gas companies that fracking does not cause water contamination. New findings may change the current leniency the natural gas industry benefits from.

Before we discuss the empirical analysis behind the paper further, it is first important to understand some of the politics behind the controversy of hydraulic fracturing wells. The main point that will be addressed here is the exemptions from federal regulations that the natural gas industry has accumulated. The most notable exemptions are from the Clean Air and Clean Water Acts as of 1990 and 1987 respectively (*New York Times*). In 2005, Congress exempted natural gas drillers from having to provide detailed reports on the potential environmental impact of some of their activities, thus exempting them from the National Environmental Policy Act (*New York Times*). Again in 2005, after an EPA study was challenged by one of its own members saying that the study's conclusions were unsupported and that some members of the study's peer review panel had conflicts of interest, Congress still exempted hydraulic fracturing from the Safe Drinking Water Act (*New York Times*). Other exemptions for hydraulic fracturing include from the Superfund Act in 1980, the Emergency Planning and Community Right to Know Act in 1986, and exemption from the Resource Conservation and Recovery Act in 1988 (*New York Times*). This relatively large list of government approved exemptions from regulations that ultimately protect Americans' health adds to our interest in the environmental justice claims that will be investigated in this paper.

II. Literature Review

Our interest in the topic was partially inspired by such articles as "The Gas Dilemma," written by Bryan Walsh of *Time Magazine* that begins by noting that the great energy potential of natural gas comes with "the catch" that it could come with significant environmental and social costs. The environmental justice movement is interested in such situations as the equal distribution of these costs across society. The movement has in recent times been gaining attention from more and more academic literature. The goal of much of this literature is to determine whether or not demographic inequalities characterize the location of sites that pose some risk to the surrounding population. Boer et al. considers the location of TSDF. Other authors have studied the location of other “locally undesirable land uses” such as landfills (Been 1993). One of these land uses that has not be researched in depth is the location of hydraulic fracturing wells. This paper adapts the methods used by other researchers on environmental justice issues to see if the locations of these wells are characterized by demographic inequalities.

The known impacts of hydraulic fracturing wells are habitat fragmentation and the risk of a fluid spill. Hazardous chemicals are used in fracking to break the shale. When the fluids come back up, they are moved to a membrane-lined storage pad to dry out so the water from the mixture can evaporate. If the pad tears or there are heavy rains during this process, these pads can develop leaks or overflow. A controversial hazard of fracking wells is the potential contamination of groundwater and more specifically residential wells. This would be caused by the release of Normally Occurring Radioactive Material (NORM). When the shale is broken, NORMs can leak up through the ground along with some of the fracking fluids. With these risks in mind, we continue our review of related studies to see how their methods can be applied to this new land use.

The econometric model used in this paper utilizes variables relevant to this study from previous literature that also evaluates environmental justice claims. In many of the other studies there are measures of the presence of an undesirable land use such as TSDF. This study uses a measure of the number of wells in a county as the dependent variable (Hamilton 1993, Boer et al. 1997).

In similar studies there are usually independent variables that account for logical reasons for the location of such a facility such as community waste generation or the cost of locating in an area (Hamilton 1993, Boer et al. 1997). The study presented in this paper similarly uses average land value to account for the cost of locating a well in a specific area.

In the study done by Boer et al., the authors found both median household income and per capita income to have statistically significant coefficients so this study uses median household income because it is less influenced by outliers (Hamilton 1993, Boer et al. 1997). The final major influence you will see in this paper from previous literature is the use of simultaneous equations. The use of this type of model is consistent with the article written by Pastor et al., which investigates the disproportionate siting and minority move-in hypotheses. This brief overview justifies the modeling techniques used here because it shows that while this study explores a different issues, its structure is based on previously peer-reviewed work.

III. Modeling

The basis of the model in this paper is the question of whether or not local income levels and other demographics can indicate to a certain extent where natural gas wells are located. There is evidence both for and against the hypothesis that these factors do impact well location. One specific claim related to the environmental justice argument is that firms consider the potential for communities to mobilize and engage in collective action in deciding where to locate locally undesirable land uses (Hamilton 1993). Hamilton finds that commercial hazardous waste firms did take this factor into account in deciding where to add capacity during the period 1987-1992. His explanation of this result is that “the differing degree to which groups organize to demand compensation and raise a firm’s costs of choosing a particular location drives a wedge between the social costs of its externalities and the costs voiced through the political process of its site selection" and therefore challenges the outcome of the Coase theorem (Hamilton 1993). The location where the potential for collective action is the least may not be where the damage of its externalities is the least (Hamilton 1993). This is just one piece of evidence from past research that suggests that demographic characteristics that stereotypically suggest less potential for collective action significantly impact the location of facilities that bring with it negative externalities born by the surrounding community.

Other potential evidence that would support our hypothesis would be if the coefficients on the income and/or the minority population variables are statistically significant in difference from 0 given our data on fracking wells and demographics of counties in Texas. Contradicting evidence would be if the coefficients on the previous variables were not statistically significant yet the coefficients on the control variables were. To test to see what evidence can be gathered from this analysis we first used the following model:

$$Wells = \beta_0 + \beta_1 Resource + \beta_2 Income + \beta_3 Minority + \beta_4 Population + \beta_5 Land$$

The hypothesis is that the income and minority population variables do significantly impact the number of wells within a county. These two variables are the focus of this research. The control variables include a proxy variable for the presence of natural gas (*Resource*), population size (*Population*), and the land area of a county (*Land*). Hamilton's paper illustrates the reason why the theory holds that these two variables may be significant, because stereotypically both low income and minority communities are seen as having less collective action potential against such issues as fracking well location. *Resource* accounts for the fact that firms will build wells where there is natural gas to extract. *Population* and *Land* are included because they are control variables included in other comparable models and they account for the fact that the less land there is open, the fewer wells that can be built due to the space required for the construction. According to the Pennsylvania Department of Conservation and Natural Resources, each natural gas well site requires between 3 to 5 acres when fully constructed.

The ordinary least squares (OLS) method is first used to estimate the coefficients of the multivariable regression but the initial model is not correctly specified. We find that our initial model has simultaneity bias and correct for this by using the two-stage lease squares (2SLS) method. Additional variables are included after further research. The final model we work with is a simultaneous equations model where *Wells* and *Income* are endogenous variables and *Resource, PopDensity, Minority, Value1997,* and *Education* are exogenous variables. The simultaneous equations that will be estimated are as follows:

$$Wells = \beta_0 + \beta_1 Resource + \beta_2 PopDensity + \beta_3 Minority + \beta_4 Value1997 + \beta_5 Income$$
$$Income = \alpha_0 + \alpha_1 Education + \alpha_2 PopDensity + \alpha_3 Minority + \alpha_4 Value1997 + \alpha_5 Wells$$

Opponents to environmental justice claims argue that firms' do not choose to locate an undesirable land use in low income communities. They argue that the location of the site is due to the cost of land because land costs are usually lower in low income communities or that low income households often relocate near these sites because land costs decrease. We do not have panel data to account for simultaneous changes in number of wells and land value. Instead, we use county income level as the instrumental variable. This study therefore cannot imply anything about the firms' or the communities' decision making. It is assumed that county demographics before the more widespread construction of natural gas wells are determined by the exogenous variable for 1997 land value. It is also assumed that this land value is equivalent to the price natural gas companies would have to pay in order to locate a well there. Given these two assumptions, we can then account for the significance of demographic characteristics and the included control variables on the number of wells in a county. The hypothesis is that county income levels do have a significant impact on the number of wells located in the county, holding constant the impact of all other explanatory variables. This hypothesis would support environmental justice claims. We continue with a more in depth description of the data used in this analysis before examining the regression results.

IV. Data

The ideal data set would be a panel data set including data on all counties in the United States for a number of time periods. The data would include measures of the number of wells built during each time period, the amount of accessible shale within each county, population density, the average value of land, the percentage of the population with a college degree, the percentage of the county population that is minority, and the median income of each county for each specified time period. Acquiring this data would allow the study to better analyze the firms' decisions on locating natural gas wells. By lagging some variables such as income, the number of wells built in the next time period would presumably reflect data the decision maker would have from the previous period. With this data, the impact of demographics such as income level and minority could be better isolated from the impact of land value on firms' decision-making. Due to time restrictions and data availability, cross-sectional data is used over all counties in Texas, a state with a large presence of the natural gas industry.

A sample of all Texas counties that had appropriate data was included in this model. This sample of 233 counties only excluded 21 counties due to missing data. The variables included in the final regression model are *Wells, Resource, PopDensity, Minority, Value1997, Income,* and *Education*. Table 1 includes descriptions of these variables and lists their sources and Figure 1 provides the basic statistics on each variable.

Table 1

Variable	Description	Source
Wells	Number of regular producing gas wells as of September 2010	Railroad Commission of Texas
Resource	Gas wells gas production in thousands of cubic feet; measured from January to December 2010	Railroad Commission of Texas
PopDensity	Persons per square mile, 2010	US Census Bureau
Minority	2010 minority population as percentage of total population	US Census Bureau
Value1997	1997 average county market value of acre of land	Texas A&M Institute of Renewable Natural Resources
Income	2009 Median household income	US Census Bureau
Education	2005-2009 percentage of population age 25+ with bachelor's degree or higher	US Census Bureau

Figure1

```
. summarize wells resource income minority popdensity value1997 education

    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
       wells |       234    432.8162    927.3171          0       6003
    resource |       234    2.85e+07    7.30e+07          0   6.49e+08
      income |       234    41162.29    9592.201      21841      80548
    minority |       234    40.49573    21.43345          6         97
  popdensity |       234    103.5985    309.8335         .1       2718
-------------+--------------------------------------------------------
   value1997 |       233    644.1245    716.5479         30       5899
   education |       233    16.49313    6.356069        6.6       43.1
```

Note that *Wells, Income,* and *Resource* have the largest standard deviations suggesting that these variables vary most about their mean relative to other included variables. Our empirical analysis may find that the variation in *Wells* is best explained by the variation of *Income* and/or *Resource*. These observations are purely speculative.

V. Evidence

As mentioned before, the analysis began with a multiple regression model that was estimated using OLS. This model was first estimated using a random sample of 30 counties in Texas. After the data on all counties in Texas were collected, the regression model was run again with the same specification. Using the Ramsey RESET test, we found that the old model specification no longer fit the data. With both regressions there were heteroscedasticity problems, which were corrected for by using robust standard errors. The results of these initial regressions are shown in Table 2.

Table 2

Variables	N=30 P-values	N=30 Coefficients	N=233 P-values	N=233 Coefficients
Resource	0.03	$6.49*10^{-6}$	0.00	$8.64*10^{-6}$
Population	0.27	-0.0026	0.07	-0.00039
Minority	0.06	2772.626	0.06	568.54
Income	0.12	0.0758	0.04	0.015
Land	0.28	0.2511	0.11	0.025

After attempting logical model specification changes using OLS regression methods, the model was tested for simultaneity bias using the Hausman Specification Test. In this process, we decided to include slightly different variables reflecting further research. The test results, shown in Figure 2, indicate that the model does have simultaneity bias because the Prob>F value (0.01) is less than 0.05. In other words, the impact of the residuals from running a regression of the reduced form equations is significant in difference from 0. This also means that there is a feedback loop so to correct for this we construct the simultaneous equations discussed above and estimate them using 2SLS. The regression results are shown in Figure 3. Before interpreting the regression results, it is also important to note that the 2SLS model was also tested to see if *Income* was a strong instrumental variable. The Stata output from this test is shown in Figure 4. The OLS regression of the instrumental variable *Income* on all included variables and the identifying variable, *Education*, indicates that *Income* is a good instrument because the Prob>F value (0.00) is less than the 0.05 level of significance so we can reject the null hypothesis that the coefficients on all included variables are 0. In other words, the Adjusted-R^2 is statistically significant in difference from 0.

Figure 2

```
. regress value resource income popdensity

      Source |       SS       df       MS              Number of obs =     233
-------------+------------------------------           F(  3,   229) =   21.81
       Model |  191255650     3  63751883.3           Prob > F      =  0.0000
    Residual |  669286270   229  2922647.47           R-squared     =  0.2223
-------------+------------------------------           Adj R-squared =  0.2121
       Total |  860541920   232  3709232.41           Root MSE      =  1709.6

------------------------------------------------------------------------------
       value |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    resource |   5.48e-07   1.59e-06     0.34   0.732    -2.59e-06    3.69e-06
      income |   .0254878   .0123509     2.06   0.040     .0011519    .0498237
  popdensity |   2.562794   .3874724     6.61   0.000     1.799327    3.326261
       _cons |    204.703   510.0005     0.40   0.689    -800.1904    1209.596
------------------------------------------------------------------------------

. predict vres, resid
(1 missing value generated)

. regress logwel resource income value vres

      Source |       SS       df       MS              Number of obs =     233
-------------+------------------------------           F(  4,   228) =   20.51
       Model |  424.679533     4  106.169883           Prob > F      =  0.0000
    Residual |  1180.12922   228  5.17600535           R-squared     =  0.2646
-------------+------------------------------           Adj R-squared =  0.2517
       Total |  1604.80875   232  6.91727911           Root MSE      =  2.2751

------------------------------------------------------------------------------
      logwel |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    resource |   1.85e-08   2.15e-09     8.62   0.000     1.43e-08    2.28e-08
      income |   .0000423   .0000184     2.30   0.023     5.99e-06    .0000787
       value |  -.0005205   .0002012    -2.59   0.010     -.000917   -.0001241
        vres |   .0006326   .0002196     2.88   0.004     .0001999    .0010653
       _cons |   2.444742   .6716718     3.64   0.000     1.121265     3.76822
------------------------------------------------------------------------------

. test vres

 ( 1)  vres = 0

       F(  1,   228) =    8.30
            Prob > F =    0.0043
```

Figure 3

```
. ivreg wells resource popdensity minority value1997 (income= popdensity minorit
> y value1997 education)
```

Instrumental variables (2SLS) regression

Source	SS	df	MS
Model	55314333.4	5	11062866.7
Residual	144908993	227	638365.607
Total	200223326	232	863031.578

Number of obs	=	233
F(5, 227)	=	34.84
Prob > F	=	0.0000
R-squared	=	0.2763
Adj R-squared	=	0.2603
Root MSE	=	798.98

wells	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
income	-.0451702	.038675	-1.17	0.244	-.1213782	.0310378
resource	9.79e-06	9.12e-07	10.73	0.000	7.99e-06	.0000116
popdensity	-.7137522	.3390545	-2.11	0.036	-1.381849	-.0456557
minority	-3.345217	6.346545	-0.53	0.599	-15.85089	9.160455
value1997	.4811013	.1198733	4.01	0.000	.2448946	.7173079
_cons	1916.833	1743.2	1.10	0.273	-1518.088	5351.755

Instrumented: income
Instruments: resource popdensity minority value1997 education

Figure 4

```
. regress income resource popdensity minority value1997 education
```

Source	SS	df	MS
Model	4.9027e+09	5	980540354
Residual	1.6161e+10	227	71192896.9
Total	2.1063e+10	232	90790902.5

Number of obs	=	233
F(5, 227)	=	13.77
Prob > F	=	0.0000
R-squared	=	0.2328
Adj R-squared	=	0.2159
Root MSE	=	8437.6

income	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
resource	.0000132	7.85e-06	1.68	0.095	-2.30e-06	.0000286
popdensity	6.732463	2.319925	2.90	0.004	2.161121	11.30381
minority	-142.6194	26.65511	-5.35	0.000	-195.1425	-90.09638
value1997	.9108222	1.068944	0.85	0.395	-1.195499	3.017144
education	244.3049	99.78071	2.45	0.015	47.6901	440.9198
_cons	41294.8	1974.299	20.92	0.000	37404.5	45185.09

The p-values for *Resource* (0.00), *PopDensity* (0.04), and *Value1997* (0.00) indicate that we can reject the null hypotheses that the coefficients on these variables are 0. In other words, their coefficient estimates are statistically significant in difference from 0. The coefficients on these variables do all have the expected sign. The coefficient on *Resource* is positive, which is logical because if there is more natural gas in a county, there should be more wells to extract it. The coefficients on *PopDensity* and *Value1997* are not as expected. This possibly can be explained by an unaccounted for model specification problem.

Previous literature has found that there is a parabolic relationship between the presence of an undesirable land use site and income. Boer et al. found that "income has first a positive, then a negative effect on TSDF location, a pattern that likely reflects the fact that the poorest communities have little economic activity while wealthier communities have the economic and political power to resist negative environmental externalities." This finding may also apply to *PopDensity* and *Value1997*. Very desolate areas where land is not habitable may correspond with a type of land where shale deposits are also not often found while very populated areas, where water and organic materials are more abundant, are too populated for the construction of a natural gas well. This example, purely speculative, describes a similar situation to that found by Boer et al. A step for further research would be to include a squared term. A similar example could be constructed for *Value1997*. This relationship is not accounted for by the current model and could explain the unexpected sign of the coefficients. The final observation from this regression analysis that is pertinent to our study is that the sign of the coefficient on *Income*, although not significant in difference from 0, has the hypothesized sign. The coefficient is negative suggesting that if income increases, the number of wells in that county will decrease, holding constant the impact of all other variables. The coefficient on *Minority* is also negative, contrary to our hypothesis. The weaknesses of this study are the lack of panel data and the model specification. Further research is needed on this issue to gain better insight into the location of these wells as the natural gas industry continues to grow.

VI. Conclusions

Although the model does not indicant that the impacts of income and minority status on the number of wells in a county are significant, further research is necessary to look at this relationship across time. We believe that analysis using panel data may find different results or at least offer a more clear interpretation and application of findings. This study suggests that income and the percentage of the population that is a minority are not significant indicators of where natural gas wells are located in Texas counties. These findings challenge claims made by the environmental justice movement. This does not mean, however, that there is any less of a need to do further research on the possible health and environmental impacts of hydraulic fracturing. Further analytical research is needed in on the issue of fracking well location that can address the issues of the best unit of observation (county, census tract, borough, etc) that should be used in the analysis and data limitations. Research is crucial for appropriate policy implementation and public understanding especially as the natural gas industry expands.

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