Land Ownership and Delay in Oil and Gas Production: A Natural Experiment[1]

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Abstract:

We examine oil and gas drilling on federal, state, and private lands in the Wyoming checkerboard by comparing permitting delays and price responsiveness. These lands were alternatively allocated to private owners at the square-mile section via the Pacific Railroad Acts between 1862 and 1871, and two of every 36 sections, numbers 16 and 36, to state governments under the General Land Ordinance of 1785. Prior to 1970, we find all three types of lands see similar delays in the time from permit submission to first drilling. However, from 1970 onwards, and especially as a result of the shale boom after 2003, well drilling on federal and to a lesser extent state land is delayed relative to wells on private land. The results suggest that bureaucratic delay has a significant effect on whether a well is drilled: post-2003 around 37% of federal wells that receive permits are never drilled versus only 17% for private wells. To test how this delay affects production, we examine the price elasticity of drilling, finding evidence that drilling on private land is more price-responsive: average drilling elasticities for gas wells in the checkerboard are around 0.78, but when separated by land type, drilling on private land is more responsive to price.

Keywords: Bureaucracy, Regulation, Natural Experiment, Checkerboard, Oil, Natural Gas

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It is ironic that bureaucracy is still primarily a term of scorn, even though bureaus are among the most important institutions in every nation in the world. Not only do bureaus provide employment for a very significant fraction of the world's population…, but also they make critical decisions which shape the economic, political, social, and even moral lives of nearly everyone on earth. Yet economists and political scientists have largely ignored bureaucratic decision making in constructing their theories of how the world operates.

-*Anthony Downs "Inside Bureaucracy" (1964, p. 1)*

I. Introduction

Governmental bureaucracy is often criticized for its inefficiency. Anecdotes of high levels of paperwork and long waits for decisions are common among people interacting with US Federal agencies and similar bureaucratic organizations. However, if these organizations provide different goods and services than less bureaucratic entities, efficiency evaluation can be difficult. Bureaucratic delay and caution may be necessary in some cases (Prendergast, 2003) and centralized coordination may be optimal where transactions costs are high (Coase 1937). Improving economic understanding of this area is important, as central governmental spending is a large part of the modern economy representing 30-60% of GDP in the OECD countries.[2] However, it is difficult to evaluate empirically whether bureaucracy is inefficient, estimate its cost, or explore the channels through which these costs are manifest.

In this paper we isolate a task, oil and gas leasing, performed by a federal governmental agency, a state governmental agency, and private landowners. Inefficiency associated with bureaucratic decision making is one of the key arguments made for transferring lands owned by the US Federal Government to state or private control, for instance Utah's call for the turnover of federal lands.[3] While these lands have myriad uses, the most valuable monetarily is the extraction of mineral resources, especially oil and natural gas, where they are available. We focus on the positive question of efficiency, namely we examine whether drilling on federal, state, and private land differs, and why? We examine a case where expected benefits of the task and its potential complexity are randomly assigned: the allocation by the US federal

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[2] OECD.org

[3] E.g. http://publiclands.utah.gov/wp-content/uploads/2014/11/1.%20Land%20Transfer%20Analysis%20Final%20Report.pdf;

government of every other square-mile section to private owners via the Pacific Railroad Acts between 1862 and 1871, and the allocation of every 16th and 36th square-mile section to state governments under the General Land Ordinance of 1785.

Generally, the paper is organized around two testable premises related to the effect of bureaucracy on economic outcomes. First, delays under the more bureaucratic systems managing state and federal land should extend the time between the decision to drill a well and its spud date, the date when drilling actually begins. Second, this delay makes production on lands managed by bureaucratic agencies less responsive to market prices. To explore these effects empirically, we collect data on production behavior and outcomes in the Wyoming checkerboard. This area, centered on the Union-Pacific Railroad line that formed the first transcontinental railroad, overlies valuable oil and gas fields in the Green River Formation and underlying Mesozoic strata. These fields were undiscovered at the time the land was assigned and therefore offer a unique natural experiment, which we utilize via an instrumental variables approach.

Prior to 1970, we find all three types of lands see similar delays in the time from permit submission to first drilling. However, from 1970 onwards, and especially as a result of the shale boom after 2003, well drilling on federal and to a lesser extent state land is delayed relative to wells on private land. The results suggest that bureaucratic delay has a significant effect on whether a well is drilled: post-2003 around 37% of federal wells that receive permits are never drilled versus only 17% for private wells. To test how this delay affects production, we examine the price elasticity of drilling, finding evidence that drilling on private land is more price-responsive: average drilling elasticities for gas wells in the checkerboard are around .78, but when separated by land type, state and private land are more elastic.

These results suggest that delay may be the fundamental mechanism through which oil and gas production is limited on federal lands. It contributes to the growing economics literature suggesting oil and gas production responds to prices primarily through the drilling of wells by examining drilling response across land ownership types, which has not been done. In section II the paper examines the literature on oil and gas production and the potential reasons for federal delay. In section III we discuss the data we use and section IV provides an empirical strategy and results, and concluding remarks follow.

II. Literature

a. Permitting and Environmental Regulations

Oil and gas are fugitive resources which can move underground across overlying land ownership boundaries, with the extent of this movement determined by geology. In the United States, oil and gas ownership is assigned via extraction, typically under a form of the correlative rights doctrine. The right to drill typically rests with the overlying landowner.[4] Land and mineral rights can be owned privately, or by the state or federal government, and regardless of overlying ownership, oil and gas sit below the surface in a common pool, unclaimed until extraction.

Because of the failure of private contracting to solve common pool losses under the rule of capture, oil and gas extraction in Wyoming is subject to mandatory unitization where contiguous fields are operated by a single operator who maximizes aggregate production value (Libecap and Wiggins 1985). An exploratory unit is typically formed prior to production, and leaseholders within the unit receive a payout and bear cost proportionate with their stake in the unit, typically determined by acreage (Marranzino et al). The unit operator determines where and when wells are drilled. In the Wyoming checkerboard, a majority of the oil and gas extraction occurs under a unitization agreement. However, within unit boundaries drilling activity is affected by underlying land ownership because of differing permitting regulations.

Drilling on all lands is permitted through the Wyoming Oil and Gas Conservation Commission (WOGCC), but drilling on federal land also requires a permit from the Bureau of Land Management (BLM). The amount of time required to receive a drilling permit from the BLM land can be much longer than from the WOGCC. The BLM permitting process to drill or recomplete a well can take anywhere

[4] For some land the federal government reserved its mineral rights, even as the overlying land was sold, creating "split-estate" where the ownership of land and right to drill for minerals rest with two different parties.

from nine months to two years depending on stipulations attached to the permit. The duration of the process has been criticized by the Office of the Inspector General, which reported that the average duration across all BLM offices to complete an application for a permit to drill (APD) is 228 days, even though 99% of all APDs are approved (Kendall 2014). The report suggests that delays increase uncertainty, put royalties at risk, and can cause the cancellation of planned drilling projects.

Under the Mineral Leasing Act of 1920, which changed mineral claims on federal lands from land patents to leases, there were limited requirements on mineral extraction and leasing. Concerns about the limited amount of production income from federal lands that was returned to taxpayers, along with increasing concern over the environmental impact of the use of federal lands, led to the Federal Land Policy and Management Act of 1976. The Act required a systematic planning process for federal lands including incorporation of physical, biological, economic, and other sciences in determining potential uses and assessing environmental consequences. Delays often occur due to the time required to assess and comply with the National Environmental Policy Act (NEPA) of 1970, Federal Land Policy Management Act (FLPMA) of 1976, Endangered Species Act (ESA) of 1973, and National Historic Preservation Act (NHPA) 1966. Evaluation and compliance with these enacted laws is performed by third party consulting firms prior to receiving a permit to drill, recomplete, or inject in wells and can cost tens of thousands of dollars. While many of the federal laws apply to all lands, the Office of the Inspector General suggests that these delays are due to processing time in addressing the requirements of NEPA, which applies only to Federal lands (Kendall 2014). In contrast, the WOGCC attempts to approve all permits within 30 days of receipt—in 2012 78% were approved within 30 days.[5]

For all land ownership types, WOGCC regulates well spacing to address common pool extraction problems (see Libecap and Wiggins 1985). WOGCC typically requires wells be spaced at 40 acres intervals. The goal of this policy is to have adequate wells to extract oil and gas without creating

[5] http://www-wsl.state.wy.us/slpub/strategic_plans/2013/2013_055_SP%20FY%2015_16.pdf

excessive well interaction effects. Although 40 acres is standard, the policy can be varied to address local conditions. To extract "tight" oil and gas, which is located in formations with low permeability—smaller pockets of oil and gas compared to conventional reservoirs—WOGCC has in many cases allowed for more closely spaced wells.[6] The process of adding wells to access tight deposits in a field that had been producing conventionally is known as infilling or downspacing. Federal well spacing is determined by the state commission as well, but the well permitting process takes longer on BLM land. The fracking boom in the early 2000s led to requests to WOGCC for downspacing, and these requests started to be approved after 2003. The BLM has proposed a rule that would more clearly define the requirements for federal fracking permits, but the rule is on hold due to ongoing litigation. Currently, operators must submit an APD for a non-conventional well to the BLM in the same manner as for conventional wells, but delays may be longer due to uncertainty over the proper rules for regulating these wells.

b. Drilling and Production

Across all ownership types, landowners often do not drill their own wells. Drilling rights are typically leased to an extraction company, and the landowner receives an upfront payment in exchange for providing the option to drill for a specified period of time. Then, if oil or gas is produced, the landowner receives a royalty payment, which is a percentage of the gross value of production. There are significant differences in contract structure between federal, state, and private leases, in large part because federal and state lease structure is standardized and private leases are not. Currently, Wyoming BLM parcels are auctioned quarterly using a competitive sealed-bid first-price auction. Unsold leases are available to be purchased non-competitively. Remaining parcels without a buyer are then recycled through the auction. Wyoming state leases are allocated in a similar manner, although the royalty rate and process for disposing of unsold leases differ slightly.

[6] http://trib.com/news/state-and-regional/ogcc-approves-tighter-gas-well-spacing/article_d7518adc-04e6-5a24-be72-c716b0a5d579.html; http://www.oilandgasinvestor.com/file/149306/download?token=NSP_TwGp

Once a lease is acquired and a drilling permit is secured, a well can be drilled. If the well strikes oil or gas, the output path of a well is generally fixed and declines exponentially (Mason and Veld 2013). This means oil and gas production on producing wells is highly price inelastic. The margin on which firms can respond to prices is in the number and type of new wells brought online (Anderson et al 2014). Oil rig activity, an indicator of exploration effort and field development activity, increases with oil price, especially in North America due to the presence of private firms and few government restrictions (Ringlund et al 2008). Natural gas reserve additions through the drilling of new wells in West Virginia were consistent with this pattern as well, with the elasticity of drilling and reserve additions positive in wellhead price (Iledare 1995). In fact, natural gas production is almost entirely determined by geological characteristics, with natural gas producers responding to market prices through drilling (Mason and Roberts 2016). Empirically, for existing wells there is no positive price response of gas production using well-level data (Newell et al 2016) or oil production using aggregate production data (Anderson et al 2014).

Non-conventional extraction approaches are those in which a horizontal well is drilled, and the economic incentives for extraction may differ under non-conventional production. Tight gas formations may have less uncertainty about whether minerals exist in paying quantities below the surface, and although the elasticity of drilling is about the same as for conventional wells, non-conventional wells produce 2.7 times more gas per well on average, meaning the price responsiveness of supply is three times as high (Newell et al 2016). This means that differences in production, especially responses to price shocks, may be amplified for non-convention wells. Because the non-conventional boom began around 2003 and typically occurs on areas with low-permeability, we explore how the effect of land ownership on drilling delay changes as a result of the shale-gas boom.

c. Checkerboard and Land Grant

To address selection issues, we utilize the randomized allocation of federal lands due to the Pacific Railroad Acts between 1862 and 1871, and state lands under the General Land Ordinance of 1785.

These acts granted every other section (1 mi^2) of land within twenty miles of either side of the proposed transcontinental route to the railroad company. When Wyoming became a state, sections 16 and 36 in every township were granted to the state "for the support of common schools." (Wyoming Admission Act, 26 Stat. 222 § 4 1890), and many of those sections were set aside as school trust lands. In aggregate each land type is likely to have the same reservoir characteristics, geology, and production drive mechanisms because land is randomly allocated and the area of most of the oil and gas pools are larger than one section (DeBruin, 1989).

Akee (2009) examines a similar checkerboard allocation in an urban setting, finding land randomly allocated to an Indian tribe was valued less than that held privately due to regulatory differences in the land's use. Fitzgerald (2010) examines land ownership regimes in federal lease auctions, finding that where mineral and surface rights are split, lease prices are lower. Similarly, Leonard and Parker (2015) use surface ownership structure on the Fort Berthold Indian reservation to examine the costs of extracting oil and gas, finding a coordination problem of divided ownership, especially for non-conventional wells.

In Wyoming, Lewis (2015a) examines the effect of environmental restrictions on drilling behavior using state trust land allocated within otherwise Federal areas as a natural experiment. Using intent to treat design to assign state ownership to every 16th and 36th section, he finds indications of preferential drilling and exploration on state sections and argues that this preference is due to higher operating costs on federal land related to more stringent environmental policies. In contrast, our paper focuses on differences in transaction costs associated with ownership regimes and the costs of bureaucratic delay.[7] In a dissertation chapter, Lewis also examines the effects of private vs government ownership within the part of the Wyoming checkerboard that intersects the Green River Basin and finds more drilling on federal land relative to private land (Lewis 2015b). The use of the checkerboard as a

[7] Lewis (2015a) acknowledges that differences in bureaucratic delay may also explain his findings.

natural experiment was also undertaken by Kunce et al (2002) and Kunce et al (2004), but the results were retracted in both cases, by Gerking and Morgan (2007a) and Gerking and Morgan (2007b) respectively.

III. Data

Spatial GIS data and data from the WOGCC are used to characterize well-drilling and production on the checkerboard. The original checkerboard was established as a 20 mile buffer around the proposed route of the Union Pacific Railroad (UPRR), which may differ slightly from the observed route. Though we do not observe the proposed route of the UPRR, we are able to identify its first established route using the 1870 railroads shapefile from the “Railroads and the Making of Modern America” project at the University of Nebraska, Lincoln. To ensure that our sample is fully within the initial railroad grant, we restrict our data to include sections within an 18 mile buffer around the 1870 UPRR route.

We identify federal subsurface ownership using the 2014 Surface Management Agency (SMA) shapefile from the BLM[8] and state subsurface ownership from the State Subsurface Ownership shapefile from the Wyoming Office of State Lands and Investments.[9] Subsurface rights that are not federally or state owned are assumed to be privately owned.[10] In the case of sections with split ownership, we assign ownership in proportion to area owned by each type.

Drilling and well data come from three sources: a comprehensive dataset of historical statewide drilling and cumulative production from the USGS, monthly production data from WOGCC, and permit data from the WOGCC.[11] The cumulative production data estimates the start and stop data of drilling for each well drilled between 1900 and 2010, as well as a cumulative production number which corresponds only to production from 1978-2010, the time period for which digital production data is available.

[8] http://www.blm.gov/wy/st/en/resources/public_room/gis/datagis/state/state-own.html
[9] States subsurface ownership last accessed 10/2016: http://gis.statelands.wyo.gov/osligis/oilandgas
[10] We cross-check our private ownership designation with ownership information from sections with approved drilling permits (r=0.99).
[11] http://pubs.usgs.gov/ds/625/; http://wogcc.state.wy.us/urecordsMenu.cfm

Data from the Wyoming Oil and Gas Commission from 1978 to 2016 includes monthly production of oil, gas, and water by well, as well as the number of days a well operated in the given month. In both data sets, wells are identified by an API well number, which is a permanent identifier for every oil and gas well drilled in the United States. The data may have multiple entries if the well in question extracts from multiple geologic formations. Along with the API number, each well has a variety of other attributes: township, range, section, quarter section, and quarter-quarter section; latitude and longitude; company name; well name; formation; and field name.

Our third source of data comes from all approved oil and gas permits issued by the WOGCC from 1900-2010, which are required to drill on any land within Wyoming. Out of the roughly 100,000 approved permits in the data set, we are able to match 98% of them to the GIS dataset and the section on which they are drilled. When we restrict permits to the checkerboard area, we are left with 17,206 approved permits across 14,405 unique well locations.

IV. Empirical Framework and Results

We use the experimental setting created by the quasi-random assignment of treatment types via the railroad checkerboard in the 19th century. Because oil and gas drilling did not start until 20th century, it seems likely that this initial land ownership allocation is independent of the quality of the oil and gas resources. Side-by-side comparisons between ownership types help ensure that the average characteristics of treatment and control groups are "balanced."

To use this quasi-random experiment there are three potential regression strategies: (i) naïve regression: current ownership is used to compare outcomes; (ii) intent-to-treat regression: parcels are characterized as retaining their original, random ownership assignment; and (iii) instrumental variables regression: the checkerboard allocation is used as an instrument for current ownership. Much of the ad-hoc work comparing private, federal, and state lands has utilized an approach similar to the naïve regression by directly comparing outcomes based on current ownership.[12] Our approach instead uses two more appropriate comparisons: the intent-to-treat regression assumes all oil and gas extraction occurred under the initial pattern of ownership (see Lewis 2015a; 2015b), while the instrumental variables regressions assume all the extraction occurred under current ownership patterns. The earlier parcels were transferred, the better the instrumental variables approximation of the causal effect of the ownership regime.

Table 1 shows that initial ownership patterns, established prior to knowledge of subsurface resources, are fairly persistent through time. The majority of changes that do occur are transfers from federal to private owners. Much of this change in ownership occurred through issuing private homesteads under the original Homestead Act of 1862 which transferred ownership of surface and subsurface rights to the private owners. Homesteads were no longer settled after 1940 and therefore the most substantial changes in ownership away from the checkerboard occur prior to much of the oil and gas production in the area. Therefore we tend to prefer the IV specifications, particularly when samples include outcomes occurring after 1940.

For the naïve regression, dummies $private_i$ and $state_i$ represent current land ownership. The dependent variable is related to private and state ownership via the following specification:

$$y_i = \alpha + \beta_p private_i + \beta_s state_i + \varepsilon_i \qquad (1)$$

Where the coefficients β_p and β_s represent the difference between federal and private and state and private ownership, respectively. However, these specifications do not control for ownership selection on characteristics related to the dependent variable of interest. The reduced form strategy, or intent to treat, uses an indicator for plausibly exogenous, even numbered sections, except the state sections 16 and 36, D_i^{even}, as a coefficient indicating a parcel lies in an area allocated to the federal government. A similar

[12] See for instance Holly Fretwell and Shawn Regan (2015) "Divided Lands: State Versus Federal Management in the West." URL: http://www.perc.org/sites/default/files/pdfs/150303_PERC_DividedLands.pdf

indicator, $D_i^{16,36}$, is used for sections 16 and 36, area allocated to the state of Wyoming through the state's Enabling Act:

$$y_i = \alpha + \beta_p D_i^{even} + \beta_s D_i^{16,36} + \varepsilon_i \qquad (2)$$

Where β_p and β_s represent the difference between land initially allocated to private relative to federal and state relative to federal, respectively. The intent-to-treat regression treats land as if it remained in its initial allocation. As can be seen in figure 1, current ownership reflects the initial allocation of land via the checkerboard, but not perfectly. To control for this change of ownership we can use initial state and federal allocation as an instrument for current allocation. Using two stage least squares, our first stage has two instruments:

$$\begin{aligned} private_i &= \pi_0 + \pi_1 D_i^{even} + \pi_2 D_i^{16,36} + u_i \\ state_i &= \rho_0 + \rho_1 D_i^{even} + \rho_2 D_i^{16,36} + u_i \end{aligned} \qquad (3)$$

The second stage then uses the fitted values for $private$ and $state$ to estimate equation (1).

Permitting Delay

While drilling on all ownership types requires a WOGCC permit, drilling on federally owned subsurface requires an additional permit from the BLM. Both applications can take place concurrently, but the federal permitting process is more substantial. Though we cannot directly measure permitting delay at the well-level because we do not have data on BLM well permits, we can observe the approval date of the WOGCC drilling permit and the spud date for each well. Because operators on federal land need BLM approval before drilling, excess delay in federal permitting is likely to be reflected in the duration between WOGCC permit approval and spud date for the well.

To measure this delay we use data from the WOGCC on all approved oil and gas permits issued by the WOGCC from 1900-2010. Though most well locations are only associated with a single permit, there are as many as 9 approved permits for a single well in the data set. WOGCC permits expire if drilling has not started within 1 year of approval.[13] Because application costs of permits are relatively low, operators often fail to drill a well within a year of permit application and reapply.

We define delay at the well-level as the difference in time between the first WOGCC approved permit and the well spud date. Because a substantial fraction of permitted wells are never drilled we measure whether or not a well was drilled within x (30 days, 90 days, 1 year) days of the first permit approval (so that the measure includes approved wells that were never drilled). We also include a measure of the wells that were never drilled, and variables are described in Table 2. We break the analysis into three periods based on the year in which the first permit for the well was approved: 1) 1900-1969; 2) 1970-2002; and 3) 2003-2010. Period 1 represents a time of relatively slow production and predates any major environmental regulation such as NEPA. Period 2 represents the period of increasing federal environmental regulations but predates the fracking boom.[14] Period 3 covers approved permits during the fracking boom up until 2010.

We estimate the intent-to-treat and IV regression for probability of delay across ownership types. Both specifications yield highly similar results, so we will refer to the IV results—the intent-to-treat results are shown in the appendix. Table 3 shows very little delay early in the data set, and no meaningful differences in delay time across ownership type. Average delay times get considerably longer in later periods. In period 2, roughly 20% of approved wells are not drilled within a year of approval and private ownership experiences less delay than federal and state ownership. In 2003-2010, delays are considerably longer on federal ownership and shortest on private. The delay on federal land is also longer than state land, but this difference diminishes the longer the delay. More permits become obsolete under federal ownership than state ownership, but this difference is not statistically significant in any period. This suggests that most delayed wells are eventually drilled. Private ownership experiences the shortest delays in every period and significantly fewer wells become obsolete than government ownership types. We

[13] Starting in January 2016, and outside of our data set, the WOGCC began allowing operators two years to start drilling before each permit expires.
[14] The choice of 2003 as the start of the fracking boom follows Mason and Roberts (2016).

attribute these differences to the delay associated with federal permitting. However, as mentioned in Lewis (2015b) these results may partially reflect leasing deadlines because federal leases have 10-yar terms, state leases five years, and private 3-5 years, encouraging leaseholders on private lands to drill more quickly to hold the lease.

Price Response

To calculate drilling price elasticity we use data on the date well start dates to construct $wells_{j,t}$, the cumulative number of wells spudded on land ownership type j at time t, where t is measured in quarters. We are able to match 58,451 wells in the state of Wyoming to their spud date via their permitting information. Of these wells 8,397 are in the checkerboard. We then construct price time series using data from the Energy Information Administration. We use two price series, NYMEX one- and four-month future prices, for Henry Hub (HH) natural gas and West Texas Intermediate (WTI) crude oil. The mean of monthly price data is used for quarterly price. We also construct an expectation of the rate at which prices will change, which is the percent increase in price from the one-month to four-month futures price. The future prices for oil are available from 1984 on and gas from 1994 on. This leaves only 416 observations for oil wells and 3,994 gas wells in the checkerboard. We include the full range for which oil price and well data is available, 1984-2010, due to the limited number of observations.

Figure 2 shows the overall levels of gas well drilling in the Wyoming checkerboard and the price of one-month futures for Henry-Hub natural gas. The figure shows the clear relationship between price and drilling activity. Higher future prices are associated with increased drilling activity, and in general the magnitude of price change corresponds to the magnitude of the drilling change. In figure 3, the drilling rates are separated into those wells drilled in private lands and those drilled on federal lands. The wells drilled on private lands show the same pattern of price response as figure 2. However, this relationship is not as clear for wells drilled on federal land, with a larger delay between price spikes and well drilling, along with reduced magnitudes of the response. Both these observations are consistent with permitting delays on federal land both slowing down and dampening federal drilling response to price changes.

We estimate drilling price elasticity similar to Anderson et al (2014). We aggregate drilling activity by date j for each type of land ownership, using initial allocation, for each type of well, as provided by WOGCC. Then, we estimate elasticity of drilling with respect to price change by land ownership type using the following reduced form, for oil and gas separately:

$$\Delta\ln(w_{jt}+1) = \alpha_j + \sum_{l=0}^{L}\left[\gamma_{jl}\Delta\ln\left(p_{t-l}^{1}\right) + \phi_{jl}\Delta ExpIncr_{t-l}\right] + \beta_j t + \varepsilon_{j,t} \tag{6}$$

Where $w_{j,t}$ is the number of wells drilled in time period t for initial ownership j. The coefficients γ are the elasticities of oil or gas drilling with respect to changes in lagged oil and gas prices, respectively, by initial ownership. The coefficients ϕ is the price responsiveness of drilling to expected price increase lag, by initial ownership. We also allow for ownership-specific linear time trends.

Results are shown in table 6. Specifications 1-5 show the results for oil drilling while 6-10 show the results for gas. (1) and (6) are for the entire state of Wyoming, (2) and (7) for the checkerboard, and (3)-(5) and (8)-(10) show results for the checkerboard separated by land ownership. Results are similar to figures 2 and 3. Overall, both oil and gas drilling are responsive to prices, but the price response to current period price is strongest for wells drilled on private lands, with estimates of both oil and gas current-price elasticities positive and significant at the 5% level. Both the point estimates of first-lagged oil and gas coefficients on federal are greater than private, although these differences are not statistically significant. However, while federal drilling may respond in later periods, the elasticity estimates are smaller overall, indicating less price responsiveness and consistent with delay leading to some drilling projects being abandoned, as suggested in the results on drilling delay.

V. Conclusion

Current work on oil and gas responsiveness to price indicates that new drilling is the primary mechanism by which firms are able to increase production (Mason and Roberts 2016; Anderson et al 2014; Mason and Veld 2013; Newell et al 2016). Building on this work, we examine how land ownership, and the regulatory delay associated with acquiring drilling permits on federal land, impacts the ability of firms to drill in response to price increases. We first examine the percentage of wells not drilled over time, given a state permit for drilling is acquired. We show that starting around 1970 federal lands began to have longer delays in drilling, relative to private land and that the relative delays have persisted and even increased during the fracking boom. While these results are indicative of federal delay reducing price responsiveness, other explanations are possible. To test responsiveness to price, we directly examine the price elasticity of drilling, finding that drilling on private lands is more responsive to price in the immediate period, and that federal lands have lower drilling price elasticities overall. Even though 99% of federal drilling permits are eventually approved, bureaucratic delay imposes costs through delay and dampening. Drilling response is slower, and thus wells on federal lands do not respond to high oil and gas prices as quickly as private lands. These delays also lead to lower overall price responses—fewer overall wells drilled in response to price increases. Our findings indicate that the potential for improving the responsiveness of federal lands to price signals could be achieved through a reduction in delay in the BLM permitting process.

Sources

Akee, R. (2009). Checkerboards and Coase: The Effect of Property Institutions on Efficiency in Housing Markets. Journal of Law and Economics, 52(2), 395-410.

Anderson, S.T., Kellogg, R. and Salant, S.W., 2014. Hotelling under pressure (No. w20280). National Bureau of Economic Research.

Coase, R.H., 1937. The nature of the firm. Economica, 4(16), pp.386-405.

DeBruin, R.H. 1989. Wyoming's Oil and Gas Industry in the 1980's a Time of Change, WGS: Public Information Circular, No. 28

Downs, A. and Rand Corporation, 1967. Inside bureaucracy (p. 264). Boston: Little, Brown.

Fitzgerald, T., 2010. Evaluating split estates in oil and gas leasing. Land Economics, 86(2), pp.294-312.

Fitzgerald, T. and Rucker, R.R., 2014. US private oil and natural gas royalties: estimates and policy considerations. Available at SSRN 2442819.

Gerking, S. and Morgan, W.E., 2007a. Effects of environmental and land use regulation in the oil and gas industry using the wyoming checkerboard as a natural experiment: Retraction. The American economic review, 97(3), p.1032.

Gerking, S. and Morgan, W.E., 2007b. Environmental and Land Use Regulation in Nonrenewable Resource Industries. Land Economics, 83(2), pp.iii-iii.

Iledare, O.O., 1995. Simulating the effect of economic and policy incentives on natural gas drilling and gross reserve additions. Resource and energy economics, 17(3), pp.261-279.

Kendall, M. 2014. Memo: Final Evaluation Report—Onshore Oil and Gas Permitting, U.S. Department of the Interior. Office of the Inspector General. Report No. CR-EV-MOA-0003-2013.

Kunce, M., Gerking, S. and Morgan, W., 2002. Effects of environmental and land use regulation in the oil and gas industry using the Wyoming checkerboard as an experimental design. The American Economic Review, 92(5), pp.1588-1593.

Kunce, M., Gerking, S. and Morgan, W., 2004. Environmental and land use regulation in nonrenewable resource industries: Implications from the Wyoming checkerboard. Land Economics, 80(1), pp.76-94.

Leonard, B. and Parker, D. 2015. Creating Anticommons: The Effects of Historical Land Privatization on Modern Natural Resource Use. Working Paper. URL: https://bryanjleonard.files.wordpress.com/2013/07/leonard-and-parker-1-12-2016-with-appendices.pdf

Lewis, E.K. 2015a. Federal Environmental Protection and the Distorted Search for Oil and Gas. Job Market Paper.

Lewis, E.K. 2015b. Three Essays on the Economics of the Oil and Gas Industry. Dissertation. University of Michigan. URL: deepblue.lib.umich.edu/handle/2027.42/113565

Libecap, Gary D., and Steven N. Wiggins. 1985. "The influence of private contractual failure on regulation: the case of oil field unitization." Journal of Political Economy 93.4: 690-714.

Mason, C.F. and van't Veld, K., 2013. Hoteling Meets Darcy: A New Model of Oil Extraction.

Mason, C.F. and Roberts, G. 2016. Price Elasticity of Supply and Productivity: An Analysis of Natural Gas Wells in Wyoming. Working Paper. URL: http://www.gavinedwardroberts.com/uploads/8/8/0/4/88043402/decline_curves_8_23.pdf

Prendergast, C., 2003. The limits of bureaucratic efficiency. Journal of Political Economy, 111(5), pp.929-958.

Thomas A. Marranzino, T.A., Pink, J.B., Cavaleri, A.C. A primer on federal unitization, unit agreements and unit operating agreements. Anadarko Petroleum Corporation. URL: http://jay.law.ou.edu/faculty/Hampton/Mineral%20Title%20Examination/Spring%202012/Federal%20Unitization%20Primer%20Tom%20Marranzino.pdf

Newell, R.G., Prest, B.C. and Vissing, A., 2016. Trophy Hunting vs. Manufacturing Energy: The Price-Responsiveness of Shale Gas (No. w22532). National Bureau of Economic Research.

Ringlund, G.B., Rosendahl, K.E. and Skjerpen, T., 2008. Does oilrig activity react to oil price changes? An empirical investigation. Energy Economics, 30(2), pp.371-396.

State Board of Land Commissioners (SBLC). 2007. Rules and regulations: board of land commissioners: Chapter 18: Leasing of Oil and Gas. URL: http://lands.wyo.gov/resources/rulesandpolicies

Tables

Table 1: Current subsurface ownership and checkerboard allocation

	Even Sections (excluding 16,36)	Odd Sections	16,36 Sections
Total Sections	6,775	7,615	836
Current Federal	**74%**	3%	3%
Current Private	23%	**97%**	7%
Current State	4%	<1%	**90%**

Notes: Table 1 shows the current section-level subsurface ownership pattern within 18 miles of the 1870 route of the Union Pacific Railroad. In the case of split subsurface ownership, ownership type is assigned in proportion to area owned within a section.

Table 2: Variables

Variable	Description	Source
$federal_i$	=1 if section i has federal mineral ownership as of 2016	BLM
$state_i$	=1 if section i has state mineral ownership as of 2016	WOSLI
D_i^{even}	=1 if section i is even, not 16 or 36	Authors' calculation
$D_i^{16,36}$	=1 if section i is 16 or 36	Authors' calculation
$nospud30_j$	Proportion of permitted wells of ownership j not spudded within 30 days	WOGCC
$nospud60_j$	Proportion not spudded within 60 days	WOGCC
$nospud365_j$	Proportion not spudded within one year	WOGCC
$nospud_j$	Proportion that are never spudded	WOGCC
$wells_{j,t}$	Number of wells of ownership j in time t	WOGCC
$p_{f,t}^c$	Average price of fuel, f $= \{gas, oil\}$, in time t, of contract type c $= \{0,1,4\}$ where 0 is spot price, 1 is one-month or front-month price and 4 is four-month future price	NYMEX Prices via EIA
$ExpIncr_{f,t}$	Expected rate of price increase of fossil fuel f in time t: $= 100\frac{p_{f,t}^4 - p_{f,t}^1}{p_{f,t}^1}$	Authors' calculation using NYMEX prices

Table 3: Second-Stage IV Regression of Delay from State Permit Approval to Drilling (1900-1969)

Predicted Probability Current Ownership	(1) No Spud after 30 Days	(2) No Spud after 90 Days	(3) No Spud after 1 year	(4) Never Spud
Private	0.03*	0.01	0.00	-0.00
	[0.02]	[0.01]	[0.01]	[0.01]
State	-0.00	0.01	-0.00	-0.00
	[0.02]	[0.02]	[0.01]	[0.01]
Constant (Federal omitted)	0.03***	0.02**	0.01**	0.01*
	[0.01]	[0.01]	[0.01]	[0.01]
Observations	1,619	1,619	1,619	1,619
R-squared	0.01	0.01	0.00	

Notes: The table 2nd-stage regression estimates of the probability that (first) permit to spud time exceeds the threshold specified in each column on current ownership type instrumented by initial ownership type. Robust standard errors clustered at the PLSS township level in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Second-Stage IV Regression of Delay from State Permit Approval to Drilling (1970-2002)

Predicted Probability Current Ownership	(1) No Spud after 30 Days	(2) No Spud after 90 Days	(3) No Spud after 1 year	(4) Never Spud
Private	-0.05***	-0.11***	-0.08***	-0.05**
	[0.02]	[0.02]	[0.02]	[0.02]
State	-0.01	-0.02	0.00	-0.01
	[0.03]	[0.03]	[0.03]	[0.03]
Constant (Federal omitted)	0.58***	0.43***	0.26***	0.18***
	[0.03]	[0.03]	[0.02]	[0.02]
Observations	5,288	5,288	5,288	5,288
R-squared	0.01	0.02	0.01	0.00

Notes: The table 2nd-stage regression estimates of the probability that (first) permit to spud time exceeds the threshold specified in each column on current ownership type instrumented by initial ownership type. Robust standard errors clustered at the PLSS township level in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Second-Stage IV Regression of Delay from State Permit Approval to Drilling (2003-2010)

Predicted Probability Current Ownership	(1) No Spud after 30 Days	(2) No Spud after 90 Days	(3) No Spud after 1 year	(4) Never Spud
Private	-0.13***	-0.35***	-0.35***	-0.20***
	[0.03]	[0.04]	[0.03]	[0.04]
State	-0.07**	-0.16***	-0.12**	-0.04
	[0.03]	[0.05]	[0.05]	[0.05]
Constant (Federal omitted)	0.97***	0.90***	0.58***	0.37***
	[0.01]	[0.01]	[0.03]	[0.04]
Observations	3,924	3,924	3,924	3,924
R-squared	0.04	0.12	0.10	0.04

Notes: The table 2nd-stage regression estimates of the probability that (first) permit to spud time exceeds the threshold specified in each column on current ownership type instrumented by initial ownership type. Robust standard errors clustered at the PLSS township level in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Drilling Responsiveness Results

VARIABLES	(1) Oil	(2) Oil	(3) Fed Oil	(4) Priv. Oil	(5) State Oil	(6) Gas	(7) Gas	(8) Fed Gas	(9) Priv. Gas	(10) State Gas
ΔLog(Front-Month Price)	1.240**	1.249**	0.299	1.619**	0.415	0.254	0.249	-0.561	0.548**	0.577
	(0.491)	(0.578)	(0.804)	(0.645)	(0.412)	(0.177)	(0.170)	(0.497)	(0.273)	(0.644)
Lagged ΔLog(Front-Month Price)	1.368**	-0.171	0.156	-0.525	-0.0917	-0.0786	0.444**	0.550	0.418	0.817
	(0.614)	(0.656)	(0.700)	(0.634)	(0.428)	(0.175)	(0.186)	(0.429)	(0.281)	(0.623)
2nd-Lagged Δ Log(Front-Month Price)	-1.216**	-0.251	0.168	-0.310	0.314	0.361*	0.0888	-0.342	0.242	0.0877
	(0.595)	(0.798)	(0.764)	(0.815)	(0.348)	(0.190)	(0.180)	(0.376)	(0.274)	(0.585)
ΔExpected Rate of Price Increase	3.794*	3.360	0.00213	0.0574*	0.00578	-0.583	-0.395	-0.0428	0.0218	0.00688
	(2.104)	(2.877)	(0.0315)	(0.0296)	(0.0193)	(1.219)	(1.158)	(0.0306)	(0.0135)	(0.0326)
ΔLagged Expected Rate of Price Increase	1.190	-1.125	0.0126	-0.0168	-0.000220	-0.533	0.405	0.00567	-0.00878	0.0310
	(2.421)	(3.249)	(0.0340)	(0.0293)	(0.0173)	(1.172)	(1.122)	(0.0317)	(0.0163)	(0.0317)
Δ2nd Lagged Expected Rate of Price Increase	-2.934	-6.532**	-0.0257	-0.0666**	0.00938	-0.0751	1.829	-0.00393	0.0345**	-0.0123
	(2.323)	(2.912)	(0.0305)	(0.0294)	(0.0149)	(1.102)	(1.161)	(0.0283)	(0.0155)	(0.0307)
Date (quarter)	7.11e-05	0.000603	0.000735	-4.48e-06	0.000321	0.000937	0.000974	0.000840	0.00100	0.00189
	(0.00206)	(0.00294)	(0.00261)	(0.00308)	(0.00184)	(0.00236)	(0.00196)	(0.00526)	(0.00279)	(0.00590)
Constant	-0.0341	-0.103	-0.119	-0.00992	-0.0687	-0.157	-0.165	-0.135	-0.171	-0.330
	(0.308)	(0.446)	(0.422)	(0.459)	(0.282)	(0.423)	(0.347)	(0.906)	(0.459)	(1.039)
Observations	101	101	101	101	101	65	65	65	65	65
R-squared	0.206	0.098	0.031	0.123	0.017	0.101	0.164	0.090	0.190	0.062
Area	All	Checker	Checker	Checker	Checker	All	Checker	Checker	Checker	Checker
Period	1984-2010	1984-2010	1984-2010	1984-2010	1984-2010	1994-2010	1994-2010	1994-2010	1994-2010	1994-2010

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Figures

Figure 1: Checkerboard instrument and current distribution of land ownership

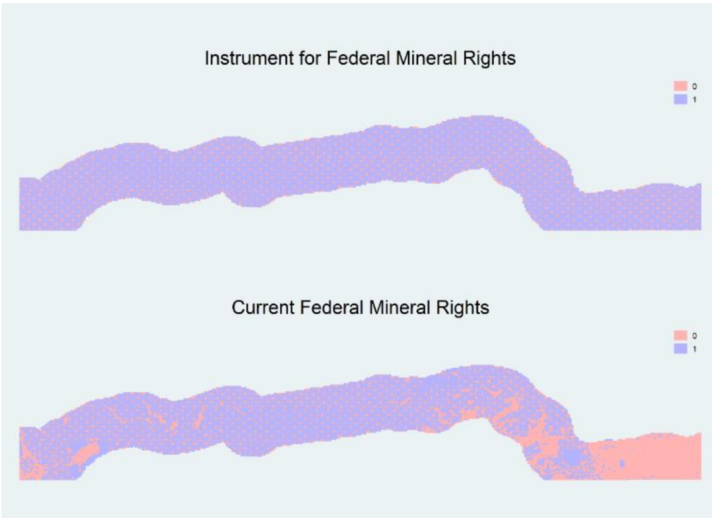


Figure 2: Gas Price and Wells Drilled in the Wyoming Checkerboard

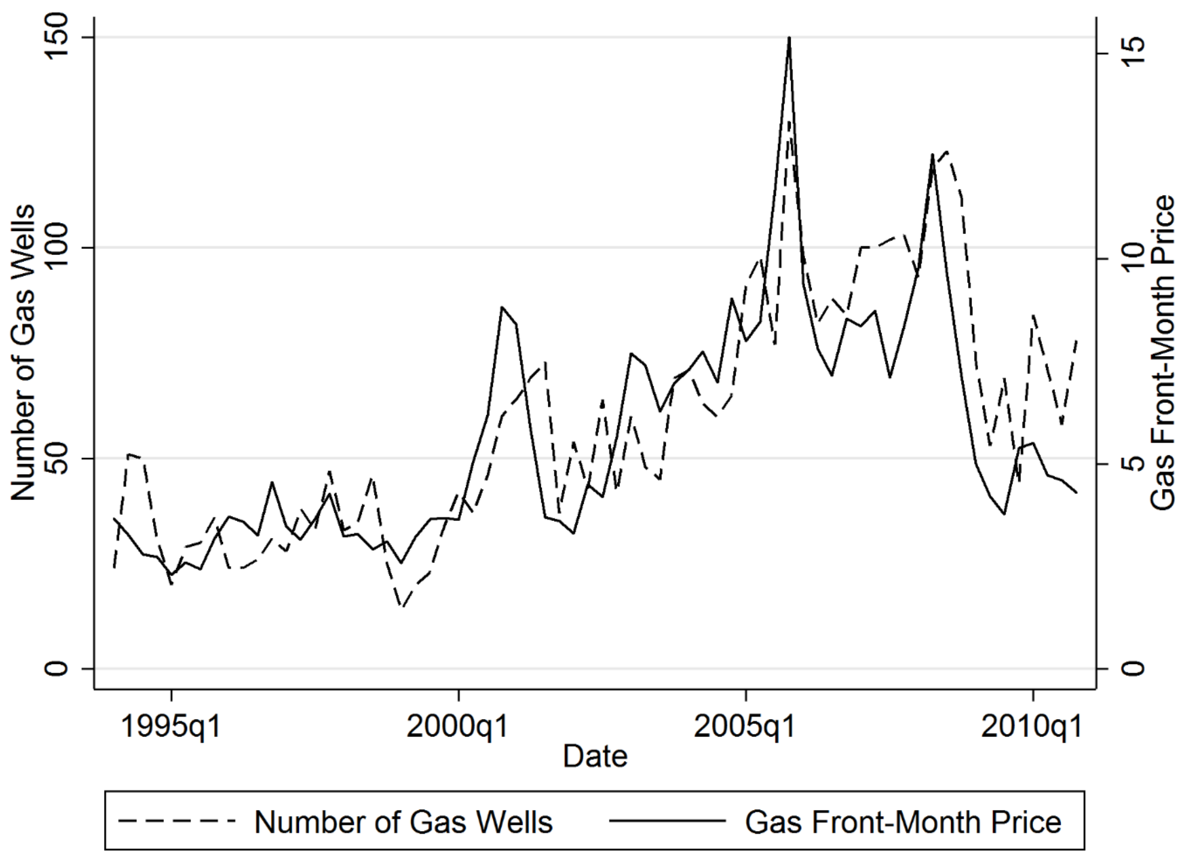
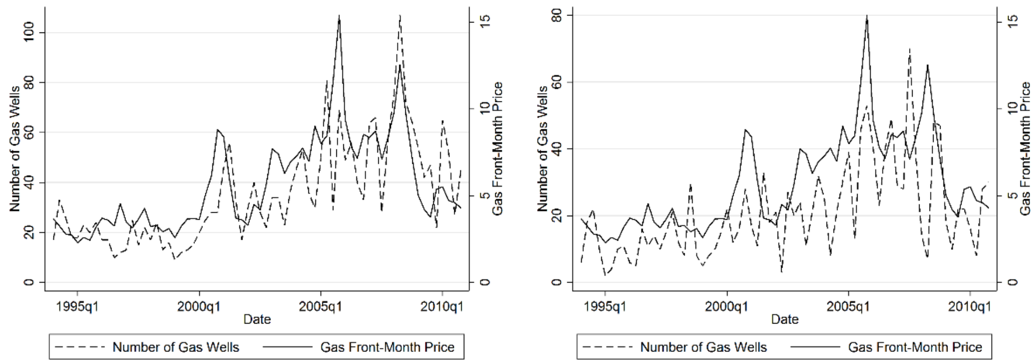


Figure 3: Gas Wells Drilled by Land Ownership Type in the Wyoming Checkerboard



Notes: wells drilled on private land (left) and federal land (right)

Appendix

Figure A1: Intent-to-Treat Regression of Delay from State Permit Approval to Drilling (1900-1969)

Initial Ownership Indicator Variables	(1) No Spud after 30 Days	(2) No Spud after 90 Days	(3) No Spud after 1 year	(4) Never Spud
Private	0.03*	0.01	0.00	-0.00
	[0.01]	[0.01]	[0.01]	[0.01]
State	-0.01	0.01	-0.00	-0.00
	[0.02]	[0.02]	[0.01]	[0.01]
Constant (Federal omitted)	0.03***	0.02***	0.01***	0.01***
	[0.01]	[0.01]	[0.00]	[0.00]
Observations	1,619	1,619	1,619	1,619
R-squared	0.00	0.00	0.00	0.00

Notes: The table reports regression estimates of the probability that (first) permit to spud time exceeds the threshold specified in each column by initial ownership type. Robust standard errors clustered at the PLSS township level in brackets. *** p<0.01, ** p<0.05, * p<0.1

Figure A2: Intent-to-Treat Regression of Delay from State Permit Approval to Drilling (1970-2002)

Initial Ownership Indicator Variables	(1) No Spud after 30 Days	(2) No Spud after 90 Days	(3) No Spud after 1 year	(4) Never Spud
Private	-0.05**	-0.10***	-0.07***	-0.04**
	[0.02]	[0.02]	[0.02]	[0.02]
State	-0.00	-0.01	0.01	-0.01
	[0.03]	[0.03]	[0.03]	[0.03]
Constant (Federal omitted)	0.57***	0.42***	0.25***	0.18***
	[0.03]	[0.02]	[0.02]	[0.01]
Observations	5,288	5,288	5,288	5,288
R-squared	0.00	0.01	0.01	0.00

Notes: The table reports regression estimates of the probability that (first) permit to spud time exceeds the threshold specified in each column by initial ownership type. Robust standard errors clustered at the PLSS township level in brackets. *** p<0.01, ** p<0.05, * p<0.1

Figure A3: Intent-to-Treat Regression of Delay from State Permit Approval to Drilling (2003-2010)

Initial Ownership Indicator Variables	(1) No Spud after 30 Days	(2) No Spud after 90 Days	(3) No Spud after 1 year	(4) Never Spud
Private	-0.12***	-0.33***	-0.33***	-0.19***
	[0.03]	[0.04]	[0.03]	[0.03]
State	-0.07**	-0.14***	-0.11**	-0.03
	[0.03]	[0.05]	[0.05]	[0.05]
Constant (Federal omitted)	0.96***	0.88***	0.56***	0.36***
	[0.01]	[0.01]	[0.03]	[0.03]
Observations	3,924	3,924	3,924	3,924
R-squared	0.03	0.12	0.11	0.05

Notes: The table reports regression estimates of the probability that (first) permit to spud time exceeds the threshold specified in each column by initial ownership type. Robust standard errors clustered at the PLSS township level in brackets. *** p<0.01, ** p<0.05, * p<0.1