The Effect of Federal Regulations on the Outcomes of Auctions for Oil and Gas Leaseholds

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Abstract

This thesis attempts to analyze the impact of the differences in regulatory frameworks that govern state-owned and federally-owned lands on the outcomes of auctions for oil and natural gas leaseholds in the state of New Mexico. The analysis tries to isolate the effect of ownership by controlling for auction structure, leasehold characteristics, and prices of underlying resources. Given past research, the hypothesis is that stricter regulations carry a heavier cost to buyers, so the expectation is that federally-owned leaseholds, which are more regulated, are traded at a discount to state-owned leaseholds. However, the result of this thesis is contradictory to the hypothesis. The conclusion is that stricter regulations do not lead to a discounted auction price for an oil and gas leasehold.

JEL Classification: C12, C21, Q35, Q58

Keywords: oil, natural gas, auction, regulation, state, federal, environment, education

Contents

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1 Introduction

Energy is one of the key industries that support society's growth and development. For the past century, the key resources that were used in transportation and generation of electricity have been fossil fuels, which have two main problems: they are scarce and they cause pollution. Hence, a significant part of government policies in this sphere has been focused on conservation of valuable materials and making sure that an uncontrolled use of fossil fuels would not lead to a major environmental disaster. Oil and gas leaseholds in the US are sold at auctions by both federal and state governments, which have different regulations regarding fossil fuels. The purpose of this thesis is to analyze the effect of these regulations on producers' willingness to bid for a leasehold at auctions.

In 1785, the United States Federal Government created the Land Ordinance which established the rules for distribution of land between federal and state authorities. Such random division provides the researcher with a perfect experiment since there is no clear suggestion whether federal or state land is better. Land was divided into six by six mile townships, which were further divided into 36 equal-sized sections [1]. New Mexico Territory became a state on January 6, 1922 and was awarded sections 2, 16, 32, and 36 as illustrated on Figure 1. This designation will be used to control for quality of land by using the distance between federal and state land: the closer parcels of land are to each other, the more similar they are. Revenue from state-owned sections of land goes into a state land trust, whose beneficiaries usually include educational and health institutions. As for the sections that are owned by the federal government, revenue is distributed between the

[1] Where those sections had previously been sold or allocated to Indian pueblos, tribal reservations or pre-existing land grants, a state was allowed to pick lands elsewhere in lieu of the four designated sections.

Treasury and a state. As can be seen from Figure 2, the Western part of the United States has a lot more land under federal ownership. New Mexico is one of the top states in terms of this statistic. Hence, despite New Mexico producing only 4.4% of the US oil output and 3.9% of the US natural gas output, given that such a large percentage of land owned by the federal government, New Mexico becomes a state of huge significance for the topic of this thesis . It has the largest oil production and the 2nd largest gas production on federal lands among all the states in the US[2]. Therefore, this is one of the main reasons why looking at New Mexico is important for this thesis.

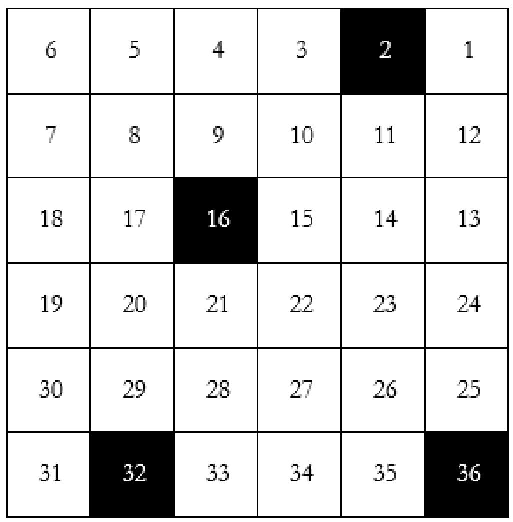

Figure 1: New Mexico Township Map

Lands that are in federal or state ownership have multiple purposes: cattle grazing, national parks, mineral development, etc. The purpose that is particularly interesting for this thesis is oil and natural gas extraction and development. Both state (as a State Land Trust) and federal

[2]Oil and natural gas extraction on federal land. (n.d.). Retrieved March 20, 2016, from `https://ballotpedia.org/Oil_and_natural_gas_extraction_on_federal_land`

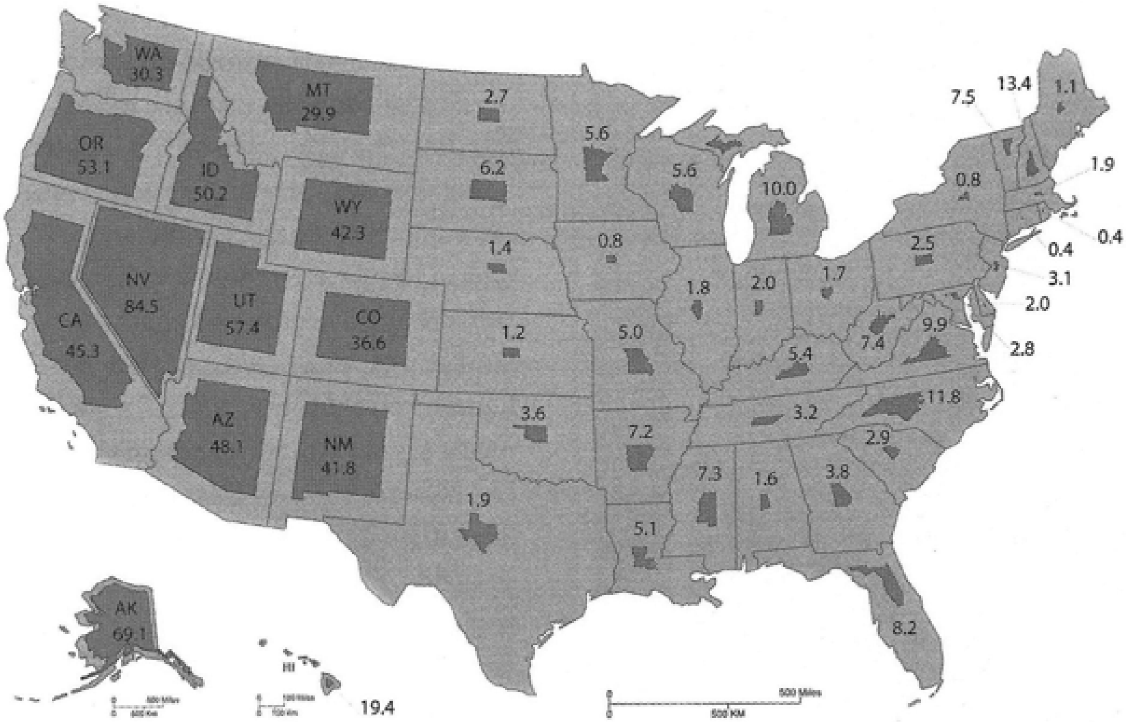

Figure 2: Percentage of Federal Land (Source: U.S. General Services Administration)

authorities (as BLM, which stands for a Bureau of Land Management) sell leases for their lands at auctions that they conduct on a monthly and on a quarterly basis respectively. The government receives money from oil and gas producers in 3 major ways: bonus, rent, and royalty. A bonus is an auction payment upfront or a price a producer pays at an auction. A rent is a payment that a producer pays while an area is not being drilled. A royalty is a fixed percentage of oil and gas revenues that a producer pays to an owner of a land after drilling a well. BLM has a uniform type of lease for all of its oil and gas lands. The term is 10 years, the rent is \$1.50 per acre for the first 5 years and \$2.00 per acre for the rest of the period, and the royalty is 12.5%. As for state authorities, the type of lease varies by state. Table 1 provides details of the lease conditions for the state of New Mexico. The term can be 5 or 10 years, the rent varies from \$0.25 to \$1.00 per acre depending on the county, while the royalty varies between 12.5% and 20.0%. The conditions

Table 1: Lease Information for New Mexico

Owner	Term	Royalty	Rent	Description	Land
Federal	10 year	1/8	\$1.50 / \$2.00	NA	NA
	10 year	1/8	\$0.25 – \$1.00	Exploratory	Unrestricted
	5 year	1/8	\$0.25 – \$1.00	Exploratory	Restricted
State	5 year	1/6	\$0.25 – \$1.00	Discovery	Restricted
	5 year	3/16	\$0.25 – \$1.00	Development	Restricted
	5 year	1/5	\$0.25 – \$1.00	Development	Restricted

of the lease are different for lands of different quality (probability of oil and gas presence): from 'exploratory' to 'development', from 'unrestricted' to 'restricted'. The higher the quality of land, the worse the conditions of a lease are for an oil and gas producer. It seems that the New Mexico State Land Office (SLO) is utilizing a more flexible strategy for selling leaseholds.

As has been mentioned before, the leaseholds are sold at auctions. Hence, it will be useful to introduce a quick overview of basic auction concepts. An auction is a sale of a particular good or service to the highest bidder. Auctions are usually used in cases when the value of an object cannot be precisely approximated by a seller. There are two main types of auctions: open-bid and sealed-bid. In the case of an open-bid auction, bidding is oral and participants can hear everyone else's bids during the auction process. As for a sealed-bid auction, the process is secret and results are only announced at the end of the auction. For each type, there is a further subdivision. The two main types of open-bid auctions are English and Dutch auctions. In an English auction, the seller sets a minimum price (a reservation price) for an object and buyers try to outbid each other throughout the process. If the final price is higher than the reservation price, the object gets sold to the highest bidder. English auctions are very commonplace and they are used in every possible field of economic activity, including oil auctions. In a Dutch auction, the process is reverse: the seller announces a very high price on the object and consequently drops it until someone is willing to buy it. Dutch auctions were famously used in the sale of tulips and arguably contributed to the severity of the infamous tulip bubble. Regarding sealed-bid auctions, there are first-price (the winner pays the highest price) and second-price (the winner pays the second-highest price) cases. Open-bid English auctions and sealed-bid second-price auctions produce the same outcomes. The same is true for open-bid Dutch auctions and sealed-bid first-price auctions. This is one of the most crucial conclusions of auction theory, which is based on the assumption of rationality of auction participants. As for this thesis, BLM uses only English auctions, while SLO uses both English auctions and first-price sealed-bid auctions. Diversity of auction and lease structures is what makes New Mexico interesting relatively to other states in the US and is another major reason why this state was chosen for the research.

So far there has been a lot of discussion about the oil and gas industry, lease types, and auctions. Yet, one part remains uncovered, and that is regulation. Among all US jurisdictions, federal regulations are by far the strictest on environmental control. This has led to more comprehensive environmental protection, but also to many inefficiencies. If it takes at most 30 days to approve an application for permission to drill (APD) by a state[3], the federal government took the whole 227 days in 2014[4]. This discrepancy is huge, and it illustrates problems that might arise with more

[3]Loris, N. (2013, June 27). Energy Production on Federal Lands: Handing Keys Over to the States. Retrieved April 03, 2016, from http://www.heritage.org/research/reports/2013/06/energy-production-on-federal-lands-handing-keys-over-to-the-states#_ftn8

[4]Humphries, M. (2015, April 3). U.S. Crude Oil and Natural Gas Production in Federal and Non-Federal Areas (USA, Congressional Research Service). Retrieved April 3, 2016, from http://instituteforenergyresearch.org/wp-content/uploads/2015/04/CRS-federal-vs.-nonfederal.pdf

regulation. The only state with regulatory framework that can rival the laws instituted by the federal government on its land is California. The last major reason why New Mexico was chosen is because it has major environmental problems. New Mexico is one of the most polluting states. It is ranked highest for methane emissions[5]. Even though environmental regulations are necessary, Eric Lewis (2015) and Branko Boskovic (2015) suggest that regulations are very costly to oil and gas producers. In his paper on the effect of environmental regulation on the drilling activity in Wyoming, Lewis (2015) estimates that federal regulations cost about $17 million per well. He attributes this to the effects of numerous environmental laws, such as NEPA, which stands for the National Environmental Policy Act (1970), ESA, which stands for the Endangered Species Act (1973), the Federal Land Policy and Management Act (1976), CAAA, which stands for the Clean Air Act Amendment (1977), and the National Historic Preservation Act (1966). Hence, it is also important to figure out how federal regulations influence auction prices for oil and gas leaseholds. Branko Boskovic and Linda Nostbakken (2015) have looked at the effect of regulation protecting endangered species on prices producers pay at auctions in Alberta, Canada. They estimated that they pay 27% less for parcels that are regulated due to the cost increase for oil producers. Independent report provided by Property and Environment Research Center (PERC) confirms the aforementioned papers: higher regulations are costly[6]. Following this logic, the hypothesis is that, ceteris paribus, federally-owned leases should be trading at a discount to state-owned leases

[5]Wright, M. (2015, June 23). Report ranks state No. 1 for methane emissions, lost gas revenues. Retrieved March 20, 2016, from `http://www.santafenewmexican.com/news/local_news/report-ranks-state-no-for-methane-emissions-lost-gas-revenues/article_6ba81fcc-69d6-528f-8d53-806d404bb768.html`

[6]Fretwell, H., & Regan, S. (2015, March 3). Divided Lands: State vs. Federal Management in the West. Retrieved March 20, 2016, from `http://www.perc.org/articles/divided-lands-state-vs-federal-management-west`

in New Mexico. However, the results of the regression on the New Mexico dataset suggest that it is not necessarily the case. The reason why this finding is important lies in the fact that for state land trusts, there is a clear cost to regulation. If it is true that environmental regulations lead to a discount in a leasehold price, then this has a detrimental effect on the revenues that educational and health institutions can get. However, if regulations carry no or minimal cost, then there might be an opportunity to help the environment without sacrificing funding for schools and hospitals. Given that California's (which has regulations comparable to NEPA) APD is limited to 10 days by law, which says a lot about the state's efficiency, there does not seem to be much of an obstacle to more regulation.

This paper consists of the following sections: Section II provides an overview of relevant literature and shows how this paper's contribution fits within it, Section III introduces the data and provides a general overview of some important variables, Section IV gives an overview of the methods that will be implemented to answer the research question, Section V contains a discussion of the quantitative results of the statistical analysis. Section VI gives the analysis of limitations, summarizes and concludes the thesis.

2 Literature Review

There are different strands of literature to review. At first, there will be a discussion of empirical papers on the issues that are the most similar to the research topic of this thesis. Then, there will be a review of papers to show whether environmental control is effective. Afterwards, there will be a review of publications on auction theory. Kunce (2002) estimated "that average drilling costs per well are about $200,000 higher on a federal property than on a private property". Eric Lewis

(2015) argues that the environmental regulations that the federal government imposes on its land result in a cost of \$17 million (2010 dollars) per well. Using the drilling data from Wyoming, USA, he establishes that "low costs on a non-federal land decreased drilling on a nearby federal land". This conclusion provided the basis for the hypothesis of this thesis. I am taking a different approach by looking at the difference in prices that producers pay for federal and state lands at oil and gas auctions rather than at the difference in drilling costs. My approach might also be more direct given that the prices are essentially present values of drilling projects. Branko Boscovic and Linda Nostbakken (2015) looked at the regulation protecting endangered species in Alberta and how it affects prices producers pay for leases at auctions. They found that producers pay "27% less on average for parcels that are regulated and that the total net present value cost of the regulation over 10 years exceeds \$1.3 billion". I will try to have a similar analysis to this paper to test the hypothesis later in the thesis.

There is a lot of literature on environmental regulations and their effect on producers and consumers. In this paragraph, I will try to give a quick overview of some important papers that make the topic of this thesis relevant to the challenges that the US society faces. First, Trent Yang et al. (2004) estimate that "benefits of air pollution regulations in USA rose steadily from 1975 to 2000 from \$50 billion to \$400 billion (from 2.1% to 7.6% of market consumption)". Moreover, Antonio Bento et al. (2015) show that a lot of the benefits from "the 1990 Clean Air Act Amendments (CAAA) were progressive", meaning "households in the lowest quintile of the income distribution received annual benefits from the program equal to 0.3% of their income on average during the 1990s, over twice as much as those in the highest quintile". However, the benefits of environmental regulations are not limited to just reduced emissions. There is evidence that environmental regulations lead to innovation, increased efficiency, and international technology transfers. Dylan Rassier and Dietrich Earnhart (2015) tested the Porter hypothesis, which states that properly designed environmental regulation motivates firms to innovate, and found that the results for actual profitability are consistent with the hypothesis. Takao Asano and Noriaki Matsushima (2014) found that an “environmental tax imposed by the government in the home country can induce a foreign firm with advanced abatement technology to license it to a domestic firm without this technology. Furthermore, when the domestic firms’ production technology is less efficient than that of the foreign firm, the foreign firm may freely reveal its technology to the domestic firm. These improvements through the voluntary transfer of technology imply that environmental regulations have positive impacts on innovation.” Yet, regulations have costs, too. Stephen Ryan (2012) evaluated the “welfare costs of the 1990 Amendments to the Clean Air Act on the U.S. Portland cement industry”, and found that they “significantly increased the sunk cost of entry, leading to a loss of between $810M and $3.2B in product market surplus”. Overall, all of these evaluations are very hard to perform, so the results should be taken into account with a grain of salt. Claire Brunel and Arik Levinson (2016) showed that “the obstacles to evaluating environmental regulatory stringency are not simply issues of data collection, rather they derive from the deeper conceptual challenges of multidimensionality, simultaneity, industrial composition, and capital vintage, which should be kept in mind when evaluating any proposed measure of stringency”. To sum up, it seems that environmental regulations are beneficial to society and should be implemented to the maximum possible extent. This explains why most of the research is focused not around whether environmental policies should be implemented, but rather on how to implement in the most efficient way.

It is also important to spend some time on a discussion of auction theory as most of the major control variables come from the way the auction is structured, the number and type of participants[7]. One of the first economists to develop a formal theory around auctions was William Vickrey (1961), who developed an early version of the revenue equivalence theorem. This theorem states that, given certain conditions, any auction mechanism that results in the same outcome, has the same expected revenue. Vickrey assumed the rationality of the buyers and the seller, risk neutrality, private value, common distribution, and absence of collusion. Therefore, the following research focused on situations with one of those assumptions relaxed. The first economists to tweak with Vickrey's theoretical work were Griesmer, Levitan and Shubik (1967), who assumed distributions with different supports, and Wilson (1969), who introduced the common-value model and was the first to analyze the concept of the winner's curse. One of the Vickrey's main assumptions was that each object that is getting sold has a private value for every participant. However, if you plan to resell it later at a preferably higher price, then it will be crucial for you what other people are willing to pay for it. Hence, there is an average value that some object has, which brings an idea of the winner's curse into play. If there is a certain number of bidders, the one who is going to win an auction is the one who greatly overestimates the value of an object sold. As a result, it will be hard for the buyer to resell a painting at a higher value afterwards since she overpaid already. Then, Myerson (1981) and Riley and Samuelson (1981) extended Vickrey's theorem of revenue equivalence to a more general case and proved that it works not only for private value auctions, but for common-value auctions as well. Henceforth, Maskin and Riley (1984) relaxed the other assumption: risk neutrality. It is very hard to say that humans do not care about risk. The

[7] The skeleton of the history on auction theory was borrowed from a remarkable paper by Paul Klemperer

next one was independence of bidders. It is unrealistic to assume that bidders' information is not correlated. Essentially, if the bidders' information is correlated to the winner, then an open-bid auction might produce higher surplus for the seller since it will minimize the winner's information rent. If a bidder sees that the winner is signaling high values, the assumption is that she will bid higher than she otherwise would. Milgrom and Weber (1982) outlined this result. In addition, bidders could have interdependent signals because they colluded, which has a negative effect on the seller's surplus. Robinson (1985) found that it is more likely that collusive agreement can work in the case of a sealed-bid auction rather than an open-bid auction. However, Hendricks, Porter, and Tan (2003) showed that in common-value environments, such as offshore oil leases, an efficient collusion may not be possible at all. Hence, answering the question of whether collusion is a significant risk will be crucial to this thesis and will be further researched. Oil and gas auctions come in the form of either sealed-bid or open-bid auctions. The decision between the two could be greatly influenced by the likelihood of collusion between oil firms.

Another crucial assumption that has been put into question is the fact that bidders' values come from the same distribution. Maskin and Riley (1999) found that "sealed-bid auctions generate more revenue than open-bid auctions when distributions have similar shapes but different supports (part of the domain where the function takes a non-zero value), whereas an open auction dominates when the distributions have different shapes but approximately the same support." The asymmetry argument will have to be taken into account when evaluating the impact of the auction type on the surplus of the federal government or the state. Hendricks, Porter and Wilson (1994) found that "the distributions are identical at bids above the support of a reservation price [for sealed-bid offshore oil auctions]". This result will need to be tested for the onshore oil data that will be used in the thesis and contrasted relatively to open-bid auctions. Looking at the same New Mexico dataset, Yunmi Kong (2015) found that sealed-bid auctions yield higher revenue because of risk aversion coupled with an endogenous entry process that makes bidders uncertain about the types of rivals they will face. The number of bidders is another factor that is crucial to the auction design. The question of how many is enough is important for the seller to know since she wants to figure out whether any barriers to entry are necessary at all and if there are barriers that have a large negative impact on the value of the seller's surplus. The key result is that bidders make a socially-correct decision of entry into an auction when the reservation price is set at the value of seller's valuation. Bulow and Klemperer (1994) illustrate that symmetry of bidders ensures that the value of additional participant can be even higher than the value of the seller's ability to set a reservation price. Since one of the goals of this thesis is to extrapolate the effect of a number of participants, this finding could be crucial. To conclude the overview of the literature on auction theory, if my research finds that there is a price difference between open-cry and sealed-bid auctions, it might tell us something about the possibility of a collusion between oil and gas firms and the type of distributions that they might have. Moreover, looking at the number of participants can shed a light on whether it makes a difference, as supported in the theory, to the magnitude of the bid. Finally, if there is a significant evidence that there is a bidder who either overpays or underpays for a piece of land, then we might investigate whether it is because of information asymmetry or not. The literature above suggests which variables are important to include as controls for the regression. Putting the theory to a test will be important in answering the final research question.

3 Data

Among federal and state land authorities, the most informative dataset has been provided by the New Mexico SLO and the New Mexico BLM in terms of variables that are available for use. As for oil and natural gas reserves, New Mexico is one of the most important states. Its proximity to Texas and exposure to the most important reserves in the country (Permian) makes it a good proxy for the nationwide effects. The dataset starts on January, 1994, which is the earliest date, for which I have all observations. This dataset provides information on the location of a parcel, the size of a parcel, the type of lease, the auction price, the auction type, the number of bidders, and the bid winner. In addition, there is Drillinginfo well data that starts from 1990. This dataset provides information on the well location, the start date, and the average and cumulative production. Altogether, there are enough observations to test the hypothesis of the thesis.

New Mexico has two main oil and gas plays: San Juan Basin (northwest) and Permian Basin (southeast), which are illustrated on Figure 3. The top map shows all leaseholds that were sold during the period of 1994-2015, while the bottom map shows all wells that were drilled from 1990 to 2015. The San Juan Basin represents a downwarp of sedimentary rocks of mostly Mesozoic age. The bones of enormous dinosaurs from that time provided this deposit with a large amount of coal and natural gas. The Fruitland Formation, specifically, has been one of the largest suppliers of coalbed methane in the US. The production of natural gas is so huge in this region that NASA researchers reported a discovery of a 2,500 square miles (6,500 km^2) methane cloud floating over the Basin, which is also a sign of pollution[8]. The Permian Basin is another sedimentary basin,

[8]Phillips, T. (2014, October 9). U.S. Methane 'Hot Spot' Bigger than Expected. Retrieved March 21, 2016, from http://science.nasa.gov/science-news/science-at-nasa/2014/09oct_methanehotspot/

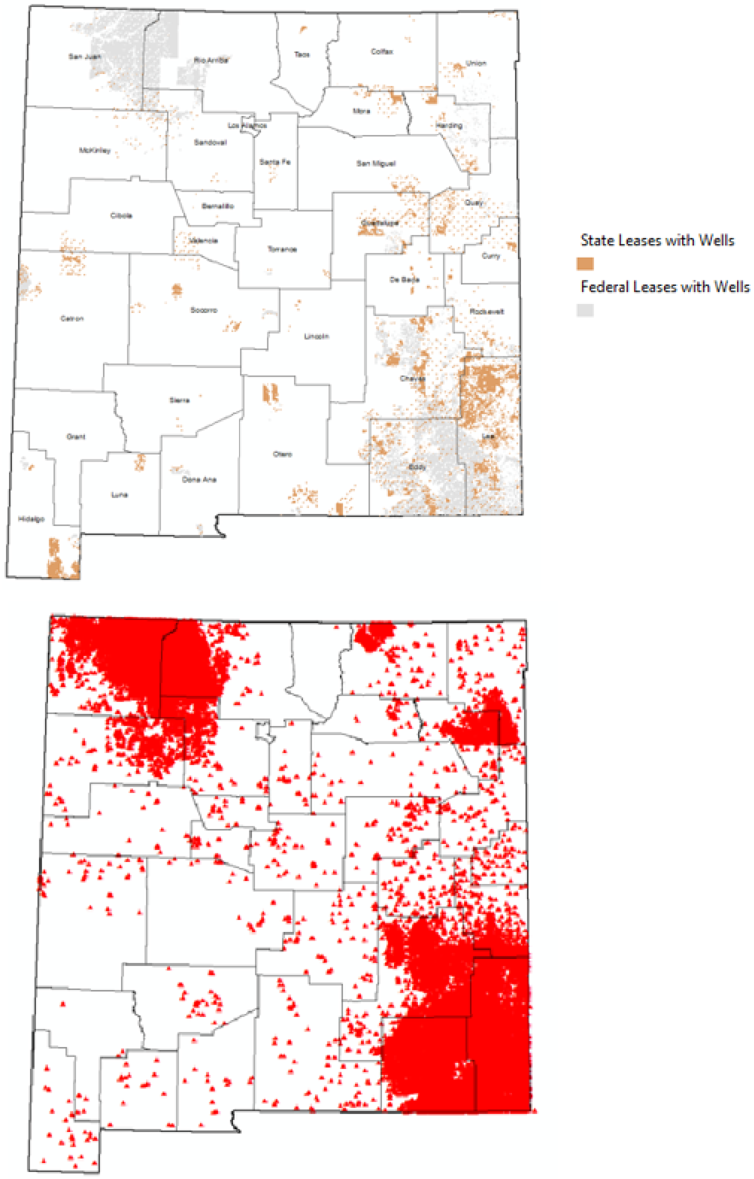

Figure 3: New Mexico Oil and Gas Map

with only a minority of its assets located in New Mexico. The reserves come from the Permian period (hence, the name), so they are older than the ones from San Juan Basin. The Permian Basin is the largest oil producing region in the US. Hence, having data from this region is very useful for my research because it builds a bridge between assumptions that go into the analysis on a local state level and the general conclusion that can be derived on a global federal level. In the dataset, 705 leaseholds sold were located in the San Juan Basin, 10,847 leaseholds - in the Permian Basin, and 3,019 leaseholds - in none of the major basins. It is easy to see why Permian would be a very popular place to drill, yet it is surprising that San Juan has such a small number of auctions held during this period.

Since 1994, there were 2,094 federal and 12,477 state auctions. Figure 4 illustrates a trend over 21 years. It seems that state authorities sold 6 times the amount of land that federal authorities did. However, if one looks at total acreage sold during that period, the federal authorities sold 1,245,406 acres, while the state authorities sold 3,902,761, which brings the ratio to 3 times. The general conclusion is that the federal authorities sell the land less often (quarterly versus monthly basis), but they sell it in bigger chunks. In terms of a total dollar amount, numbers seem to be even closer: \$751,450,922 for the state government and \$711,272,149 for the federal government. It seems that overall revenue from auction sales seems to be equal for the state and federal authorities during the same period of time. The last numbers suggest that, given that the overall acreage sold by the SLO is higher than that sold by the BLM, the federal lands are sold on average at a higher price (\$571.12) than the state lands (\$192.54). Even though there are a lot of factors that come into play, this is a very interesting observation.

4 Theory and Methodology

This section will discuss the methodology that will be used to analyze the New Mexico dataset. Equation 1 shows a preliminary overview of regression variables that will be used to predict an adjusted leasehold price per acre (P_L), where T_R is a resource type, P_R - a resource price, S_F - a futures curve slope, O_L - a lease owner, B - a basin, T_L - a land type, S_L - a lease size, T_A -

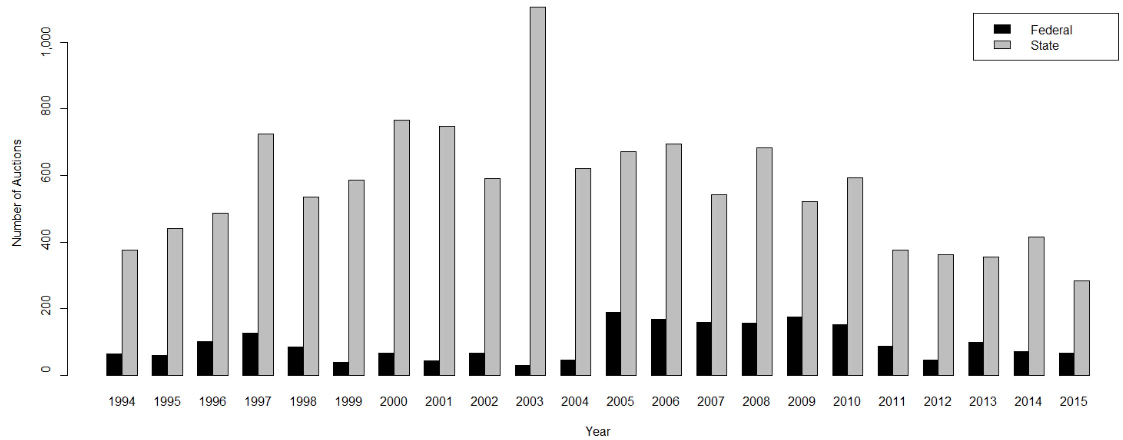

Figure 4: Number of Auctions through Time

an auction type, N_B - a number of bidders, and T_B - a bidder type. The coefficients were used in the formula to categorize the variables, the ones with α are the variables related to underlying resource prices, the ones with β are the variables for land characteristics, and the ones with γ are the variables for auction structure. Each variable will be discussed in a great detail, which will include possible transformations, introduction of new control variables, and formulation of a hypothesis for the values of coefficients.

$$P_L = \theta_0 + T_R * (\alpha_1 * P_R + \alpha_2 * S_F) + \beta_3 * O_L + \beta_4 * B + \beta_5 * T_L + \beta_6 * S_L + \gamma_7 * T_A + \gamma_8 * N_B + \gamma_9 * T_B \quad (1)$$

4.1 Leasehold Price

It is crucial to make all the necessary adjustments to the winning bids that are paid for leaseholds at auctions. First, the winning bids are divided by the number of acres to get the winning bid per acre. Then, the bids are adjusted for inflation using Personal Consumption Expenditures Price Index (PCE). The reason why this index was used instead of Consumer Price Index (CPI) is because it covers a broader range of expenditures, is weighted according to business surveys that are more reliable than consumer surveys, and adjusts for short-term changes in consumer behavior. In addition, it is used by the Federal Reserve, so it is a better metric of inflation for the purpose of this analysis. Next, the bid prices are adjusted for lease structure. In the data, there are leases with different royalties as seen on Figure 5. Hence, comparing them without adjusting for the royalty is not correct. Since the auction price is essentially the present value of all future cash flows from the oil and gas production on a leasehold, from Equations 2 and 3, to standardize all bids for the royalties, one just needs to divide each price by $(1-r)$, where r is the royalty rate, P_i is the future cash flow, i is the discount rate, n is the time period, and PV is the bid price. Unlike royalties, one cannot adjust leasehold prices for rents because one cannot know when the decision about drilling will be made. However, since rents are so small relatively to other forms of payment, they can be ignored.

$$PV = \frac{P_1 * (1-r)}{1+i} + \cdots + \frac{P_n * (1-r)}{(1+i)^n} = (1-r) * \left(\frac{P_1}{1+i} + \cdots + \frac{P_n}{(1+i)^n} \right) \tag{2}$$

$$\frac{PV}{1-r} = \frac{P_1}{1+i} + \cdots + \frac{P_n}{(1+i)^n} \tag{3}$$

The leases also have different terms. All of federal leases are given for a period of 10 years, while state leases are most often given for a period of 5 years with a few of them given for 10 years as seen on Figure 6. Given that for the case of state leaseholds a 10 year lease is only given for a land that is located on an unrestricted territory (the land with the highest risk for a producer, meaning little or no proven reserves), it is not correct to include it as a regression term since it will have a negative coefficient (a tested statement), which can also be inferred from Figure 7. As any box plot used later, the bold line in the middle illustrates a median, the box stands for a 75%

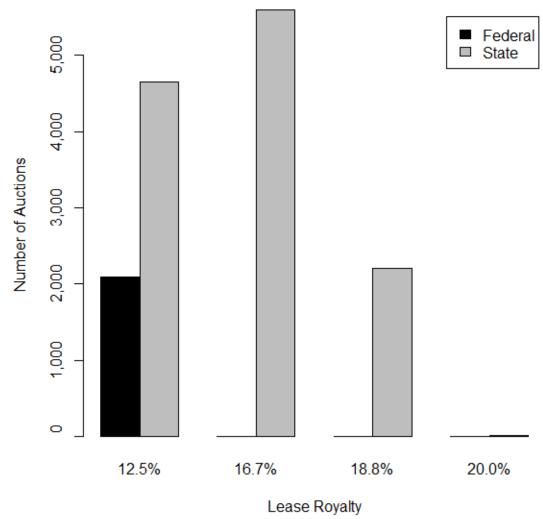

Figure 5: Lease Royalty

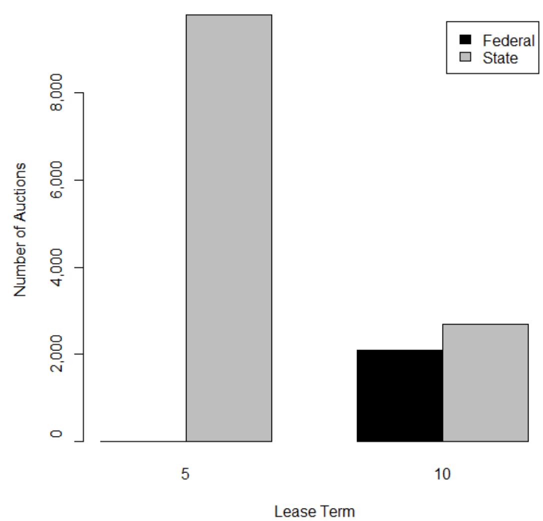

Figure 6: Lease Term

interval, and the empty dots outside of the plot show outliers. A 10 year lease is strictly better than a 5 year lease for the same piece of land. If it is otherwise, then there must be conflating factors. The fact that 10 year state leases are only given for poor quality land is also the reason

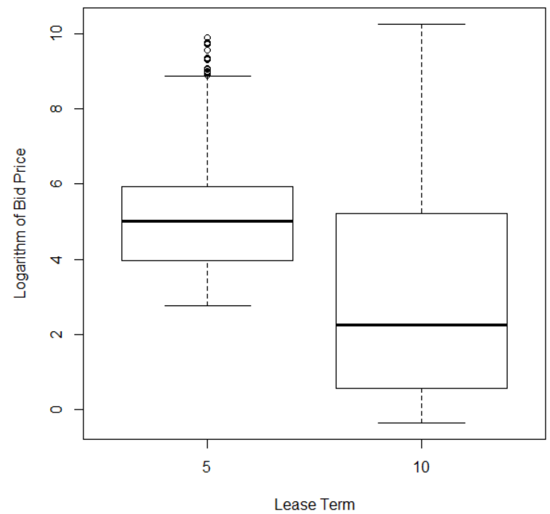

Figure 7: Lease Term and Bid Price

why it is not correct to run a regression on just 10 year leases because the result will obviously lead to a conclusion that state leases are worse than federal leases. Hence, there needs to be another way to control for the term of a lease. Since the method is very imprecise, there will be 3 cases. The first case makes an assumption that a lease is an 'option' to drill for resources. This way it can be compared to an in-the-money stock call option (spot of 100 and strike of 94 due to an industry average profit margin of 6%), where an auction price is a 'premium' paid for an option. If one uses a Black Scholes Merton (BSM) Calculator[9] and calculates premiums for identical options with a volatility of 35% (weighted oil and natural gas price volatility from 1994 to 2015, which is also approximately equal to a historical CBOE Crude Oil ETF Volatility Index), interest rate of 4% (approximately an average for a nominal 30 year treasury yield) for periods of 10 and 5 years, by taking the ratio between the two one gets 1.4. Following up on this approach, one needs to divide

[9]Black Scholes Calculator by Montgomery Investment Technology, Inc. (n.d.). Retrieved March 21, 2016, from `http://www.fintools.com/resources/online-calculators/options-calcs/options-calculator/`

all prices for leaseholds of 10 years by this number. The approach of applying the option theory to real assets has been widely used in economic literature. It is applicable to oil and gas assets as was illustrated by Graham Davis and Radford Schantz (2004). The second case completely ignores the term by assuming that most of the drilling happens in the first 5 years of the lease, and since the lease gets extended if production is still happening at the end of the lease, the difference in price between a 10 year and a 5 year lease should not be significant. The third case assumes that since 10 years is 2 times 5 years, then 10 year leases are 2 times more expensive than 5 year ones. Therefore, one needs to divide all 10 year lease prices by 2. A regression will be run for all of these cases. Eventually, after all the transformations, there is a variable for the adjusted price per acre (P_l). Finally, from Figure 8 it can be established that a logarithmic transformation is necessary since the distribution of the variable is skewed. 1 is added to each price to avoid a mathematical error that is produced when the auction price is 0, which is the case for some federal auctions. That is not surprising since the government is still compensated through royalties. However, it is definitely idiosyncratic given that BLM has a minimum bid price. Most likely, it is land that was sold at special auctions for leaseholds without proven reserves.

4.2 Land Characteristics and Ownership

The key explanatory variable that this thesis pays attention to is ownership of the land. Does it matter for a bid price if the land is owned by a state or by the federal government? Directly comparing state and federal land will be very difficult since there is no variable that controls for resource quality. Looking at the number of wells that were built after leaseholds were bought could give a light on the quality of the leases. We know how much these wells produce and the depth

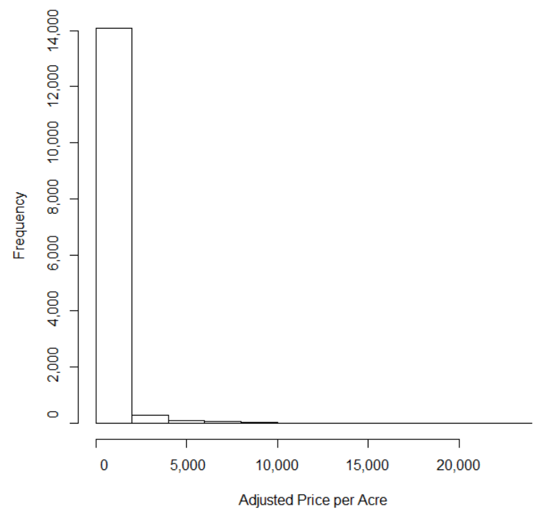

Figure 8: Histogram of Adjusted Price per Acre

at which they produce (proxy for cost), which is useful in applying a hot spot analysis to rank wells, and subsequently leaseholds, based on their quality. This is done by looking at Getis-Ord Gi Statistic, which is similar to a Z-score. The result can be seen on Figure 9. The darker the well, the more productive it is. Yet, it does not seem to be as useful as originally planned. There seems to be an obvious distinction between the quality of land and that distinction comes from the fact that leaseholds are located in different basins. Figure 10 confirms the previous observation. Indeed, it seems that the Permian Basin has higher quality than the San Juan Basin. Hence, there is no need to include a quality score in the regression. A categorical variable for a basin should suffice.

So far we have not decided how to control for similar quality of a leasehold. Boskovic (2015) and Lewis (2015) suggest looking at leaseholds that are closest to each other. They provide enough evidence for me to explore a similar approach for my regression. The next step leads to a discussion about categories in which the land should be divided. State land is taken as a

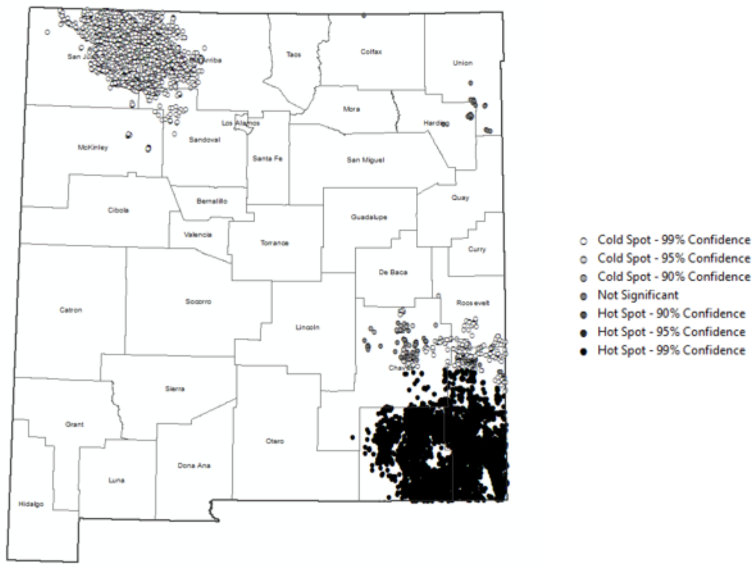

Figure 9: Result of Hot Spot Analysis

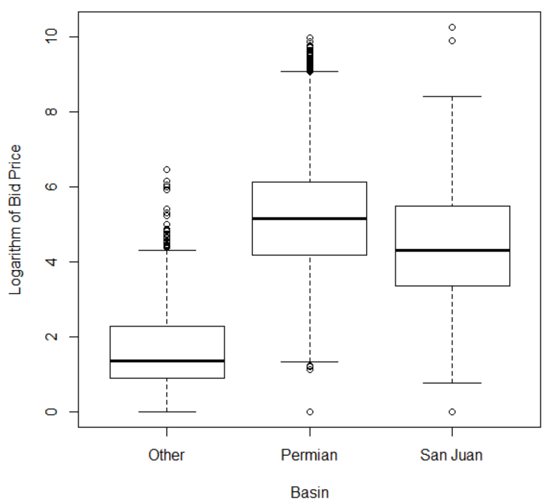

Figure 10: Basin and Bid Price

baseline, while federal land is divided into categories as illustrated on Figure 11. Hence, there are 6 categories: state, federal < 1 mile, federal $<\sqrt{2}$ miles, federal < 2 miles, federal $<\sqrt{5}$ miles, and federal $\geq\sqrt{5}$ miles. This approach should allow the researcher to control for the quality of a lease

$\sqrt{2}$	1	$\sqrt{2}$	1	S	1
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	1	$\sqrt{2}$
2	1	S	1	2	$\sqrt{5}$
$\sqrt{5}$	$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$	2
$\sqrt{2}$	1	$\sqrt{2}$	$\sqrt{5}$	$\sqrt{2}$	1
1	S	1	$\sqrt{2}$	1	S

Figure 11: Township Breakdown by Distance

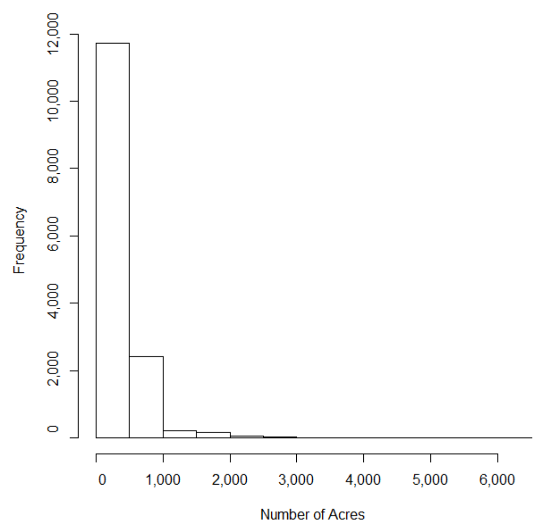

Figure 12: Histogram of Number of Acres

since a coefficient for leaseholds that are closest to each other will be looked at first. The closer the lands are to each other, the more likely it is that they have similar geological profile. To check for spatial autocorrelation, the method that Boskovic used in his paper will be utilized. In the regression a two-term quadratic that includes latitude and longitude[10] will be used. Eventually, this should be enough to control for similarity in the quality of land.

An important set of variables that is crucial for our investigation is the one that contains land information. First, lease size may contain information on the 'wholesale effect'. Looking at its regression coefficient helps to identify whether the government usually sells big fields at a discount to smaller fields. From Figure 12 one can see that the distribution for acreage is skewed, so logarithmic transformation is necessary. Second, a variable that controls for land type is also important. State land has two types of land that they sell: restricted and unrestricted. Unrestricted is the worse option between the two since such land has little or no proven reserves[11]. For the purpose of the analysis, the assumption is that all federal land is in a restricted area. There does not seem to be any indication that BLM sells a land with no proven reserves. The expectation is that restricted leaseholds are sold at a premium to unrestricted leaseholds as illustrated on Figure 13.

4.3 Price of Underlying Resources

Now, there will be a discussion of the underlying product. First, it is necessary to include historical, inflation-adjusted (PCE) prices of oil and natural gas as separate variables in the regression. The oil extraction company's decision whether to buy a leasehold depends heavily on the underlying price of the product it could potentially sell in the market. Benchmark prices for oil and natural gas are West Texas Intermediate (WTI) and Henry Hub (HH) respectively. Figure 14 illustrates that the two prices are not necessarily correlated. The two fossil fuels have different drivers behind

[10] $x^2 + y^2 + xy + x + y$

[11] Except for the ones that are sold for \$0.0, but these cases are very rare

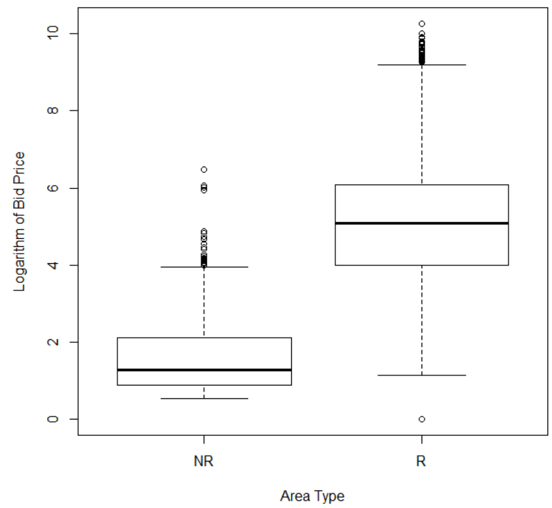

Figure 13: Area Type and Bid Price

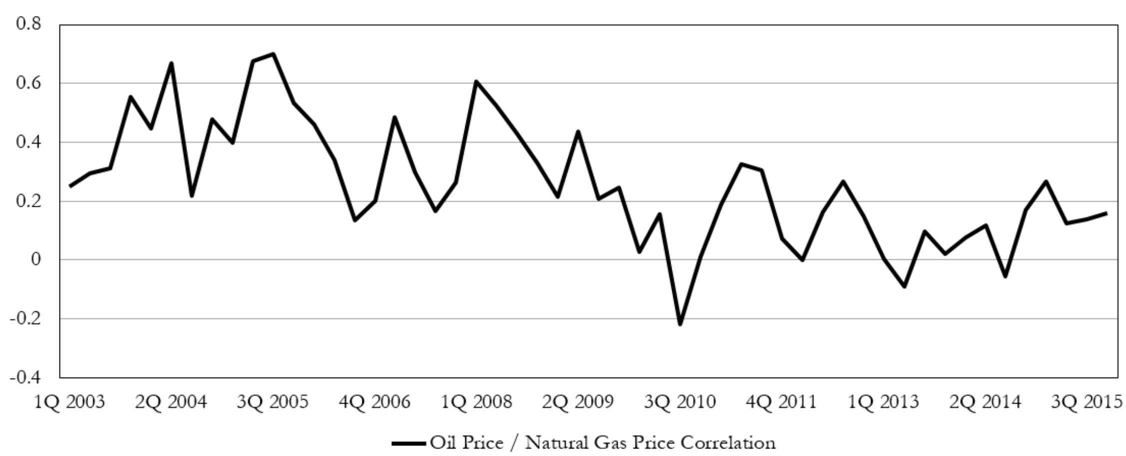

Figure 14: Discrepancy between the prices of oil and natural gas (Source: EIA)

their prices. Natural gas is used mainly in generation of electricity, while oil is mainly used for transportation. Natural gas is very hard to transport, so prices vary greatly depending on the part of the world. Natural gas prices in Asia are higher than those in Europe, which are, in their respect, higher than those in the US. Given the discrepancy, it is necessary to separate natural gas leasehold auctions from oil leasehold auctions, which can be done using the geographic location of a leasehold. The algorithm used is the following. Natural gas prices are converted in a unit of $ per barrel of oil equivalent (BOE) by multiplying it by 6, as there are 6 thousand cubic feet (MCF) in 1 barrel of oil equivalent (BOE). Then, if a leasehold is located in the San Juan Basin, then natural gas price is the only one that matters. If the leasehold is in the Permian basin, then the final price is the weighted price between oil and natural gas based on the current ratio of production in the Permian basin (37% - natural gas, 63% - oil). If the leasehold is the neither basin, then the weight is 50/50 (a guesstimate given little information about the other areas). In addition, current oil and natural gas prices are not the only things that are important for the decisions of producers. Expectations of prices are as meaningful and relevant. To control for that issue, I decided to use a historical slope of a forward-looking 3 month futures curve. Essentially, at a particular point in time a future 3-month price is taken and is divided by the current price at that moment. This could help me understand the general opinion of the market in terms of the direction of oil and natural gas prices. The higher the slope, the more bullish the market is on a oil or natural gas price and vice versa.

4.4 Auction Structure

The next set of variables that is worth taking a look at is related to the auction structure. The first variable is the auction type. This variable needs to be treated as a factor. The result of a coefficient for this variable may have a profound impact on policy-making. If one is strictly better than the other, why use the worse one? Kong (2015) found using the same data that a sealed-bid auction leads to higher prices, which is also suggested by Figure 15. It will be interesting to see if the regression of this thesis will show a similar result. Still, this coefficient standalone will not

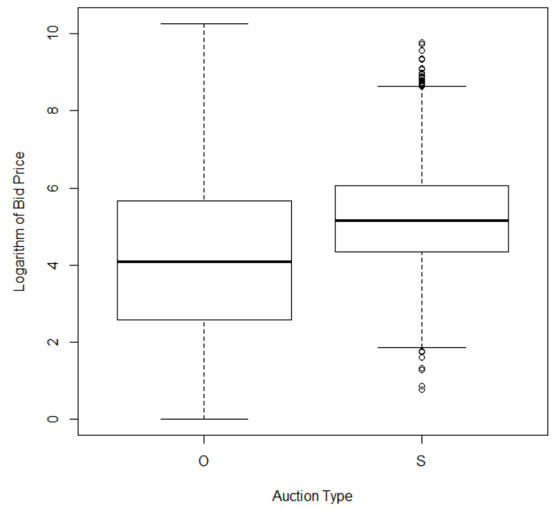

Figure 15: Auction Type and Bid Price

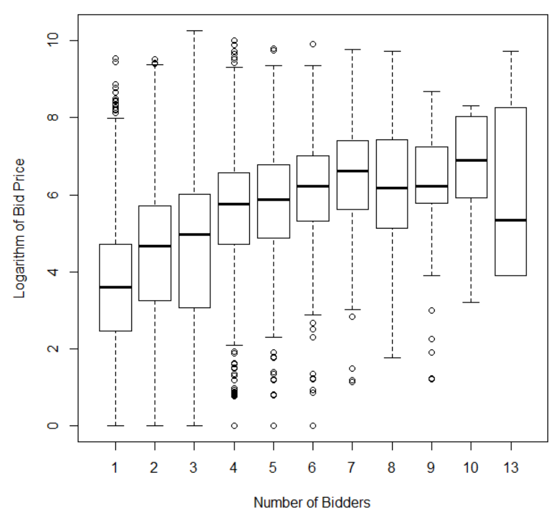

Figure 16: Number of Bidders and Bid Price

be able to tell the whole picture. That is why information about bidders is so important. Hence, the next two variables to look at are the number of bidders and the bid winner. The number of bidders is a crucial variable. The theory predicts that each additional bidder is worth a lot to the seller provided bidders have symmetric information. Testing this hypothesis is one of the major goals of this study. If proved correct for oil and gas auctions, it could be interesting to think how to best attract bidders to the auction. Since there is no data on the number of bidders available for open-bid auctions, it will have to be inferred from sealed-bid auctions using multiple imputation by chained equations (MICE)[12]. There seems to be visual evidence from Figure 16 that suggests that the number of bidders is positively correlated to the bid price. The variable that stands for the bid winner is very useful as well. The way to deal with it is to look at producers that bid the most and create a categorical variable for frequent and rare participants. This will allow us to figure out if certain group of bidders has an advantage in terms of information. Given that Yates Petroleum Corporation has won almost a third of all auctions, there will be a binary variable to identify this company in the regression. So far, it seems that Yates buys land for cheaper than everyone else as can be seen from Figure 17.

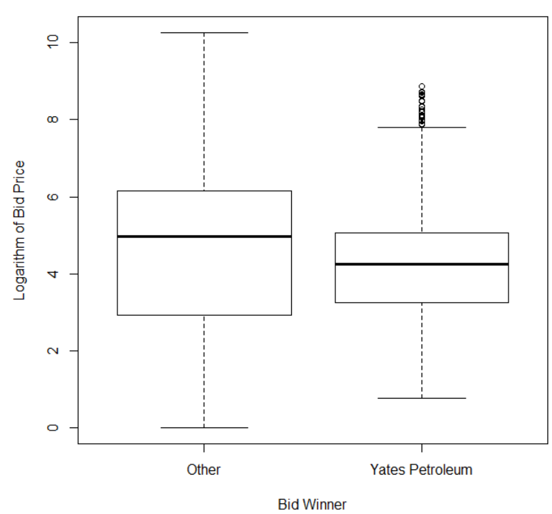

Figure 17: Bid Winner and Bid Price

[12]Package 'mice' in R.

4.5 Statistical Techniques

We discussed each individual variable, but we have not mentioned how the regression will be implemented. It will be worthwhile to explore the whole breadth of statistical techniques applicable to the problem. The approach will be to start with a simple multivariable Gaussian regression in R, with and without fixed effects for time and location. Afterwards, for robustness test, more sophisticated statistical techniques can be applied to see if the results will stay the same. Given the large number of variables, a holistic cross-validation is impractical to do, so LASSO and Ridge regressions could be used instead. They introduce a penalty term for model complexity. The model automatically selects which coefficients to drop to zero given that one variable may be highly correlated to the other. All of this can done using 'glmnet' package in R. In addition, Bayesian techniques can be used as well. For example, one can use Monte Carlo Markov Chain (MCMC) Generalized Linear Mixed Models to get posterior distributions for coefficients of each variable. This can be implemented using 'MCMCglmm' package in R. MCMC is useful for visualization of where a coefficient might lie on a number line. It might also show if a coefficient distribution is multimodal, which can shed even more light on the nature of some relationships. Eventually, the results of these techniques should match with each other to give the answer to the main research question of whether regulatory frameworks impact the prices that producers pay at auctions.

5 Results and Discussion

Figure 18 shows the density of an adjusted price per acre. It has the whole 3 modes, which says that there are many things that go into pricing of leaseholds at auctions. Hence, breaking the results of the regression step by step to figure out what drives the shape of this distribution is a primary goal of the analysis. This section will start with discussion of the results from 3 simple linear regressions for 3 cases of dealing with the term of the lease. To refresh memory, all cases represent different coefficients, which are used to divide 10 year lease bid prices. Case 1 assumes a BSM coefficient, Case 2 assumes a coefficient of 1, and Case 3 assumes a coefficient of 2. All of the coefficients will be rigorously discussed in the context of the relevant theory. Then, spatial auto-correlation will be explored through introducing latitude and longitude parameters. Moreover, regressions with fixed effects for time and counties will be included in the discussion. As can be seen from Appendix A, except for the regression with county fixed effects, the adjusted R^2 are all above 0.6, which suggests that a lot of variation is explained by the models. Finally, robustness tests will be performed by running LASSO & Ridge and MCMC algorithms to see if the results stay the same or if more advanced models illustrate a different perspective on some of the coefficients. The tables in the subsections summarize results from the tables in the Appendix A by breaking them down by discussion topic.

5.1 Prices Underlying Resources

Not to jump in to final conclusions, it is worth discussing coefficients for control variables first to see if they are according to expectations or not. First, it is interesting to look at coefficients for the group of variables that is responsible for the price of the underlying product, which are shown on Table 2. Coefficients for the natural resource price are almost all positive and statistically significant, no matter for which case or which method is used, except for the regression with fixed effects for time, but that is because time and natural resource prices are highly correlated. The

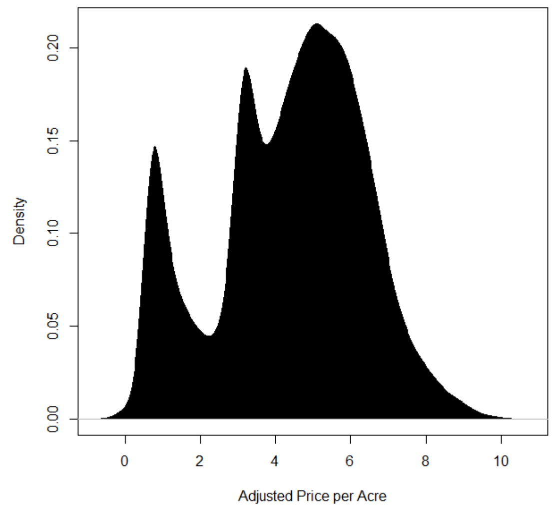

Figure 18: Adjusted Price per Acre Distribution

values of the coefficients are small, but that can be explained by the fact that the dependent variable is a logarithm. The fact that it is positive suggests that the higher the natural resource price, the higher the price of the leasehold. This result is according to expectations since higher price of an underlying resource should lead to higher future cash flows from a lease. More surprising is the fact that the futures slope has in most cases a negative coefficient, which might suggest an interaction with the present price. However, it is meaningless since in most cases this variable is statistically insignificant. It is likely that given that oil and natural gas prices are so volatile, producers rarely try to predict where futures prices might. Another reason might lie in the fact that the futures slope is only for 3 months, which is a very short-term period, so it is irrelevant for the long-term choices of the producers. Both can be true since they are not mutually exclusive. An interesting observation is that the futures slope is significant for the latitude/longitude regression and the time fixed effects regression, mainly because of interaction with the newly introduced parameters.

Table 2: Results for Natural Resource Price and Futures Slope

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Linear Regression			
Natural Resource Price	0.010^{***}	0.011^{***}	0.011^{***}
Futures Slope	-0.221	-0.191	-0.146
Linear Regression with Latitude and Longitude			
Natural Resource Price	0.009^{***}	0.009^{***}	0.009^{***}
Futures Slope	-0.461^{***}	-0.482^{***}	-0.436^{***}
Linear Regression with Fixed Effects for Time			
Natural Resource Price	0.001	-0.007^{***}	-0.006^{***}
Futures Slope	0.231	-1.498^{***}	-1.397^{***}
Linear Regression with Fixed Effects for Counties			
Natural Resource Price	0.012^{***}	0.012^{***}	0.012^{***}
Futures Slope	-0.029	-0.047	-0.008
Regularized Regression			
Natural Resource Price	0.009	0.009	0.008
Futures Slope	...	...	...
MCMC			
Natural Resource Price	0.011^{***}	0.011^{***}	0.011^{***}
Futures Slope	0.010	-0.197	-0.153
Note 1:	MCMC coefficients stand for posterior means		
Note 2:	*p<0.05; **p<0.01; ***p<0.001		
Note 3:	no p-value for regularized regression due to algorithm		

5.2 Land Characteristics

The next thing to look at is Table 3. The first variable to explore is related to the basin, to which leaseholds belongs. In every case and using every method, the result is the same. If a leasehold is located in the San Juan Basin, it is traded at a premium to the baseline land. If a leasehold is located in the Permian Basin, it is traded at even bigger premium. The result is statistically significant, which confirms our initial discussion. The magnitude of the coefficients is huge. It seems that the basin to which the leasehold belongs plays a major role in the price paid at an auction. As has been seen from the hot spot analysis of wells, Permian is better than San Juan. The most likely reason for this fact is that Permian has more oil and the average depth of wells is lower. Another result that is interesting to notice is related to the area type. Notice that a variable for the basin is not included in the latitude/longitude regression and the county fixed effects regression because it would be highly correlated to the newly introduced parameters. As expected, all the regressions uniformly confirmed that leaseholds located on restricted land (which has proven reserves) are better than unrestricted land (which has little or no proven reserves). This makes sense given that absence of proven reserves portrays a leasehold as the riskier investment. The other variable that met expectations is the lease acreage. The coefficient is always negative and statistically significant. This suggests that there is a 'wholesale effect', meaning leaseholds that are sold in a large package are sold at a discount. The implication of this finding is that the state's approach of selling land in small packages on a monthly versus quarterly basis is more preferable. However, it has to be taken into account with the cost of organizing an auction.

Table 3: Results for Basin, Area Type, and Lease Acreage

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Linear Regression			
Permian Basin	2.876^{***}	2.901^{***}	2.809^{***}
San Juan Basin	2.028^{***}	2.067^{***}	1.981^{***}
Restricted Area	0.698^{***}	0.387^{***}	0.948^{***}
Logarithm of Acreage	-0.251^{***}	-0.255^{***}	-0.247^{***}
Linear Regression with Latitude and Longitude			
Restricted Area	2.070^{***}	1.818^{***}	2.318^{***}
Logarithm of Acreage	-0.225^{***}	-0.227^{***}	-0.222^{***}
Linear Regression with Fixed Effects for Time			
Permian Basin	2.922^{***}	2.926^{***}	2.834^{***}
San Juan Basin	1.899^{***}	1.885^{***}	1.806^{***}
Restricted Area	0.688^{***}	0.449^{***}	1.006^{***}
Logarithm of Acreage	-0.248^{***}	-0.251^{***}	-0.243^{***}
Linear Regression with Fixed Effects for Counties			
Restricted Area	0.703^{***}	0.427^{***}	0.983^{***}
Logarithm of Acreage	-0.200^{***}	-0.202^{***}	-0.198^{***}
Regularized Regression			
Permian Basin	2.375	2.284	2.321
San Juan Basin	1.441	1.399	1.282
Restricted Area	1.180	0.990	1.336
Logarithm of Acreage	−0.209	−0.209	−0.200
MCMC			
Permian Basin	2.877^{***}	2.900^{***}	2.807^{***}
San Juan Basin	2.031^{***}	2.067^{***}	1.982^{***}
Restricted Area	0.697^{***}	0.388^{***}	0.950^{***}
Logarithm of Acreage	-0.252^{***}	-0.256^{***}	-0.246^{***}

Note 1: MCMC coefficients stand for posterior means

Note 2: $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Note 3: no p-value for regularized regression due to algorithm

Note 4: no basin variable for lat/long and county fixed effects regressions

5.3 Auction Structure

The next step of discussion is focused around the variables for auction structure in Table 4. The result for the auction type is the same across the board. The coefficient is positive and statistically significant. That is according to the initial hypothesis and confirms Kong's (2015) result. The reason for that is probably along the same lines: "risk aversion coupled with an endogenous entry process that makes bidders uncertain about the number of rivals they will face". It also tell us that, given Hendricks (1994) finding that the distributions have the same shapes, the densities of the producers should have different supports. However, among the producers of New Mexico, there is an exception: Yates Petroleum Corporation. All regressions suggest that this company buys leases at a significant discount relatively to everyone else. It seems that its distribution might be skewed. Given that this company operated for as long as 100 years in New Mexico, it is possible that it accumulated a lot of adjacent land that can serve as a source of information inaccessible to other participants. There is no evidence that suggests that it buys riskier land or that it mostly participates in sealed-bid auctions (which are supposed to underperform when distributions have different shapes). Another thing that the coefficient for a sealed-bid auction suggests is that it is unlikely that there is a collusion between bidders, which supports Hendricks (2003) conclusion on the case of offshore oil and gas leases. Finally, the number of bidders also has a positive, statistically significant coefficient that is supported by all regressions. This is according to the theory and it makes sense since more competition leads to a higher price at the auction. After including an interaction term between the auction type and the number of bidders, it has been noticed that sealed-bid auctions only perform better if there are 2 or more bidders. It seems that in an open auction, there is a 'prevention factor' at play, a case when a producer tries to prevent other participants from entry by posting a value that is higher than necessary. That is unlikely to be the case for sealed-bid auctions since the participant is not aware how much other producers are bidding for a lot.

Table 4: Results for Auction Structure

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Linear Regression			
Sealed-Bid Auction	0.390^{***}	0.379^{***}	0.380^{***}
Number of Bidders	0.170^{***}	0.173^{***}	0.172^{***}
Yates Petroleum	-0.608^{***}	-0.613^{***}	-0.625^{***}
Linear Regression with Latitude and Longitude			
Sealed-Bid Auction	0.359^{***}	0.358^{***}	0.359^{***}
Number of Bidders	0.166^{***}	0.167^{***}	0.165^{***}
Yates Petroleum	-0.518^{***}	-0.513^{***}	-0.524^{***}
Linear Regression with Fixed Effects for Time			
Sealed-Bid Auction	0.383^{***}	0.385^{***}	0.386^{***}
Number of Bidders	0.161^{***}	0.165^{***}	0.164^{***}
Yates Petroleum	-0.644^{***}	-0.640^{***}	-0.653^{***}
Linear Regression with Fixed Effects for Counties			
Sealed-Bid Auction	0.361^{***}	0.361^{***}	0.361^{***}
Number of Bidders	0.146^{***}	0.146^{***}	0.146^{***}
Yates Petroleum	-0.558^{***}	-0.555^{***}	-0.562^{***}
Regularized Regression			
Sealed-Bid Auction	0.282	0.244	0.310
Number of Bidders	0.170	0.175	0.173
Yates Petroleum	−0.543	−0.544	−0.505
MCMC			
Sealed-Bid Auction	0.379^{***}	0.390^{***}	0.380^{***}
Number of Bidders	0.172^{***}	0.170^{***}	0.172^{***}
Yates Petroleum	-0.617^{***}	-0.608^{***}	-0.624^{***}
Note 1:			MCMC coefficients stand for posterior means
Note 2:			*p<0.05; **p<0.01; ***p<0.001
Note 3:			no p-value for regularized regression due to algorithm

5.4 Ownership

In the end, here is a discussion on the most important group of exploratory variables, which is related to the ownership of the land. The result of this section should give an answer to the research question: do stricter regulations lead to a worse price for the owner of land? The answer from all the regressions is unequivocal, as shown in Table 5. Not only that, but in Case 1 and Case 2, the results suggest that a federal land is actually sold at better prices than state land. The coefficient that is the most relevant is the one for the dummy variable of the federal land that is within 1 mile from the state land. It is not significant only for the Case 3, which divides all 10 year lease prices by 2. The regression with latitude and longitude parameters included shows that in some cases federal coefficients are even negative. However, it is doubtful that there is a linear relationship between the lease term and the lease price. There might be multiple reasons for why the federal land is priced higher. First, the adjustment for the term is very imprecise and leaves a lot of information out. Second, the adjustment for lease royalty might be imprecise. Rodgers Oil and Gas Consulting (2015) and Busby (2011) have been debating whether royalties or bonus bids are better. The assumption of this thesis is that there is a linear relationship between them, which makes them essentially the same. It is hard to discount the debate, which suggests that my model might be imprecise. Finally, given that the state land trust sold 3 times more land during the period, while having only 1/9 ownership of each township, might suggest that on average it sold the land of worse quality. It might be the case that the approach for controlling the quality of the land might not have captured the whole effect. All of the three aforementioned reasons are not only possible explanations for why federal land is sold at higher prices, but also serve as the major limitations of this thesis. Regardless, there seems to be no evidence that suggests that state land is more attractive than federal land. The consequence of this result is contradictory to the previous research on a similar topic. Either the producers in New Mexico do not take costs of regulations into account, which would be irrational, or the costs of the regulations are negligible. Henceforth, this result shows that the state land office can safely implement strict environmental rules on its land without sacrificing revenues for education and health purposes.

Table 5: Results for Land Ownership

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
<u>Linear Regression</u>			
Federal < 1 mile	0.361^{***}	0.691^{***}	0.013
Federal $<\sqrt{2}$ miles	0.360^{***}	0.694^{***}	0.035
Federal < 2 miles	0.303^{**}	0.654^{***}	-0.007
Federal $<\sqrt{5}$ miles	-0.103	0.208	-0.450^{***}
Federal $\geq\sqrt{5}$ miles	0.303^{**}	0.621^{***}	-0.042
<u>Linear Regression with Latitude and Longitude</u>			
Federal < 1 mile	0.100^{***}	0.428^{***}	-0.245^{***}
Federal $<\sqrt{2}$ miles	0.124	0.445^{***}	-0.213^{***}
Federal < 2 miles	0.099	0.422^{***}	-0.239^{**}
Federal $<\sqrt{5}$ miles	-0.256	0.065	-0.593^{***}
Federal $\geq\sqrt{5}$ miles	0.117	0.438^{***}	-0.219^{**}
<u>Linear Regression with Fixed Effects for Time</u>			
Federal < 1 mile	0.367^{***}	0.693^{***}	0.016
Federal $<\sqrt{2}$ miles	0.369^{***}	0.700^{***}	0.042
Federal < 2 miles	0.307^{***}	0.606^{***}	-0.053
Federal $<\sqrt{5}$ miles	-0.127	0.181	-0.475^{***}
Federal $\geq\sqrt{5}$ miles	0.191^{**}	0.461^{***}	-0.195^{**}
<u>Linear Regression with Fixed Effects for Counties</u>			
Federal < 1 mile	0.287^{***}	0.615^{***}	-0.059^{*}
Federal $<\sqrt{2}$ miles	0.265^{***}	0.585^{***}	-0.073
Federal < 2 miles	0.219^{**}	0.541^{***}	-0.119
Federal $<\sqrt{5}$ miles	-0.178	0.142	-0.514^{***}
Federal $\geq\sqrt{5}$ miles	0.125	0.447^{***}	-0.213^{**}
<u>Regularized Regression</u>			
Federal < 1 mile	0.159	0.438	...
Federal $<\sqrt{2}$ miles	...	0.252	...
Federal < 2 miles	...	0.106	...
Federal $<\sqrt{5}$ miles	...	...	...
Federal $\geq\sqrt{5}$ miles	...	0.070	...
<u>MCMC</u>			
Federal < 1 mile	0.361^{***}	0.691^{***}	0.013
Federal $<\sqrt{2}$ miles	0.359^{***}	0.693^{***}	0.032
Federal < 2 miles	0.304^{***}	0.654^{**}	-0.012
Federal $<\sqrt{5}$ miles	-0.101	0.207	-0.459^{**}
Federal $\geq\sqrt{5}$ miles	0.302^{**}	0.622^{***}	-0.043
Note 1:			MCMC coefficients stand for posterior means
Note 2:			*p<0.05; **p<0.01; ***p<0.001
Note 3:			no p-value for regularized regression due to algorithm

6 Conclusion and Limitations

The first part of this section will be dedicated to the discussion of the limitations. This thesis has many areas of potential weaknesses that could be improved in a further research.

1. As have been mentioned before adjustments for a price per acre were not perfect. It is very hard to compare assets with different terms and royalties. BSM method that was used was also imprecise and very simplistic. The assumption that all leaseholds are in-the-money is speculative, given that producers' costs (strike price) are stochastic rather than deterministic. The volatility assumption might have underestimated the true volatility in the leasehold price given that it most likely fluctuates more than the underlying resource price. Furthermore, a leasehold is not technically an option, but more of an option on a forward that afterwards turns into a swap. This could be evaluated, but it is a research project of its own. Controlling for differences in rent could be explored deeper as well. Yet, there is no perfect method to control for this factor.

2. A more precise method could be used to control for the distance between two leaseholds. A method of figuring out whether a state lease belongs to a particular section and then identifying a federal lease not only based on proximity to state land, but to the state land of a specific section could lead to better results. Yet, running 4 regressions separately for each section (especially, if one narrows it down even further by looking at leases that are on borders) might result in a loss of interaction between these sets of observations. Still, controlling for resource quality has proven to be a challenge. Even though distance should serve as a good predictor of similarity between leaseholds, there is still a lot of variability

that was not captured by the model.

3. There is no perfect variable that controls for long-term natural resource price expectations. It might be possible to look for more long-term futures curves. Yet, the slope is not linear and taking a simple ratio might result in imprecision.

4. The approach of weighting natural resource price used in this thesis might be too simplistic. Looking at wells and their production breakdown is a better approach. Yet, not all leaseholds have wells on them (especially, the more recent ones), so leaving them out might lead to a significant loss of observations.

5. Some variables had missing observations, so imperfect imputation methods had to be used for the number of bidders and the area type. For the number of bidders, the method has theoretical justification, while the imputation for the area type was based solely on an educated guess.

6. Despite the evidence coming from multiple news articles and the Lewis' paper that suggest that there is a significant difference in state and federal regulatory frameworks regarding management of land and protecting the environment, given the lack of legal expertise, it is hard to evaluate the precise difference between the laws.

To conclude, despite all of the mentioned above, there is still a strong result supported by evidence coming from multiple regressions that were obtained using different statistical methods. State lands do not seem to be more attractive to producers because the strict federal regulations do not have an effect on the state land. It seems that stricter laws have no impact on future cash flows of the oil and gas investment. Whether this is because of the producer's irrationality or a regulation-induced incentive to innovate and become more efficient is an area for further research. This result has major policy implications. If it is indeed true that strict environmental controls can go hand in hand with a profit maximizing objective of state land trusts, then there is no conflict of interest. The environmental laws could then be passed without introducing a discount for bid prices at which leaseholds are sold at an auction. This could lead New Mexico to follow California's example and potentially solve New Mexico's environmental problems.

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7 Appendix

7.1 Appendix A: Regression Results

Table 6: Results for Linear Regression

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Constant	2.304***	2.562***	2.021***
	(0.157)	(0.159)	(0.155)
Prices of Underlying Product			
Natural Resource Price	0.010***	0.011***	0.011***
	(0.001)	(0.001)	(0.001)
Futures Slope	−0.221	−0.191	−0.146
	(0.137)	(0.138)	(0.135)
Ownership			
Federal < 1 mile	0.361***	0.691***	0.013
	(0.035)	(0.035)	(0.035)
Federal $<\sqrt{2}$ miles	0.360***	0.694***	0.035
	(0.084)	(0.085)	(0.083)
Federal < 2 miles	0.303**	0.654***	−0.007
	(0.107)	(0.109)	(0.106)
Federal $<\sqrt{5}$ miles	−0.103	0.208	−0.450***
	(0.166)	(0.168)	(0.164)
Federal $\geq\sqrt{5}$ miles	0.303**	0.621***	−0.042
	(0.092)	(0.093)	(0.091)
Basin			
Permian Basin	2.876***	2.901***	2.809***
	(0.063)	(0.064)	(0.063)
San Juan Basin	2.028***	2.067***	1.981***
	(0.074)	(0.074)	(0.073)
Auction Structure			
Sealed-Bid Auction	0.390***	0.379***	0.380***
	(0.023)	(0.023)	(0.023)
Number of Bidders	0.170***	0.173***	0.172***
	(0.007)	(0.007)	(0.007)
Yates Petroleum	−0.608***	−0.613***	−0.625***
	(0.024)	(0.024)	(0.023)
Other			
Restricted Area	0.698***	0.387***	0.948***
	(0.067)	(0.068)	(0.066)
Logarithm of Acreage	−0.251***	−0.255***	−0.247***
	(0.012)	(0.012)	(0.012)
Adjusted R^2	0.667	0.646	0.688

Note: *p<0.05; **p<0.01; ***p<0.001

Table 7: Results for Linear Regression with Latitude and Longitude

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Constant	784.799***	791.189***	776.230***
	(21.336)	(21.571)	(21.066)
Coordinates			
Longitude	7.316***	7.375***	7.237***
	(0.202)	(0.204)	(0.199)
Latitude	−22.444***	−22.604***	−22.224***
	(0.625)	(0.632)	(0.618)
Interaction between Longitude & Latitude	−0.210***	−0.211***	−0.208***
	(0.006)	(0.006)	(0.006)
Prices of Underlying Product			
Natural Resource Price	0.009***	0.009***	0.009***
	(0.001)	(0.001)	(0.001)
Futures Slope	−0.461***	−0.482***	−0.436***
	(0.134)	(0.136)	(0.132)
Ownership			
Federal $<$ 1 mile	0.100***	0.428***	−0.245***
	(0.034)	(0.035)	(0.034)
Federal $<\sqrt{2}$ miles	0.124	0.445***	−0.213***
	(0.083)	(0.084)	(0.082)
Federal $<$ 2 miles	0.099	0.422***	−0.239**
	(0.106)	(0.107)	(0.105)
Federal $<\sqrt{5}$ miles	−0.256	0.065	−0.593***
	(0.164)	(0.166)	(0.162)
Federal $\geq\sqrt{5}$ miles	0.117	0.438***	−0.219**
	(0.089)	(0.090)	(0.088)
Auction Structure			
Sealed-Bid Auction	0.359***	0.358***	0.359***
	(0.023)	(0.023)	(0.023)
Number of Bidders	0.166***	0.167***	0.165***
	(0.007)	(0.007)	(0.007)
Yates Petroleum	−0.518***	−0.513***	−0.524***
	(0.024)	(0.024)	(0.023)
Other			
Restricted Area	2.070***	1.818***	2.318***
	(0.040)	(0.040)	(0.039)
Logarithm of Acreage	−0.225***	−0.227***	−0.222***
	(0.012)	(0.012)	(0.012)
Adjusted R^2	0.674	0.653	0.695

Note: *p<0.05; **p<0.01; ***p<0.001

Table 8: Results for Linear Regression with Fixed Effects for Time

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 2: BSM Coefficient	Case 1: Coefficient of 1	Case 3: Coefficient of 2
Prices of Underlying Product			
Natural Resource Price	0.001	-0.007^{***}	-0.006^{***}
	(0.001)	(0.001)	(0.001)
Futures Slope	0.231	-1.498^{***}	-1.397^{***}
	(0.159)	(0.168)	(0.164)
Ownership			
Federal $<$ 1 mile	0.367^{***}	0.693^{***}	0.016
	(0.035)	(0.035)	(0.034)
Federal $<\sqrt{2}$ miles	0.369^{***}	0.700^{***}	0.042
	(0.082)	(0.082)	(0.081)
Federal $<$ 2 miles	0.307^{***}	0.606^{***}	-0.053
	(0.105)	(0.106)	(0.104)
Federal $<\sqrt{5}$ miles	-0.127	0.181	-0.475^{***}
	(0.162)	(0.164)	(0.160)
Federal $\geq\sqrt{5}$ miles	0.191^{**}	0.461^{***}	-0.195^{**}
	(0.091)	(0.091)	(0.089)
Basin			
Permian Basin	2.922^{***}	2.926^{***}	2.834^{***}
	(0.063)	(0.063)	(0.062)
San Juan Basin	1.899^{***}	1.885^{***}	1.806^{***}
	(0.072)	(0.074)	(0.073)
Auction Structure			
Sealed-Bid Auction	0.383^{***}	0.385^{***}	0.386^{***}
	(0.023)	(0.023)	(0.022)
Number of Bidders	0.161^{***}	0.165^{***}	0.164^{***}
	(0.007)	(0.007)	(0.007)
Yates Petroleum	-0.644^{***}	-0.640^{***}	-0.653^{***}
	(0.024)	(0.024)	(0.023)
Other			
Restricted Area	0.688^{***}	0.449^{***}	1.006^{***}
	(0.067)	(0.067)	(0.066)
Logarithm of Acreage	-0.248^{***}	-0.251^{***}	-0.243^{***}
	(0.012)	(0.012)	(0.012)
Adjusted R^2	0.631	0.611	0.657
Note:			*p<0.05; **p<0.01; ***p<0.001

Table 9: Results for Linear Regression with Fixed Effects for Counties

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 2: BSM Coefficient	Case 1: Coefficient of 1	Case 3: Coefficient of 2
Prices of Underlying Product			
Natural Resource Price	0.012***	0.012***	0.012***
	(0.001)	(0.001)	(0.0005)
Futures Slope	−0.029	−0.047	−0.008
	(0.134)	(0.136)	(0.133)
Ownership			
Federal < 1 mile	0.287***	0.615***	−0.059*
	(0.034)	(0.035)	(0.034)
Federal $<\sqrt{2}$ miles	0.265***	0.585***	−0.073
	(0.080)	(0.081)	(0.079)
Federal < 2 miles	0.219**	0.541***	−0.119
	(0.103)	(0.104)	(0.102)
Federal $<\sqrt{5}$ miles	−0.178	0.142	−0.514***
	(0.159)	(0.161)	(0.157)
Federal $\geq\sqrt{5}$ miles	0.125	0.447***	−0.213**
	(0.097)	(0.098)	(0.096)
Auction Structure			
Sealed-Bid Auction	0.361***	0.361***	0.361***
	(0.022)	(0.022)	(0.022)
Number of Bidders	0.146***	0.146***	0.146***
	(0.007)	(0.007)	(0.007)
Yates Petroleum	−0.558***	−0.555***	−0.562***
	(0.023)	(0.023)	(0.023)
Other			
Restricted Area	0.703***	0.427***	0.983***
	(0.068)	(0.069)	(0.067)
Logarithm of Acreage	−0.200***	−0.202***	−0.198***
	(0.012)	(0.012)	(0.012)
Adjusted R^2	0.218	0.229	0.218

Note: *p<0.05; **p<0.01; ***p<0.001

Table 10: Results for Regularized Regression (Weighted between LASSO and Ridge)

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Constant	1.965	2.245	1.760
Prices of Underlying Product			
Natural Resource Price	0.009	0.009	0.008
Futures Slope	...	...	...
Ownership			
Federal $<$ 1 mile	0.159	0.438	...
Federal $<\sqrt{2}$ miles	...	0.252	...
Federal $<$ 2 miles	...	0.106	...
Federal $<\sqrt{5}$ miles	...	...	...
Federal $\geq\sqrt{5}$ miles	...	0.070	...
Basin			
Permian Basin	2.375	2.284	2.321
San Juan Basin	1.441	1.399	1.282
Auction Structure			
Sealed-Bid Auction	0.282	0.244	0.310
Number of Bidders	0.170	0.175	0.173
Yates Petroleum	−0.543	−0.544	−0.505
Other			
Restricted Area	1.180	0.990	1.336
Logarithm of Acreage	−0.209	−0.209	−0.200

Note: This algorithm drops variables when it finds them insignificant, so there is no p-value.

Table 11: Results for MCMC Multivariate Generalized Linear Mixed Models

	Dependent variable: Logarithm of Adjusted Price per Acre		
	Case 1: BSM Coefficient	Case 2: Coefficient of 1	Case 3: Coefficient of 2
Constant	2.312***	2.572***	2.023***
Prices of Underlying Product			
Natural Resource Price	0.011***	0.011***	0.011***
Futures Slope	0.010	−0.197	−0.153
Ownership			
Federal < 1 mile	0.361***	0.691***	0.013
Federal $<\sqrt{2}$ miles	0.359***	0.693***	0.032
Federal < 2 miles	0.304***	0.654**	−0.012
Federal $<\sqrt{5}$ miles	−0.101	0.207	−0.459**
Federal $\geq\sqrt{5}$ miles	0.302**	0.622***	−0.043
Basin			
Permian Basin	2.877***	2.900***	2.807***
San Juan Basin	2.031***	2.067***	1.982***
Auction Structure			
Sealed-Bid Auction	0.379***	0.390***	0.380***
Number of Bidders	0.172***	0.170***	0.172***
Yates Petroleum	−0.617***	−0.608***	−0.624***
Other			
Restricted Area	0.697***	0.388***	0.950***
Logarithm of Acreage	−0.252***	−0.256***	−0.246***

Note: coefficients stand for posterior means; *p<0.05; **p<0.01; ***p<0.001

7.2 Appendix B: A Brief History of Oil and Natural Gas

Since the major theme of this thesis is related to an oil and gas industry, it will be helpful to give a quick overview of the main drivers of the industry's history. Crude oil was first used in a form of kerosene for lighting as a substitute for expensive whale oil. With development of an automobile and an electric bulb, gasoline became the most common and useful oil derivative. Since then oil became a major commodity in an international market. Humanity switched from horses to cars, which led to a huge transition in world trade and a military strategy. Before WWI, as the First Lord of Admiralty, Winston Churchill realized that speed at sea was going to help his country win a potential war against a major belligerent neighbor. Hence, he oversaw a transition of all military ships from coal to oil, which later helped The Great Britain to win the war against Germany. The WWII landscape was largely determined by innovation in military transportation: tanks and planes, both of which operated using gasoline. With a discovery of oil reserves in the Middle East, Arab powers, completely irrelevant to the world order before, came to play an important part in international politics. The Embargo of 1973, during the Yom Kippur War, showed that the power of oil producers is huge and the country with the most oil resources is always a force to be reckoned with. Saudi Arabia allied itself with Venezuela and other major oil producers to form the Organization of the Petroleum Exporting Countries (OPEC). This organization's production quotas are some of the most important metrics to look at when trying to understand dynamics of this industry. They determine and fix each member's contribution to world's oil supply to stabilize prices at a level that guarantees producers a large economic surplus. The history of natural gas is closely tied to the history of oil by the nature of their geology - the two commodities are very often found together. However, unlike oil, natural gas is used mostly in heating and electricity generation. Hence, it is a direct competitor of coal, nuclear, and renewable sources of energy. The oil and natural gas industry experienced significant shocks in the past 10 years. One of the major breakthroughs was the shale revolution, which propelled the US to the one of the most important oil and gas producers of the early 21st century. Currently, oil from hydraulic fracturing accounts for about a half of current US crude oil production[13]. Developments in hydraulic fracturing significantly reduced the costs of extracting both oil and natural gas from a shale rock. This reduced prices of natural gas in the US and since it is a greener source of energy than coal, it has been gradually substituting coal in electricity production. Oil and natural gas are crucial commodities that ensure a well-functioning US economy. Recently, the US Congress passed a bill that lifted a 40-year oil and natural gas export ban, propelling the US 'Big Oil' onto the world stage. From the demand side, the United States consumed a total of 11.66 billion barrels of oil equivalent in 2015[14][15]. From the supply side, the US domestic production is estimated to be at 8.94 billion barrels of oil equivalent in 2015[16]. Hence, it is very hard to underestimate the significance of the oil and gas industry to the US economy. In 2014, Saudi Arabia grew weary of increasing competition from US shale producers, untrustworthy allies in the OPEC, the rise of different renewable technologies (especially, solar) and decided to get back its market share

[13] Cook, T., & Perrin, J. (2016, March 15). Hydraulic fracturing accounts for about half of current U.S. crude oil production. Retrieved March 20, 2016, from `https://www.eia.gov/todayinenergy/detail.cfm?id=25372`

[14] How much oil is consumed in the United States? (2016, March 17). Retrieved March 20, 2016, from `https://www.eia.gov/tools/faqs/faq.cfm?id=33`

[15] U.S. Natural Gas Total Consumption (Million Cubic Feet). (n.d.). Retrieved April 03, 2016, from `https://www.eia.gov/dnav/ng/hist/n9140us2M.htm`

[16] Monthly Crude Oil and Natural Gas Production. (2016, February 29). Retrieved March 20, 2016, from `https://www.eia.gov/petroleum/production/#oil-tab`

in energy by increasing production. Moreover, Iran plans to produce more due to a lift of the embargo. Therefore, the industry is currently at an interesting point with many companies and countries expected to default in a near-term future. All of the historical facts and the recent events contribute to our knowledge of the oil and gas market dynamics and will have to be taken into consideration when answering the research question of this paper.