SUBSIDIZING STRIPPERS: THE IMPACT OF ROYALTY RATE REDUCTIONS ON THE INTENSIVE AND EXTENSIVE PRODUCTION MARGINS OF MARGINALLY PRODUCING OIL WELLS

by

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ABSTRACT

Substantial research has been conducted on the impacts of taxation on oil production. However, a void in the literature exists as the distinction has not yet been made between significant and marginal oil production. Using well-level production data from the state of Wyoming, this thesis estimates the impact of royalty rate reductions on marginally-producing, federal oil wells—commonly referred to as stripper wells. The empirical analysis is conducted using fixed effects double- and triple-difference models and a more traditional multiple regression model. The results suggest that production from federal stripper wells increased substantially during the royalty rate reduction program—on both the intensive and extensive production margins.

INTRODUCTION

With the United States consistently ranking in the top three for petroleum production, the field of crude oil extraction garners polarizing attention throughout the country. Media outlets of every form debate the morality of extraction procedures, roughnecks work long, arduous hours on oil rigs, engineers develop revolutionary ways to counteract production decline, and economists analyze extraction decisions subject to various constraints such as resource reserve levels and taxation. The impact of taxation on extraction decisions has been analyzed on numerous margins. Academics have researched onshore production, offshore production, oil wells and gas wells and paired them all with production taxation, property taxation, and income taxation.

Surprisingly, a void in the literature on the taxation of natural resource production is represented by a group of wells that contribute over 20 percent of total production and make up over 80 percent of the total well count—as reported by the U.S. Energy Information Administration (EIA). Additionally, those two statistics remain on an upward trajectory. These wells are commonly referred to as stripper wells. These marginally producing wells average less than 15 barrels of oil per day (bbl/day). Consequently, they are thought of as nearing the end of their economic profitability, as the marginal benefit of each barrel of oil coming out of these wells approaches zero.

Because crude oil is a nonrenewable resource, the number of wells becoming economically unprofitable increases every day. Until advancements in cheaper substitutes to crude oil are made, incentives must be provided to operators of crude oil wells to keep the oil flowing. This thesis uses well-level data from the state of Wyoming to investigate whether the operators of these wells can increase their economic profitability by reducing a form of financial burden associated with the well.

Visual representations of the substantial impact of stripper wells, which produced over 320 million barrels of oil in 2009, are displayed below. The EIA uses rate classes, which group production levels by the average number of barrels of oil per day, to classify production levels.[1] The cumulative distributions of wells by rate class over time are shown in figure 1. The cumulative distributions of well production by rate class over time are shown in figure 2. Production rate classes of eight and below all represent stripper wells.

The question of interest in this thesis is how does the subsidization, through royalty rate reductions, of marginally producing oil well properties (i.e., stripper well properties) on federal leases impact the output of these properties? This kind of policy can have impacts on both the intensive and extensive production margins. Consequently, this thesis addresses how this policy affects the production from the average stripper well property, the number of properties producing, and the percentage of wells on a property that qualify as a stripper well.

The initial econometric specification investigates the binary impact of the royalty relief program on the intensive and extensive production margins in order to quantify the impact of the existence of said program. This is done using double- and triple-difference, fixed effects models. The second econometric specification, taking into account the intricacies of the program, investigates the continuous impact of the royalty relief

[1] These rate classes are displayed in table A1 in Appendix A.

program on the intensive and extensive production margins. This is done using a more traditional multiple regression, fixed effects model.

The rest of this thesis is organized in the following manner: Chapter 2 covers the Stripper Oil Well Property Royalty Rate Reduction Program. Chapter 3 provides an overview of the basics of resource taxation, prior literature, and the basics of oil production. Chapter 4 covers the theoretical modeling of resource extraction under a royalty rate. Chapter 5 discusses the data as well as the empirical strategies employed in this thesis. Chapter 6 discusses the results and their implications. Finally, Chapter 7 provides concluding remarks.

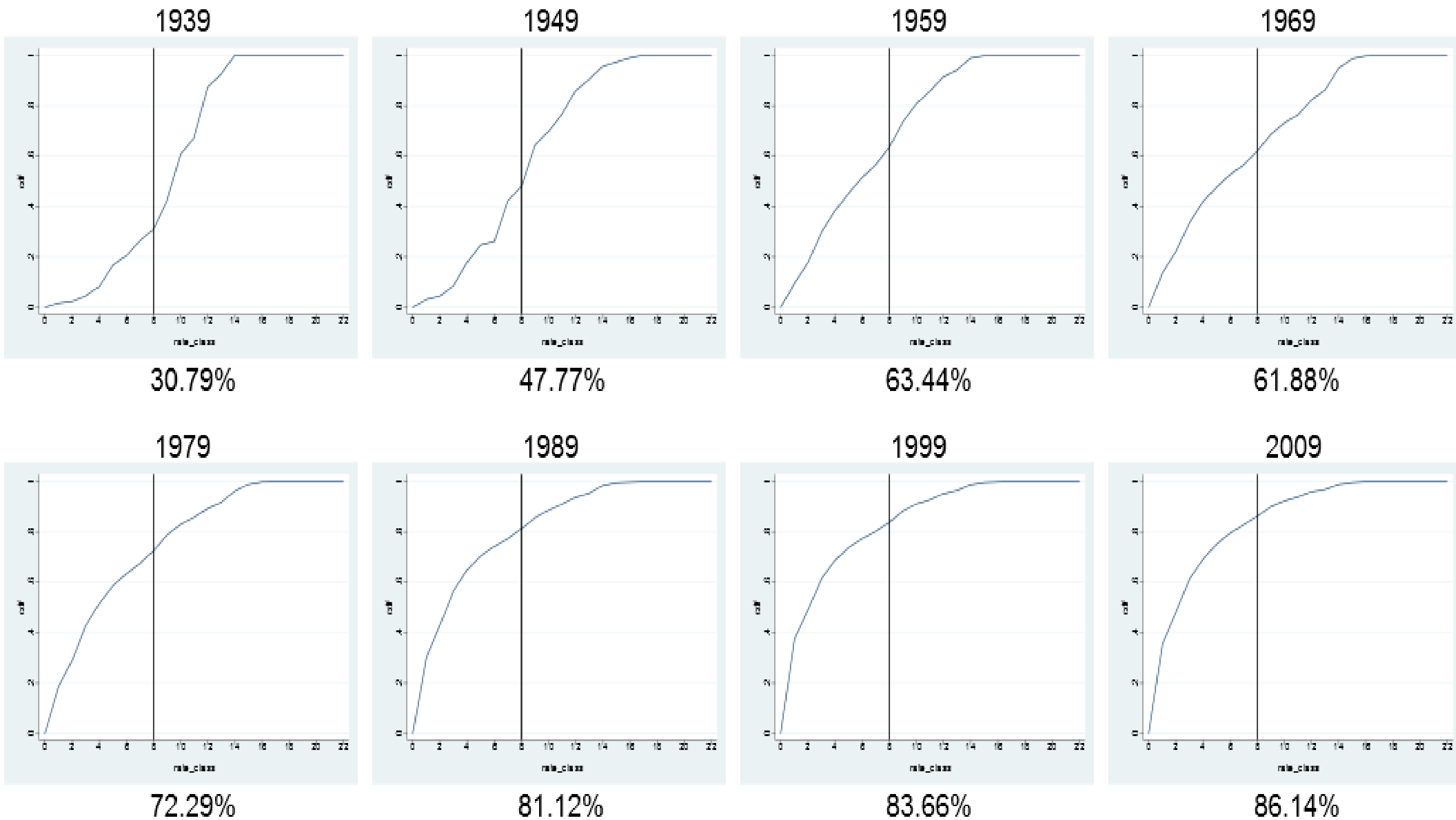

Figure 1: Well Distributions by Rate Class (CDF)

Note: Production rate class is plotted on the vertical axis. The vertical line represents the stripper cutoff point. Everything to the left of the line qualifies as a stripper (Rate classes 8 and below). The percentage of total wells that qualify as strippers is noted beneath each graph. Data were obtained from the EIA.

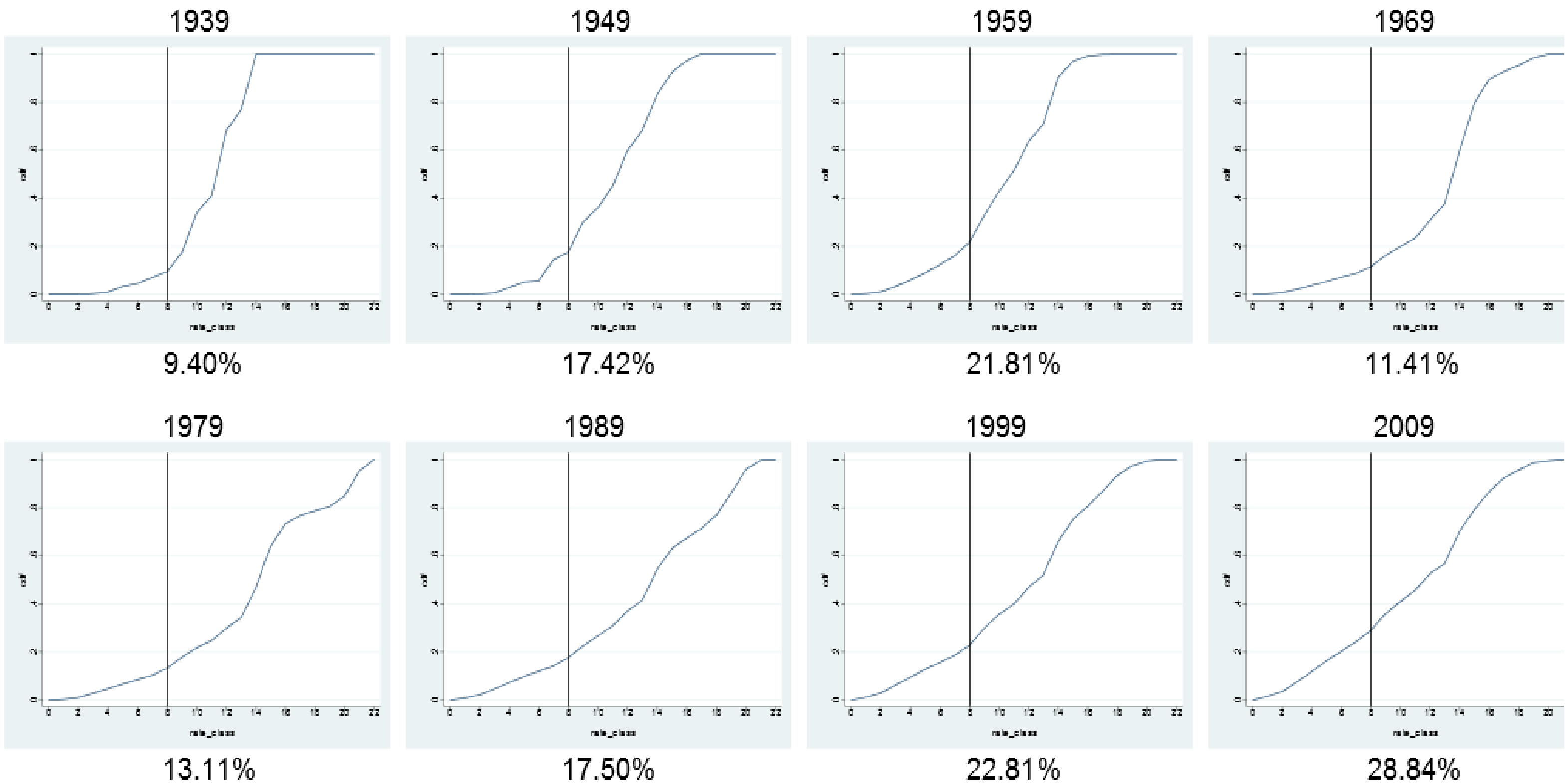

Figure 2: Well Production by Rate Class (CDF)

Note: Production rate class is plotted on the vertical axis. The vertical line represents the stripper cutoff point. Everything to the left of the line qualifies as stripper production (Rate classes 8 and below). The percentage of total production that qualifies as stripper production is noted beneath each graph. Data were obtained from the EIA.

STRIPPER OIL WELL PROPERTY ROYALTY RATE REDUCTION PROGRAM

The Mineral Leasing Act of 1920 was enacted to promote the extraction of coal, oil, gas and other nonrenewable resources on public land. An amendment to section 39 of the act, written in 1946, allows the federal government to adjust royalty rates on federal leases for the purpose of enhancing production. Regarding rental or royalty reduction or suspension, it states that "the Secretary of the Interior…is authorized to waive, suspend, or reduce the rental, or minimum royalty, or reduce the royalty on an entire leasehold, or on any tract or portion thereof segregated for royalty purposes…"(30 U.S. Code § 209).

Past royalty reductions have been made for marginal extraction property in cases in which the market price of oil drops below a certain point for an extended period of time. One example of this is a case in which the "spot price of West Texas Intermediate crude oil…, is, on average, less than $15 per barrel for 90 consecutive trading days…" (42 U.S. Code § 15903). These concessions are normally temporary and are removed once the price increases above a certain point for a reasonable amount of time or the property increases production and loses its marginal status. The previously mentioned reduction, for example, is removed once the "spot price of West Texas Intermediate crude oil…exceeds $15 per barrel for 90 consecutive trading days…or the property no longer qualifies as a marginal property…" (42 U.S. Code § 15903). Additionally, specific government programs have also been implemented—such as the Stripper Oil Well Property Royalty Rate Reduction Program (RRRP), which lightened the tax burden on stripper oil well operators.

The RRRP was instituted by the Bureau of Land Management (BLM). The BLM, a sub-agency of the U.S. Department of the Interior, is responsible for managing both federal surface lands and federal sub-surface minerals across the United States. This specific program, which was in place from October 1, 1992 to February 1, 2006, decreased the royalty rate for stripper well properties on federal onshore leases from a standard 12.5 percent to a lower, production-determined percentage.[2] A lease represents a contractual agreement between an oil company or extraction crew and the land and/or mineral rights owner, granting access to the minerals. A federal lease represents a share contract between an oil company or operator and the federal government. The federal government grants access to the minerals in exchange for a percentage of the gross value of the resource that is extracted. This is known as a royalty. The royalty rate designates the exact percentage that is to be paid to the lessor.

It is important to establish the difference between a well and a property. While a well is a singular entity, a property is a collection of one or more wells usually assigned a "marginal" status for the purpose of a royalty reduction. However, both a well and a property represent a subset of a lease and do not cross between leases. The benefit of forming a property is that it allows a subset of wells on a given lease to receive a different royalty rate than the rest of the wells on the same lease. In the case of the program analyzed in this thesis, the formulation of properties allowed operators to pay a lower royalty rate on wells classified as stripper wells.

[2] A stripper well property is "any Federal lease or portion thereof segregated for royalty purposes…that produces an average of less than 15 barrels of oil per eligible well per well-day from the qualifying period" (Stripper well royalty reductions, 43 C.F.R. § 3103.4-2 (2010)).

Aside from the definition of a stripper well property quoted in a previous footnote, any insight into the formation of these properties is unobserved. However, if the profit maximizing operator was unconstrained in the creation these properties, we could hypothesize that operators would either place all of the wells that qualify as a stripper well on their own individual property, or they would place all of the wells that qualify as a stripper well together on one property. Any inclusion of high-producing wells on a property, created for the purpose of royalty rate segmentation, would only increase the minimum royalty rate that an operator would receive and would therefore not be profit maximizing. The situation would get less ideal for operators if they were constrained geographically in the formation of properties. For example, the area of a property cannot exceed 100 acres, or the distance between wells on a property cannot exceed 1 mile.

Because stripper wells produce less than the average well, they can carry a higher variable cost-to-production ratio. The previous standard onshore royalty rate was 12.5 percent, regardless of the level of production. Under this program, stripper well property royalty rates range from 0.5 to 11.7 percent—depending on the level of production. The less a stripper property produces on average, the larger the decrease in the royalty rate.[3] This is analogous to switching from a flat tax system to a progressive tax system where the higher producing stripper properties pay a higher royalty than lower producing stripper properties.

[3] A stripper property that averages 14 bbl/day receives a royalty rate of 11.7 percent, while a stripper property that averages 1 bbl/day receives a royalty rate of 1.3 percent.

The purpose of this program was to increase, restart, or enhance production on marginally producing oil wells on federal leases.[4] This could be done by increasing the quality of the well, implementing secondary and tertiary recovery techniques, or resuming production on shut-in wells.[5]

The initial qualifying period for the RRRP was from August 1, 1990 through July 31, 1991. The well operator calculated the average daily property production over the 12-month period. The resulting number was then rounded down to the nearest whole barrel—this rounding resulted in a step-wise royalty rate schedule. Finally, this value was plugged into the formula below to calculate the new royalty rate percentage. The operator reported the updated royalty rate to the Minerals Management Service (MMS).[6] The program rates are graphed along with the flat 12.5 percent rate in figure 3. The equation used to calculate the new royalty rate is:

$$Royalty\ Rate\ Percentage = 0.5 + (0.8)(Average\ Daily\ Production\ Rate) \quad (1)$$

Production decline was recognized by the program, as any federal property that did not qualify during the initial 12-month qualifying period could still qualify in any subsequent 12-month period during the life of the program. At the end of each subsequent 12-month period, the property average daily production was recalculated by the operator and an updated royalty rate was determined. The new royalty rate was then

[4] In an attempt to reduce opportunistic behavior, the regulations for the program stated: “For the qualifying period and any subsequent 12 month period, the production rate shall be the result of routine operational and economic factors for that period and for that property and not the result of production manipulation for the purpose of obtaining a lower royalty rate. A production rate that is determined to have resulted from production manipulation will not receive the benefit of a royalty rate reduction” (Stripper well royalty reductions, 43 C.F.R. § 3103.4-2 (2010)).

[5] A shutting in a well represents a temporary stoppage of production.

[6] The MMS was an agency within the Department of the Interior. The MMS was dissolved in 2011 and replaced by the Office of Natural Resource Revenue (ONRR).

compared to the initial qualifying royalty rate. If the new royalty rate was greater than or equal to the qualifying royalty rate, the qualifying royalty rate prevailed. However, if the new royalty rate was less than the qualifying royalty rate, the new royalty rate prevailed. This ensured that once a property qualified for the RRRP, the maximum royalty rate that would have to be paid on a given property was equal to the royalty rate calculated during its qualifying period.

Figures 4 and 5, found in the Code of Federal Regulations, provide two examples of RRRP qualification and subsequent royalty rate fluctuation. Figure 4 provides an example of a property that immediately qualified for the program. The property in this example averages 10 bbl/day during the initial qualifying period. Using the formula, this equates to a royalty rate of 8.5 percent. 8.5 percent is now fixed as the maximum royalty rate this property will pay during the life of the program. In the second 12-month period, this property averages 8 bbl/day. This equates to a royalty rate of 6.9 percent. Because 6.9 percent is less than the qualifying rate of 8.5 percent, 6.9 percent becomes the new royalty rate. In the third 12-month period the property averages 12 bbl/day. This equates to a royalty rate of 10.1 percent. Because 10.1 percent is greater than the qualifying royalty rate of 8.5 percent, 8.5 percent becomes the new royalty rate. Even in the fourth and fifth 12-month period when production increases above the stripper qualification level, the royalty rate remains at 8.5 percent.

Figure 5 provides an example of a property that did not qualify for the RRRP in the initial qualifying period but did qualify in the subsequent 12-month period due to a production decline. The property qualifies for the program in the second 12-month period by averaging 8 bbl/day. This equates to a 6.9 percent royalty rate, which remains the maximum royalty rate paid for the remainder of the program.

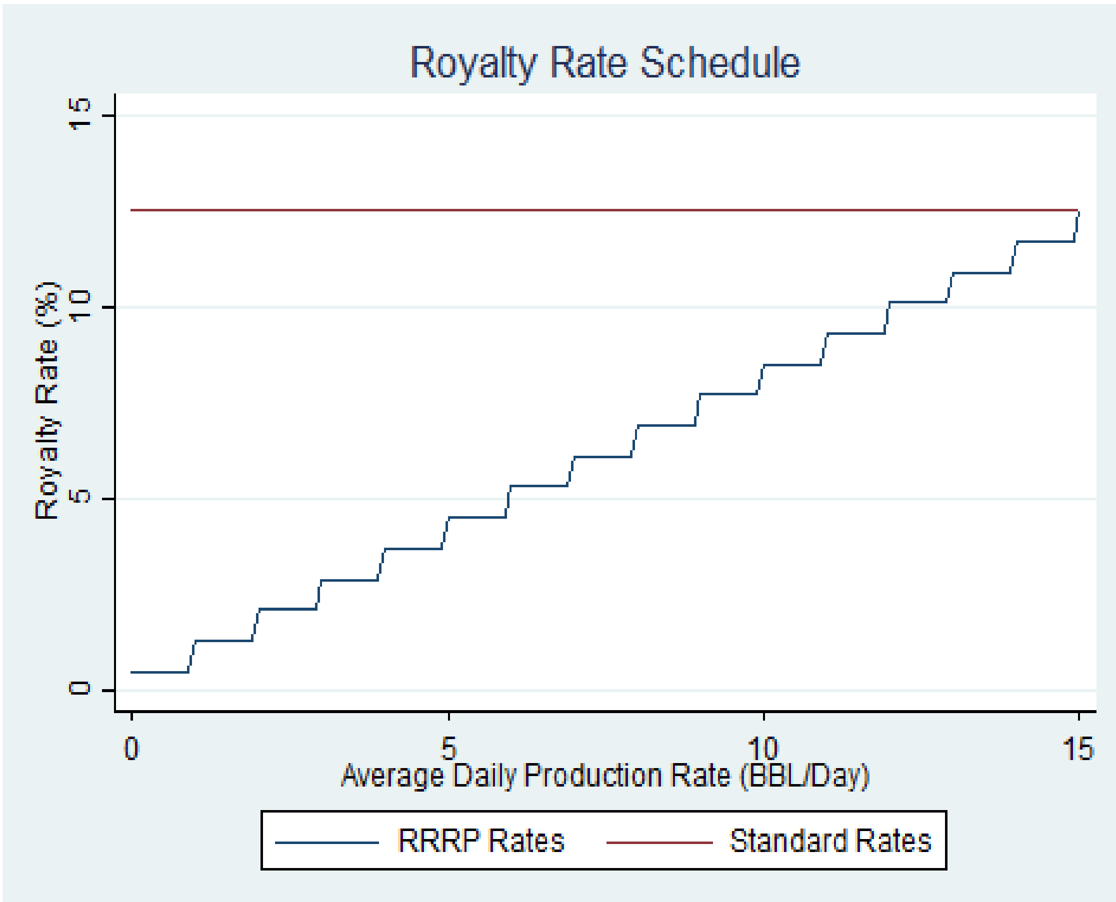

Figure 3: Stripper Oil Property Royalty Rate Schedule

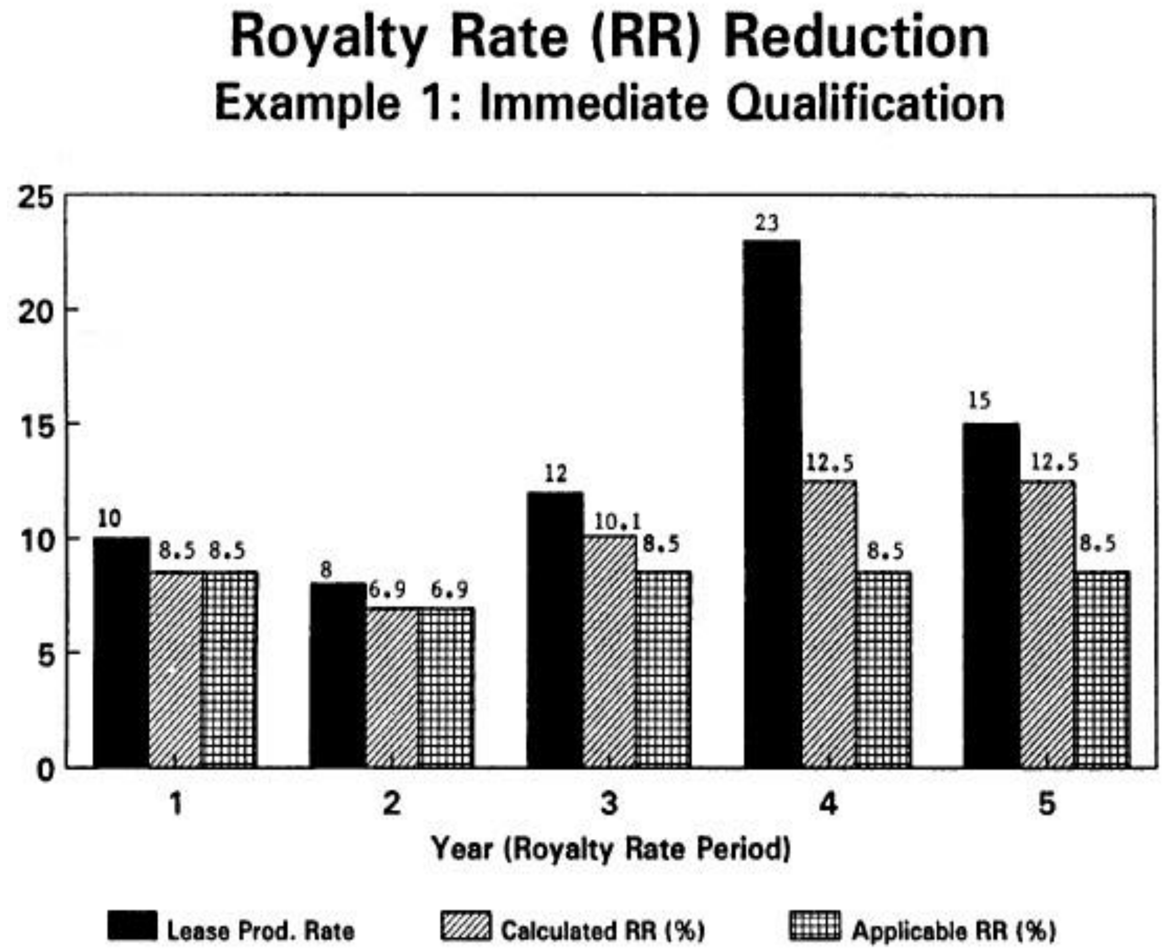

Figure 4: Royalty Rate Reduction Example 1 (Immediate Qualification)

Note: Figure taken from 43 C.F.R. § 3103.4-2 (2010).

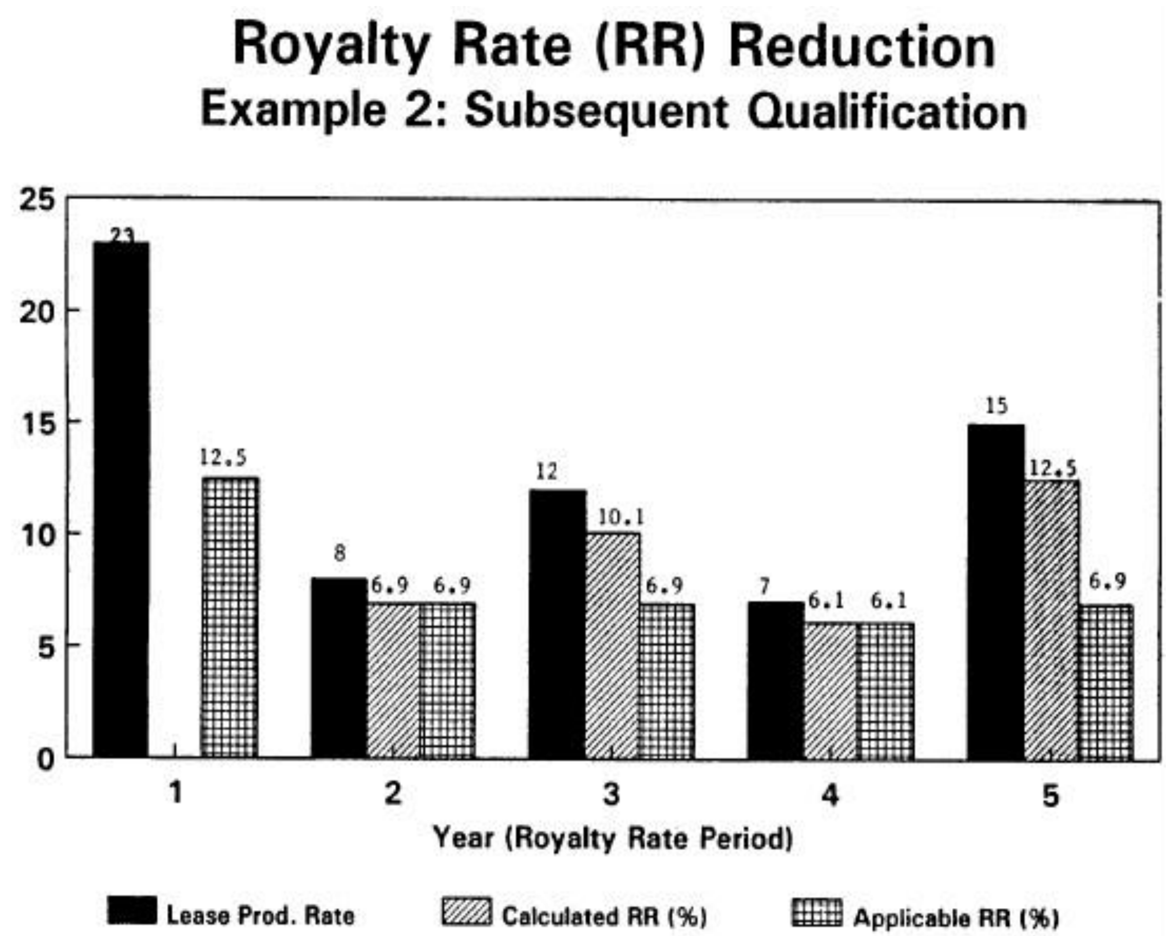

Figure 5: Royalty Rate Reduction Example 2 (Subsequent Qualification)

Note: Figure taken from 43 C.F.R. § 3103.4-2 (2010).

LITERATURE

The impact of taxation on natural resource extraction is well studied in the economic literature. The literature discussed in this chapter covers various methods of taxation on natural resource extraction practices.

While comparing investments in oil to other uses of financial capital, Davidson (1963) provides a theoretical explanation of the logic behind tax cuts in which he describes two assets—asset A and asset B. Initially both assets have the same present values and income functions—making a consumer indifferent between the two. Suddenly, the tax laws are changed making a portion of asset A's future income tax exempt. This increases the present value of asset A making the consumer willing to incur a higher cost to obtain asset A. This same example can be applied to the RRRP. Once the program is implemented, the royalty burden on federal stripper properties is reduced, increasing the present value of resources extracted from stripper wells, and making the operator more willing to incur higher costs to obtain these resources.

Taxation of the U.S. Oil Industry

The literature researching the taxation of the U.S. oil industry provides a solid literary foundation for this thesis. This is because the royalty rate system acts the same way as a severance tax, which will be discussed next.

Chakravorty, Gerking, and Leach (2009) break down state and local government taxation of the nonrenewable resource sector into three categories: production taxation, income taxation, and property taxation. Production taxes, also known as severance taxes, are "levied on the gross value (or volume) of production of the resource as it is "severed" from the ground." This form of taxation is the most common and is implemented in most nonrenewable resource producing states. The royalty rate is a form of production/severance taxation. Theoretically, the royalty rate and the severance tax are set up the same way. Allowing a royalty rate to be denoted by τ, a severance tax rate to be denoted by σ, output price to be denoted by p, and quantity extracted to be denoted by q, the royalty revenue generated by the royalty rate is represented by $(\tau)pq$ and the tax revenue generated by the severance tax is represented by $(\sigma)pq$. From the point of view of the profit-maximizing operator, these formulae are represented by $(1-\tau)pq$ and $(1-\sigma)pq$, respectively. The Wyoming state severance tax on non-stripper oil sits at 6 percent of the gross value of production.[7] The Wyoming state severance tax on stripper oil sits at 4 percent of the gross value of production.

Income taxes, which are "levied against the accounting net income of extraction firms," are "generally aimed at extracting economic rents earned by producers from the sale of nonrenewable resources." The income tax differs from the severance/production tax in its theoretical representation. Adding a total cost variable c, and an income tax rate ε, the revenue generated by the income tax is represented by $(\varepsilon)(pq-c)$. From the point of view of the profit-maximizing operator, this formula is represented by $(1-\varepsilon)(pq-c)$. It is important to mention that any royalties paid before, during, and after the RRRP are independent of any income taxation faced by operators. The state of Wyoming does not impose an income tax on individual wage income.

[7] This rate remains consistent throughout the life of the RRRP.

Lastly, property taxes can either be levied on the value of the extraction equipment above the ground or the value of the resource reserves beneath the ground. Letting total reserves to be denoted by R, and a property tax rate on reserves γ, the revenue generated by the property tax is represented by $(\gamma)Rp$. From the point of view of the profit-maximizing operator, this formula is represented by $(1-\gamma)Rp$. It is important to note that the operators on federal land included in this analysis did not face property taxes, as property taxes are not assessed on federal minerals.

Deacon (1993) analyzes the impacts of the three tax forms on production and calculates the deadweight losses associated with each one. Taxes create deadweight loss because producers. Any relief in the tax burden should increase production. Deacon's results indicate that the income tax is the least distortionary—displaying the least amount of deadweight loss. Because Deacon finds a significant amount of deadweight loss regarding the existence of a production tax, a decrease in royalty rates should lead to a decrease in deadweight loss.

Prior Literature

Royalty Rates

The royalty rate structure, which is the form of taxation analyzed in this thesis, has been researched previously. But the distinction between marginal and significant production has not yet been made. According to the EIA, Wyoming contains more federal oil and gas leases than any other state in the country. Fitzgerald (2014) estimates that over 63 percent of the minerals in the state of Wyoming were owned by the federal government in 2012. This is roughly 14 percentage points higher than the state of Utah which, according the EIA, contains the fourth most mineral producing federal leases in the United States. Because of this, federal royalty revenue from the state of Wyoming made up nearly 24 percent of all federal royalty revenue collected from 2003 to 2014.[8] The large amount of federal minerals in the state of Wyoming make it an excellent state to analyze a federal natural resource policy such as the RRRP.

Fitzgerald and Rucker (2016) find that royalty payments made to private mineral owners are substantial—in 2011 and 2012, they "estimate that $21-22 billion was owed to private owners of onshore oil and gas minerals." Despite being a paper pertaining to private royalties and not federal royalties, it still highlights the substantial impact of onshore royalty revenue in the United States. Royalty rate reductions, such as the ones implemented by the RRRP, represent a tradeoff between higher royalty rates paired with lower production and lower royalty rates paired with higher production, as optimal production practices adjust to changes in parameter values. The impact of a decrease in the royalty rate depends on the elasticity of the operator's supply response function. The more elastic an operator's supply curve; the more responsive production will be.

Research has been done that suggests royalty rate reduction programs do not accomplish their goals of providing incentives for implementing enhanced recovery techniques and overall increases in production, and should be revoked. Hallwood (2007) researches royalty relief in offshore oil production. He concludes that the forgone revenue resulting from royalty relief is expensive and that royalty relief is ineffective in

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[8] The data for this estimate were obtained from the Office of Natural Resource Revenue (ONRR), which displays royalty revenue data starting in 2003.

increasing offshore oil producing in the United States. Despite representing an analysis on royalty rate reductions, this paper analyzes offshore production and certainly does not single out stripper wells.

Severance Taxes

Kinnaman (2014) researches the impact of severance taxes on natural gas prices. The author concludes that a severance tax of 5 percent would increase the price of natural gas by as much as 3.82 percent and decrease gas extraction by an estimated 1.16 percent. Regarding the impact of the severance tax on public revenue, the author estimates that the implementation of a 5 percent severance tax results in between $443 and $486 million per year in public revenue for the Commonwealth of Pennsylvania.

Kunce et al. (2003) explore the impact of state level severance taxes on both production and exploration in the state of Wyoming. The authors implement a simulation model containing variables such as exploration costs, extraction costs, reserve additions, prices and tax parameters. The simulation shows that a doubling of the Wyoming severance tax would results in a 19.3 percent decrease in drilling, a 5.7 percent decrease in production and a 91.5 percent increase in severance tax revenue. This results in the authors declaring an inelastic response of oil production to changes in the state severance tax.

Kunce (2003) also wrote another paper in which he uses Pindyck's (1978) model to analyze the impact of state level severance taxes on the 20 states that produce a significant amount of oil. The simulation in this study finds that a 2 percentage point rate reduction in the Wyoming severance tax results in only a 1.6 percent increase in production, but a decrease in state severance tax revenue by about 33 percent. Consequently, Kunce again finds an inelastic relationship between production and severance tax rates, providing empirical evidence that small increases in drilling and large decreases in tax revenue result from a severance tax reduction. Both Kunce et al. (2003) and Kunce (2003) estimate the impacts of state severance taxation on oil production. However, in these analyses, the distinction between high producing wells and stripper wells is not examined—not allowing for the existence of separate impacts for the two groups.

Using the time paths for exploration, extraction, and prices as well as changes in deadweight loss, Yücel (1986) analyzes the impact of severance taxation on firms in an exhaustible resource industry. The author concludes that the imposition of a severance tax decreases exploratory effort and therefore decreases added reserves—leading to a more rapid depletion of the reserve base.

Yücel (1989) expands on the research done in Yücel (1986). The author uses the time paths for exploration, extraction, and prices as well as changes in deadweight loss to compare the impact of a severance tax on exhaustible resource producing competitive and monopolistic firms. Yücel (1989) finds that severance taxes have an impact on both the competitive and monopolistic producers—reducing production and exploratory effort in both cases. The existence of multiple well operators eliminates the possibility of a monopolistic market in this thesis; however, it is important to note the non-zero impact of taxation across different levels of competition.

Gamponia and Mendelsohn (1985) compare the efficiency and equity effects of four forms of taxation—yield, property, windfall profits, and unit taxes. The yield tax and property tax in this paper correspond with the production tax and property tax from Chakravorty, Gerking, and Leach (2009). The windfall profits tax resembles the income tax from Chakravorty, Gerking, and Leach (2009), with an additional condition—the tax does not become active until profits exceed a specified amount. The unit tax is represented by a fixed dollar amount, instead of a tax rate, which is multiplied by the quantity of the resource extracted. In their concluding remarks, the authors state that the gross yield tax, which they find shifts extraction into the future, is the most efficient.

Supply Elasticity

The following two papers analyze the supply elasticity of the nonrenewable resource market through a mechanism other than taxation—price.

In an analysis of sunk costs in natural resource production, Muehlenbachs (2015) differentiates between the responses of an output price change on two margins of natural gas production—the reserve base and the well count. The author concludes that a doubling of the price of gas results in an increase of more than 100 percent in the reserve base and a 6 percent increase in the number of active wells.

Also examining the various margins of resource production, Kellogg, Anderson and Salant (2014) test Howard Hotelling's (1931) exhaustible resource extraction model using Texas oil production data. The authors conclude that price incentives have no impact on oil production, but do have an impact on the number of new wells drilled. Their reformulation of Hotelling's (1931) model is centered on their key assumption that operators do not choose the amount of oil to extract. They argue that the amount of oil extracted is determined by the reservoir pressure, which decreases as the resource is extracted. While evidence from the engineering sector says that this may be true, the authors still fail to mention the ways in which operators can either improve reservoir pressure or circumvent decreasing reservoir pressure. Price incentives can motivate operators to engage in enhanced recovery techniques, which increases oil production.[9]

While the impact of taxation on natural resource extraction has been well documented, the distinction has not yet been made between the impact of taxation on low producing and high producing wells.

Basics of Oil Production

Oil production is generally grouped into three recovery levels: primary, secondary, and tertiary. As a resource is extracted, the reservoir pressure responsible for moving the resource up and out of the wellbore decreases. Consequently, an operator must either engage in secondary and tertiary recovery techniques in order to counteract the decreasing production or abandon the well. Engaging in these secondary and tertiary recovery techniques allows the operator to extract a larger percentage of the resource contained within the underground reservoir. However, moving from primary to secondary or secondary to tertiary recovery results in higher costs as more work is required. Primary recovery requires the least amount of work to extract oil from the reservoir. Consequently, it is also the most profitable.

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[9] These enhanced recovery techniques are discussed in the next section of this chapter.

Raymond and Leffler (2006) break primary recovery down into two stages—natural flow and artificial lift. Under natural flow, the reservoir pressure alone moves the crude from the reservoir, up the pipe, and out of the wellbore. This recovery technique is utilized at the beginning of a well's lifespan when the reservoir pressure is still high. Artificial lift is implemented once the reservoir pressure is no longer sufficient to move the crude to the surface. During this phase, a pump is installed on the well to lift the crude upwards and out of the wellbore.

Because the reservoir pressure and the quantity of the resource extracted share a negative relationship, more effort must be put forth as time passes to make extraction profitable. Raymond and Leffler (2006) center their discussion of secondary recovery around waterflooding. During this phase of extraction, water is injected into the reservoir to "supplement the natural reservoir energy (pressure), to slow production decline…" This method is a form of displacement that is meant to counter the decreasing pressure of the reservoir. Waterflooding has been a widely used method in Wyoming—constrained only by the availability of water.

The purpose of the recovery techniques to this point have been to either utilize reservoir pressure or to counteract the decreasing reservoir pressure. Tertiary recovery aims to make the resource itself easier to extract. The most common form of an enhanced oil recovery technique is CO_2 injection. During this process, carbon dioxide is injected into the reservoir. This "allows more oil to detach itself from the walls of the pores and flow to the producing well" (Raymond & Leffler, 2006). Early on, this technique was tested in Wyoming and has been a popular extraction technique for operators today—constrained only by the availability of CO_2.[10]

As with any mechanical process, setbacks and problems will occur. Raymond and Leffler (2006) list the most common production issues. These include mechanical failures, changes in production characteristics, plugging in the production tubing, and general disappointments resulting from Murphy's Law. Once a problem is detected in a well, the operator must either conduct a workover on the well (i.e., fix or improve the well), keep producing at a lower rate, temporarily cease production, or plug the well completely. If the operator decides that a workover is the best course of action, a portable workover rig is brought to the well site in order to fix the problem and increase the production rate. An operator must be sure that the post-workover revenue will be enough to cover both the cost of the workover as well as the lost revenue due to the production halt during the workover. Figure 6 displays the impacts of the phases of production on reservoir pressure.[11]

[10] For information regarding the sequestration of CO_2 for enhanced oil recovery, see van t' Veld, Mason and Leach (2013).

[11] Unfortunately, my data does not allow me to observe the production technique/phase that a given property is using. However, it is important to explain the kinds of techniques that the RRRP was attempting to incentivize.

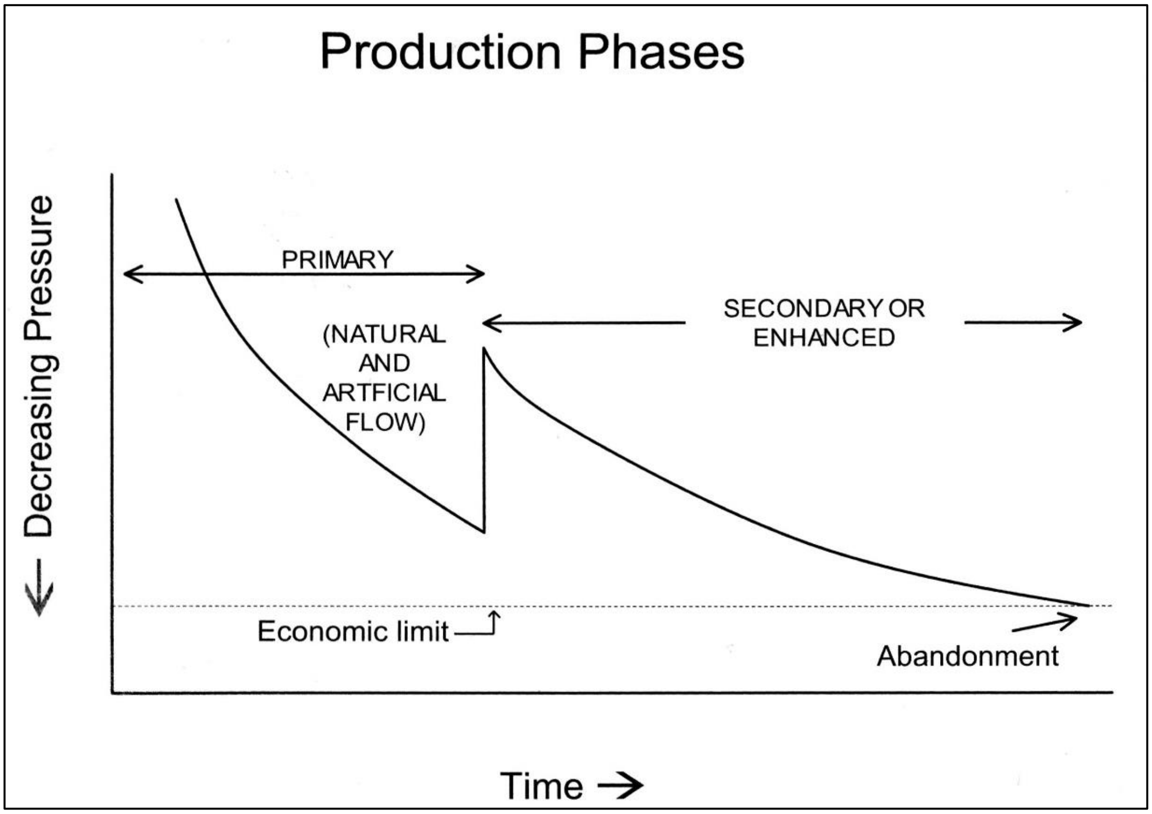

Figure 6: Production Phases

Note: Figure taken from Raymond & Leffler (2006).

THEORY

Figure 7 represents a static representation of a royalty rate on the quantity of oil extracted by an operator facing a linear marginal cost curve. In the absence of a royalty rate, the operator receives an output price of P_0 and produces q_0. Under the imposition of a flat royalty rate, the operator receives an output price of $P_{1-\tau}$ and produces q_τ. During the RRRP, the operator receives output price P_{RRRP} and produces q_{RRRP} barrels. Assuming that a property qualifies for the RRRP, q_{RRRP} will fall somewhere between q_τ and q_0. It is important to note that as quantity approaches zero, the price under the RRRP approaches P_0. The average intensive impact across wells of the RRRP ($\bar{q}$) can be calculated using the following formula:

$$\bar{q} = \frac{1}{n} \times \sum_{i=1}^{n} \Delta q_i$$

in which

$$\Delta q = q_{RRRP} - q_\tau$$

Welfare effects can also be derived from figure 7 for the operators and the federal government. In the time period before the RRRP, operator surplus is equal to area G and federal surplus is equal to area A+C+E. During the RRRP, area E is transferred from federal surplus to operator surplus. Operator surplus also adds area F and federal surplus adds area B+D. During the RRRP, overall surplus increases by area B+D+F. Operator welfare experiences an overall increase in surplus due to the RRRP. Federal surplus may either increase or decrease depending on the relative sizes of areas B+D and E. If area

B+D is larger than area E, the federal government experiences a net gain. However, if area B+D is smaller than area E, the federal government experiences a net loss. The relative sizes of B+D and E depend on the elasticity of marginal cost curve. A more elastic marginal cost curve increases the likelihood that B+D is greater than E. Conversely, a more inelastic marginal cost curve decreases the likelihood that B+D is greater than E.

Figure 8 displays a more extensive representation in which the intensive quantity (bbl/day) is replace by the extensive quantity (wells). By taking the total change in the number of wells producing during the RRRP

$$\Delta Q = Q_{RRRP} - Q_{\tau}$$

you can multiply that number by $\bar{q}$, discussed previously, to achieve an estimated overall impact in the number of barrels produced per day.

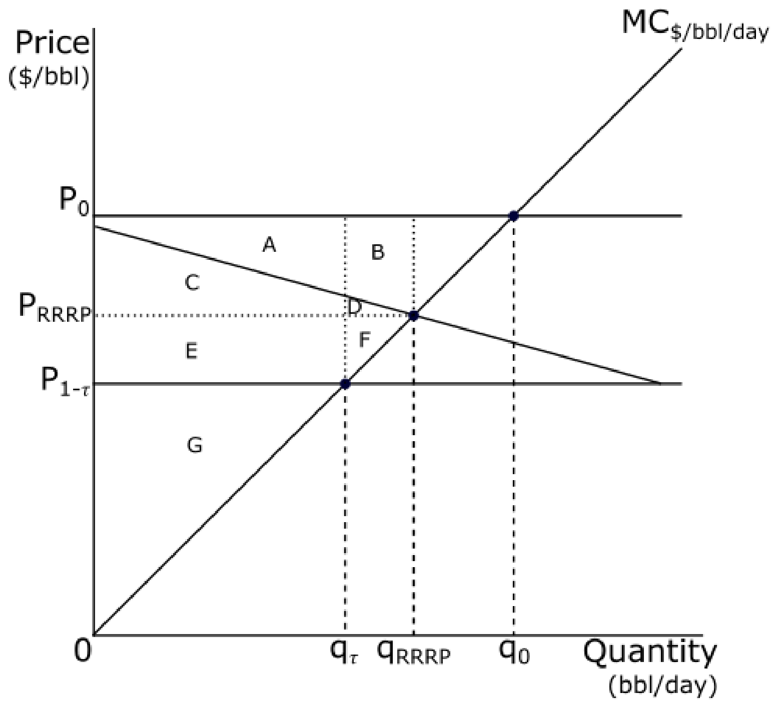

Figure 7: Static Royalty Rate Representation (Intensive)

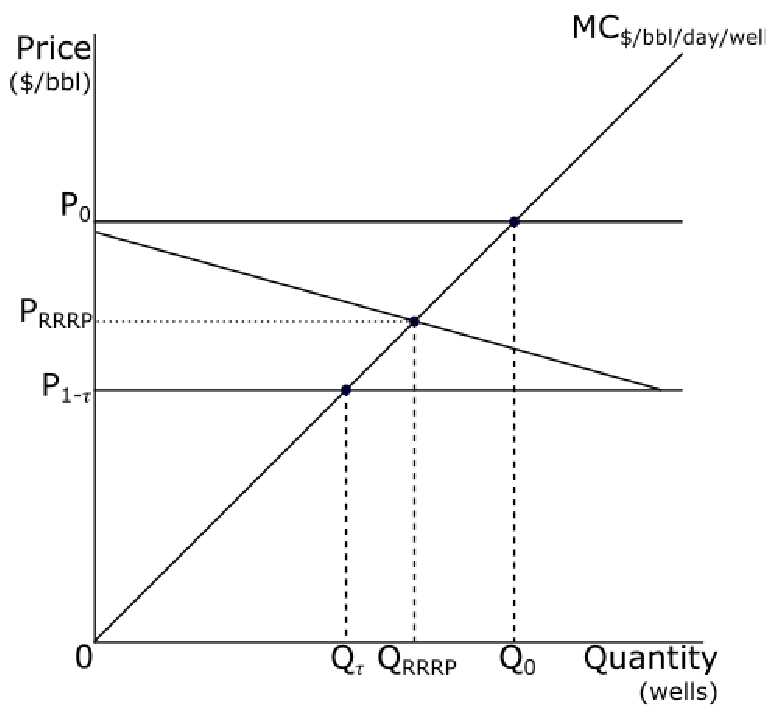

Figure 8: Static Royalty Rate Representation (Extensive)

DATA & METHODOLOGY

Data

The data used for in analysis consists of monthly, well-level production for all federal, state, and private wells in the state of Wyoming from 1980 to 2014. These data were obtained from the Wyoming Oil and Gas Conservation Commission (WOGCC)—a state level government organization that oversees resource extraction in Wyoming. Individual wells are identified by their unique API number.[12] Initially, the dataset contained almost 75,000 individual federal, state, and private wells. Because the royalty rate reduction program only applied to oil and injection wells, wells not classified as such are eliminated. This decreased the number of individual wells in the dataset to approximately 25,000 wells. The data, as reported by the well operator to the WOGCC, contain the number of barrels of oil a given well produced in a given month. It also contains the number of days that the well was active during that month. These two variables are then used to find the average number of barrels of oil extracted per day. *Barrels per Day* (bbl/day), which is in terms of barrels per well per day, is the dependent variable for the intensive margin analysis.

To address the unobserved nature of the stripper oil well property definition, this analysis is conducted on three different spatial levels. The first spatial level made the assumption that each well was located on its own individual property. As these properties are represented by a single point, and do not have an area greater than zero, they are

[12] The API numbering system was established by the American Petroleum Institute and is used as a means of uniquely identifying wells.

referred to as 0 acre properties.[13] The remaining spatial two levels consisted of square properties of increasing size: 0.25 mile × 0.25 mile and 0.5 mile × 0.5 mile properties. These two property levels corresponded to areas equal to 40 and 160 acres. For the remainder of this thesis, these properties will be referred to as 40 acre and 160 acre properties, respectively. Geographic information system (GIS) software was used to group wells together that fall inside the same property boundaries as one another. This was done in order to control for any geographical proximity constraints that operators may have faced in the formation of properties. Two hypothetical examples of a geographical proximity constraint, listed previously, are that the area of a property cannot exceed 100 acres, or the distance between wells on a property cannot exceed 1 mile. Despite not participating in the RRRP, state and private wells were also grouped into properties in the same manner as federal wells to keep the unit of analysis consistent throughout.[14]

According to the guidelines of the RRRP, qualification for the program is based on the average barrels per day produced on the property. It is important to note that if these geographical proximity constraints are nonexistent, two scenarios could occur that would understate the impact of the RRRP. The first scenario, displayed in figure 9, represents a situation in which a stripper well is left out of the RRRP. Wells A, B and C are grouped together on a federal property with dimensions, x miles × x miles. Well A averages 30 bbl/day, well B averages 40 bbl/day, and well C averages 11 bbl/day. Well C

[13] This is done to keep the language consistent throughout the analysis.
[14] It is important to note that federal, state and private properties are independent of one another. Wells of various land types cannot be on the same property. Additionally, as the data do not allow wells to be matched to leases, communitized production is unobserved.

meets the requirements to be considered a stripper well but will not be included in the RRRP because the average bbl/day of the property exceeds 15 bbl/day. The second scenario, displayed in figure 10, represents a situation in which a non-stripper well is included in the RRRP. Wells D, E and F are grouped together on a second federal property with dimensions, x miles × x miles. Well D averages 2 bbl/day, well E averages 3 bbl/day, and well F averages 17 bbl/day. Well F does not meet the requirements for stripper well status but will be included in the RRRP because the average bbl/day of the property is less than 15 bbl/day.

Tables 1 and 2 contain property level production mean values for the intensive and extensive margins, respectively. Figure 11 displays simple mean values for the intensive production margin for each property size differentiating between federal and non-federal properties over three time periods—before the RRRP, during the RRRP, and after the RRRP. The first figure includes all properties. The second includes only stripper properties. And the third includes only non-stripper properties. These figures display decreasing production over each time period for non-federal properties and federal stripper properties, while federal stripper properties display a large increase in production during the RRRP followed by a sharp decrease in the post-RRRP period. It is interesting to note that this impact disappears as the estimated properties get larger.

An active property count variable is created by adding up the number of distinct producing properties.[15] Because production is tracked monthly, this variable exists at the month level. Within a given time period, this variable varies by federal, state, private and

[15] Because properties only enter and exit the data between years, creating a property count variable consisting of only producing properties provides a more accurate variable to use for analysis.

stripper designations—representing six different property count designations for a single time period. *Active Property Count* represents the first dependent variable for the extensive margin. Unfortunately, because this variable does not vary by property, a continuous impact regression cannot be conducted for this dependent variable.

Figure 12 displays simple mean values for the *Active Property Count* variable for each property size, differentiating between federal and non-federal properties over three time periods—before the RRRP, during the RRRP, and after the RRRP. Again, the first, second and third graphs include all properties, stripper properties, and non-stripper properties, respectively. These graphs show an increase in the number of federal stripper properties during the RRRP and then a decrease in the post-RRRP period. This might indicate shut-in wells coming back into production during the program period and then abandonment during the post program period. This could also indicate the drilling of new wells during the program period and then plugging or shutting-in wells during the post program period. Similar to the impacts from figure 11, these impacts also disappear as the properties get larger. It is also important to note that the number of federal non-stripper properties decreases over time.

A second dependent variable for the extensive production margin is created that can be used to analyze both the binary and continuous impacts. This is the *Percentage Stripper* variable, which represents the percentage of wells on a given property that qualify as stripper wells. As the maximum number of wells that lie on a 0 acre property is one, the analyses using this variable are conducted on the 40 and 160 acre properties only.

Figure 13 displays simple mean values for the *Percentage Stripper* variable for the 40 and 160 acre properties, differentiating between federal and non-federal properties over three time periods—before the RRRP, during the RRRP, and after the RRRP. Only one graph is included for this variable as the stripper property distinction is not required for this dependent variable. This graph shows an increase in the percentage of stripper wells on a federal property during the RRRP and then a decrease in the post-RRRP period. It is also important to note that the non-federal portion of the graph displays a steady increase in the percentage of stripper wells on a property between each time period.

Proved crude oil reserve levels for the state of Wyoming (*Reserves*) were obtained from the U.S. Energy Information Administration (EIA).[16] This annual variable is an estimate of the total number of recoverable barrels of crude oil within the state. Unfortunately, this variable cannot be broken down by land ownership. However, the BLM states that the mineral rights on 41.6 million acres of the 62.34 million acres of total land in Wyoming, are federally owned.[17] This equates to almost 67 percent.

Lifting cost data were also provided by EIA.[18] The operating cost variable (*Cost*) initially represents the national average operating cost in a given year for a 10 well lease. This number is then divided by 10 to represent the national average operating cost in a year for a single well. Additionally, this variable is deflated to 2009 dollars using the

---

[16] Link to Wyoming crude oil reserve levels:
https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RCRR01SWY_1&f=A.
[17] Link to BLM publication: http://www.blm.gov/public_land_statistics/pls13/pls2013.pdf.
[18] Link to lifting cost data:
http://www.eia.gov/pub/oil_gas/natural_gas/data_publications/cost_indices_equipment_production/current/coststudy.html.

gross domestic product, implicit price deflator from the Federal Reserve Bank of St. Louis.[19] While not an exact representation of extraction costs for the state of Wyoming, these data are the most trusted and accurate data available. The yearly data are published by the EIA from 1976 to 2009. The missing values for 2010 to 2014 were estimated by regressing cost on both year and year-squared. The year-squared term is included in order to account for a possible non-linear relationship between year and cost. The regression estimated suggests a strong relationship between time and cost with an R-squared equal to 0.92.

The monthly oil price data I included in my dataset were also obtained from the EIA. The price variable is the Wyoming first purchase price (*FPP*).[20] This is a monthly, state specific price. These price data are available for the entire length of my analysis (1980-2014). Like the operating cost variable, this price variable is deflated to 2009 dollars using the same gross domestic product, implicit price deflator from the Federal Reserve Bank of St. Louis. This specific price was chosen over other benchmark prices because it is the first price assigned to a barrel of oil after it exits the wellbore. This price is established before any increases due to transportation costs. Table 3 displays the summary statistics for the previous three control variables—reserves, cost, and price.

The royalty rate variable in this analysis varies by the type of land on which a property is located. The royalty rate for properties on federal land is 12.5 percent for the months before and after the royalty rate reduction program. During the program, the royalty rate is calculated according to the rules of the program using equation 1. The

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[19] Link to GDP: Implicit Price Deflator: https://fred.stlouisfed.org/series/GDPDEF.
[20] Link to Wyoming First Purchase Price Data: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=F004056__3&f=M.

process used to create the royalty rates is identical to the two examples from figures 4 and 5. Royalty rates on state land are set at 16.67 percent.[21] As royalty rates for properties on private land are not published, I rely on the research of Fitzgerald (2014) and Brown et al. (2015)—both of whom estimate private royalty rates for oil, in the state of Wyoming, in recent years to average 15.33 percent. Table 4 lists the mean royalty rate values for all federal properties and federal stripper properties for every property level. Figure 14 displays the mean federal stripper property royalty rate for every property level over time.

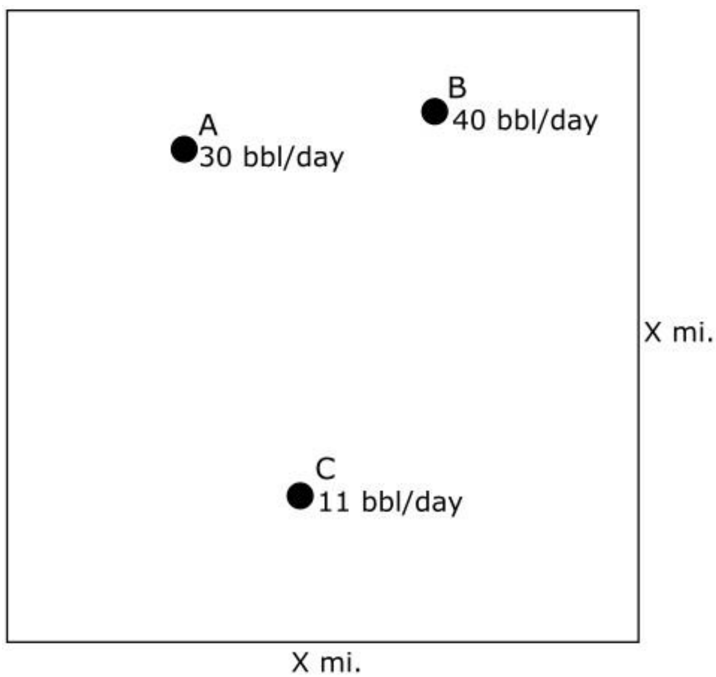

Figure 9: Property Scenario 1 (Exclusion)

[21] It is important to mention that some leases on state land contain a royalty rate of 12.5 percent. Unfortunately, I am unable to match wells to leases. Consequently, all wells on state land are assigned the more recognized 16.67 percent.

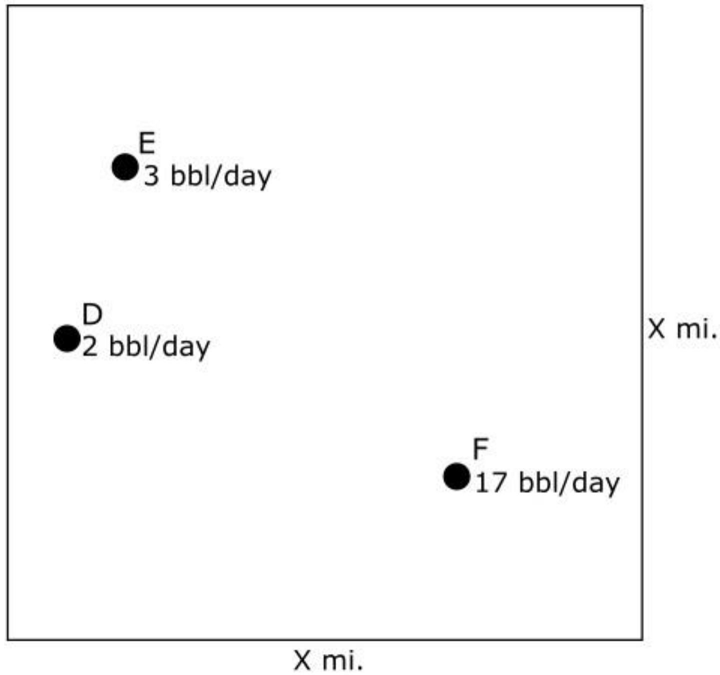

Figure 10: Property Scenario 2 (Inclusion)

Table 1: Property Scenario 2 (Inclusion) : Intensive Production Margin Mean Values

Property	Property BBL/Day	Stripper Property BBL/Day	Federal Property BBL/Day	Federal Stripper Property BBL/Day
0 acre	12.82	3.25	13.19	4.12
	(19.56)	(5.47)	(20.33)	(7.09)
40 acre	12.91	3.19	12.38	3.73
	(18.66)	(5.08)	(17.85)	(5.95)
160 acre	12.08	3.05	10.52	3.21
	(16.81)	(4.63)	(14.58)	(4.84)

Note: Values in terms of barrels per day per well per property (bbl/day/well/property) for every property level. Parentheses indicate mean values across observations with production greater than zero.

Table 2: Extensive Production Margin Mean Values

Property	Number of Properties	Number of Federal Properties	Wells Per Property	Stripper Wells Per Property	Wells Per Federal Property	Stripper Wells Per Federal Property	Wells Per Federal Stripper Property	Percent Stripper
0 acre	24,426	7,969	1	0.77	1	0.76	1	-
40 acre	17,659	4,958	1.30 (2.89)	1.03 (2.45)	1.44 (2.82)	1.14 (2.33)	1.43 (2.87)	69.84
160 acre	12,586	3,034	1.79 (3.83)	1.47 (3.29)	2.28 (4.28)	1.92 (3.67)	2.17 (4.20)	71.22

Note: Parentheses indicate mean values for observations containing more than one well.

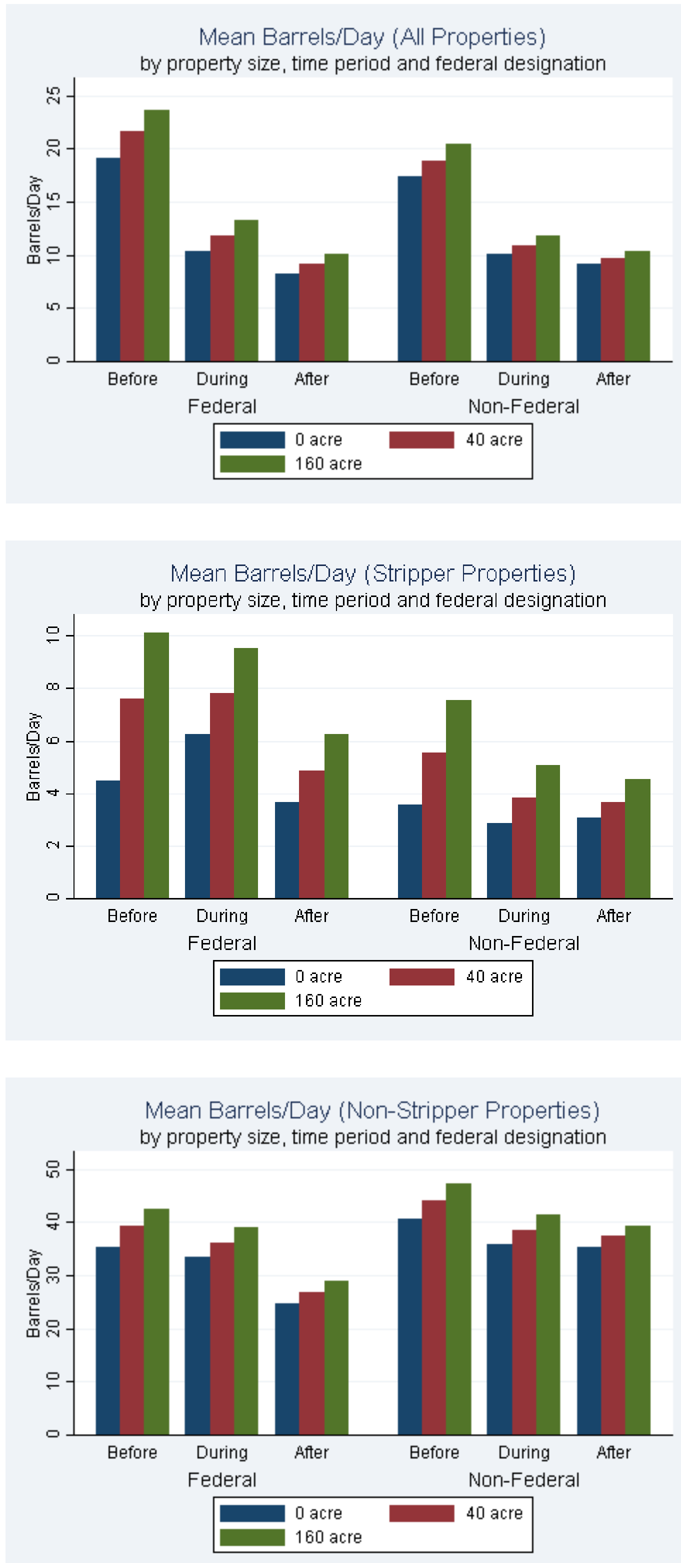

Figure 11: Mean Barrels per Day

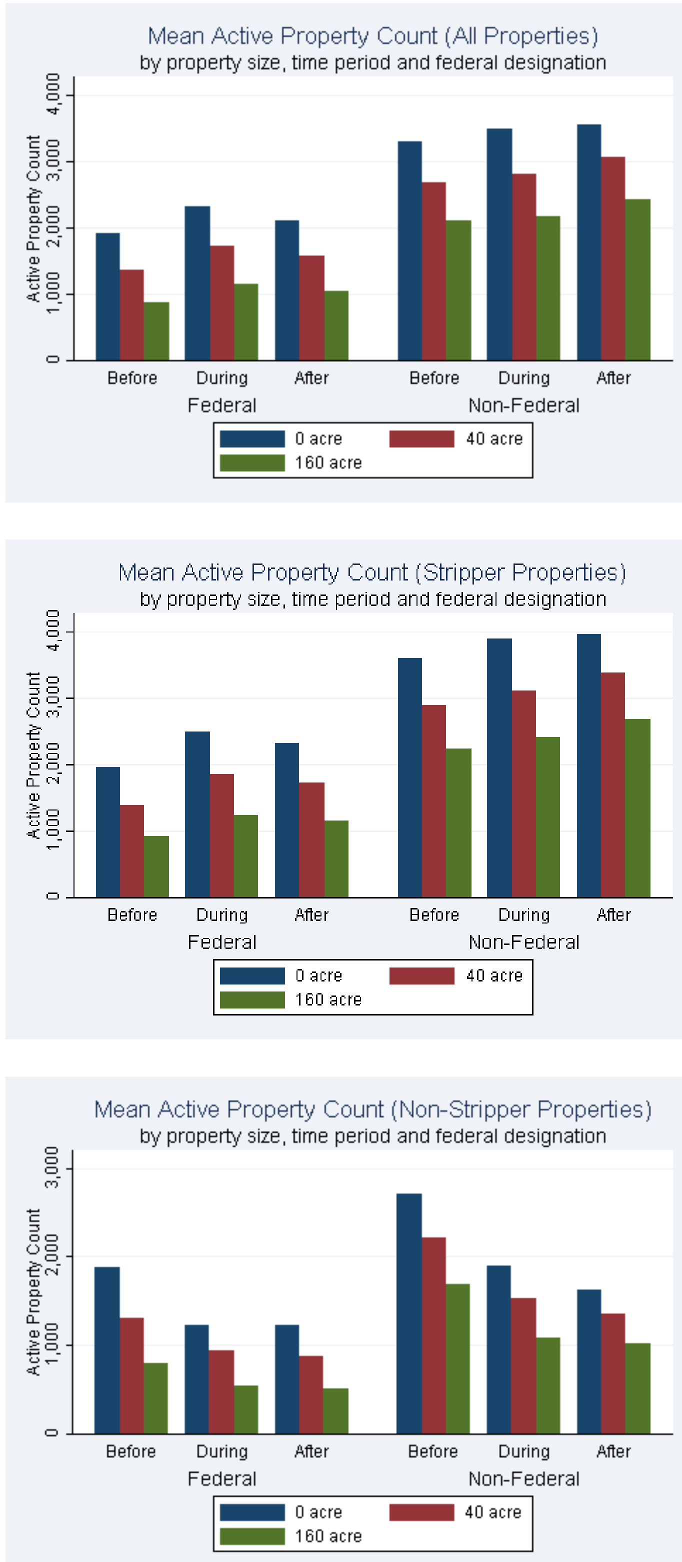

Figure 12: Mean Active Property Count

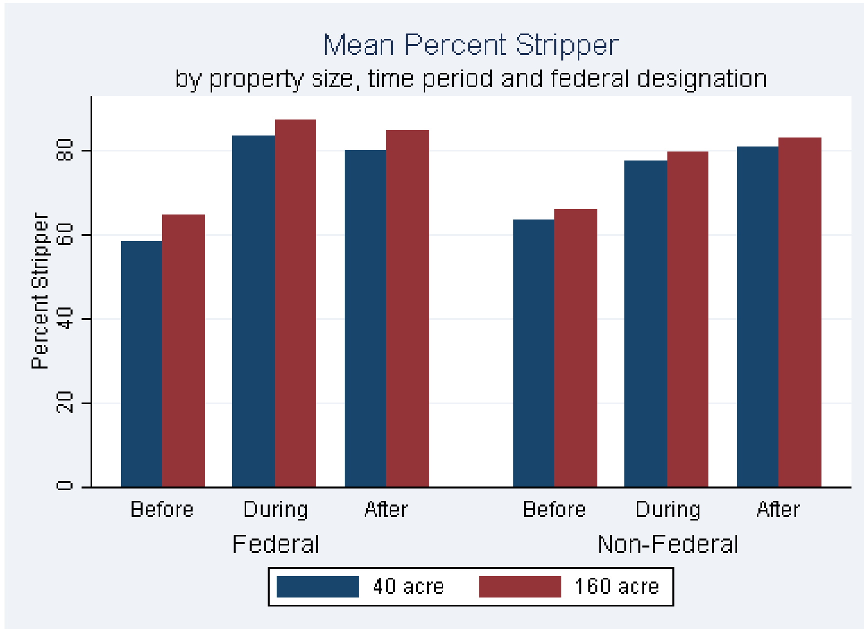

Figure 13: Mean Percentage Stripper

Table 3: Control Variables Summary Statistics

	Level	N	Mean	Std. Dev.	Min	Max
Wyoming Reserves (MMbbl)	Year	35	708.49	144.42	489	957
Operating Cost	Year	35	31,457.83	4,210.04	26,635.1	42,529
Wyoming FPP	Month	420	41.98	22.29	10.27	121.06

Note: Operating Cost and Wyoming FPP deflated to 2009 dollars.

Table 4: Federal RRRP Royalty Rate Mean Values

Property	All Federal Properties	Federal Stripper Properties
0 acre	4.49	3.14
	(6.19)	(4.60)
40 acre	4.74	3.37
	(6.24)	(4.69)
160 acre	4.76	3.45
	(6.12)	(4.62)

Note: Parentheses indicate mean values across observations with production greater than zero.

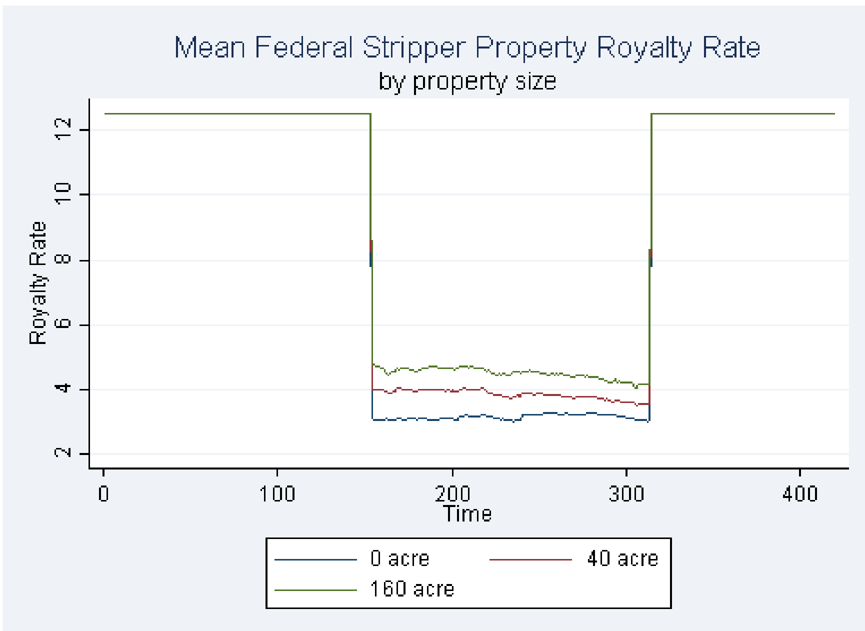

Figure 14: Stripper Oil Property Royalty Rates

Note: Time runs from January 1980 (time=1) to December 2014 (time=420).

Empirical Methodology

Binary Impact

Before analyzing the impact that the magnitudes of the royalty rate reductions have on production, the effect of the existence of the program is estimated. This is done using a fixed effects difference-in-difference-in-difference (triple difference) model and a fixed effects difference-in-difference (double difference) model. These models are used in order to control for unobservable factors. Unobservable factors with regard to stripper properties include changes in extraction technology. Unobservable factors with regard to federal properties include policy changes, other than the RRRP.

Log(Barrels per Day). The first binary empirical model uses *log(Barrels per Day)* as the dependent variable.[22] The following three models are triple difference models containing a time component and two categorical components. The time component is a binary variable equal to one during the life of the program (*RRRP*), which varies by time (*ym*).[23] The first categorical component is a binary variable equal to one if the property is a stripper property (*Stripper*), which varies by property (*p*) and time. The second categorical component is a binary variable equal to one if the property is a federal property (*Federal*), which varies only by property.

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[22] Box-Cox test provided theta values equal to 0.055 (0 acre), 0.078 (40 acre), and 0.078 (160 acre), resulting in the use of a log-level specification. The critical values for these tests are 363.83 (0 acre), 524.18 (40 acre), and 518.87 (160 acre). The Box-Cox test analyzes the normality of a given distribution. Non-normal distributions can be transformed in order to achieve the normality desired for an empirical analysis.

[23] The *ym* designation, representing time, is the interaction between year and month of year.

Equation 2 contains property fixed effects (δ_p), in order to account for differences between properties that are constant over time, as well as three control variables: Wyoming First Purchase Price (*FPP*), Wyoming Oil Reserve Base (*Reserves*) and Operating Cost (*Cost*). Equation 3 omits the three control variables and includes both year (δ_y) and month of year (δ_m) fixed effects along with the property fixed effects. The year fixed effects control for unobserved long-term changes in production. The month of year fixed effects control for unobserved seasonal changes in production. Finally, equation 4 contains month-by-year fixed effects and property fixed effects. The *Federal* indicator has been omitted from equations 2, 3 and 4 because it is perfectly correlated with the property fixed effects. The *RRRP* indicator has been omitted from equation 4 because it is perfectly correlated with the month-by-year fixed effects.

$$Log(Barrels\ per\ Day)_{p,ym} = \beta_0 + \beta_1 Stripper_{p,ym} + \beta_2 RRRP_{ym} + \beta_3 Federal \times Stripper_{p,ym} + \beta_4 RRRP \times Federal_{p,ym} + \beta_5 RRRP \times Stripper_{p,ym} + \beta_6 RRRP \times Stripper \times Federal_{p,ym} + \beta_7 FPP_{ym} + \beta_8 Reserves_y + \beta_9 Cost_y + \delta_p + \mu \qquad (2)$$

$$Log(Barrels\ per\ Day)_{p,ym} = \beta_0 + \beta_1 Stripper_{p,ym} + \beta_2 RRRP_{ym} + \beta_3 Federal \times Stripper_{p,ym} + \beta_4 RRRP \times Federal_{p,ym} + \beta_5 RRRP \times Stripper_{p,ym} + \beta_6 RRRP \times Stripper \times Federal_{p,ym} + \delta_p + \delta_y + \delta_m + \mu \qquad (3)$$

$$Log(Barrels\ per\ Day)_{p,ym} = \beta_0 + \beta_1 Stripper_{p,ym} + \beta_2 Federal \times Stripper_{p,ym} + \beta_3 RRRP \times Federal_{p,ym} + \beta_4 RRRP \times Stripper_{p,ym} + \beta_5 RRRP \times Stripper \times Federal_{p,ym} + \delta_p + \delta_{ym} + \mu \qquad (4)$$

The coefficient of primary interest in equations 2 and 3 (β_6) and equation 4 (β_5) represents the average impact of the program on the production, in barrels per day, of federal stripper properties after netting out the change in means of both non-stripper federal properties and all non-federal properties. These regressions are conducted on all three property levels. The results for equations 2, 3 and 4 are found in table 5.

Active Property Count. The next binary empirical model uses *Active Property Count* as the dependent variable.[24] The following three models are also a triple difference models containing a time component (*RRRP*) and two categorical components (*Federal* & *Stripper*).

Equation 5 contains group fixed effects (δ_g), in order to account for differences between groups that are constant over time, as well as the three control variables: Wyoming First Purchase Price (*FPP*), Wyoming Oil Reserve Base (*Reserves*) and Operating Cost (*Cost*).[25] Equation 6 omits the three control variables and includes both year (δ_y) and month of year (δ_m) fixed effects along with the group fixed effects. Lastly, equation 7 contains month-by-year fixed effects and group fixed effects. The *Federal* indicator has been omitted from equations 5, 6 and 7 because it is perfectly correlated with the group fixed effects. The *RRRP* indicator has been omitted from equation 7 because it is perfectly correlated with the month-by-year fixed effects.

$$Active\ Property\ Count_{g,ym} = \beta_0 + \beta_1 RRRP_{ym} + \beta_2 RRRP \times Federal_{g,ym} + \beta_3 RRRP \times Stripper_{g,ym} + \beta_4 RRRP \times Stripper \times Federal_{g,ym} + \beta_5 FPP_{ym} + \beta_6 Reserves_y + \beta_7 Cost_y + \delta_g + \mu$$

(5)

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[24] Box-Cox Test provided theta values equal to 0.998 (0 acre), 0.879 (40 acre), and 0.713 (160 acre), resulting in the use of a level-level specification. The critical values for these tests are 1,433.16 (0 acre), 1,310.64 (40 acre), and 1,132.43 (160 acre). The Box-Cox test analyzes the normality of a given distribution. Non-normal distributions can be transformed in order to achieve the normality desired for an empirical analysis.

[25] These six groups are: Federal Non-Stripper, Federal Stripper, State Non-Stripper, State Stripper, Private Non-Stripper and Private Stripper.

$$Active\ Property\ Count_{g,ym} = \beta_0 + \beta_1 RRRP_{ym} + \beta_2 RRRP \times Federal_{g,ym} + \beta_3 RRRP \times Stripper_{g,ym} + \beta_4 RRRP \times Stripper \times Federal_{g,ym} + \delta_g + \delta_y + \delta_m + \mu \quad (6)$$

$$Active\ Property\ Count_{g,ym} = \beta_0 + \beta_1 RRRP \times Federal_{g,ym} + \beta_2 RRRP \times Stripper_{g,ym} + \beta_3 RRRP \times Stripper \times Federal_{g,ym} + \delta_g + \delta_{ym} + \mu \quad (7)$$

The coefficient of primary interest in equations 5 and 6 (β_4) and equation 7 (β_3) represents the average impact of the program on the number of producing federal stripper properties after netting out the change in means of both non-stripper federal properties and all non-federal properties. This regression is conducted on all three property levels. Because the properties are unobserved and therefore, estimated, the standard errors resulting from this regression may be larger than the actual standard errors. The results for equations 5, 6, and 7 are found in table 6.

Percent Stripper. The last binary empirical model uses *Percent Stripper* as the dependent variable.[26] Two additional binary impact regression models are run using the percent stripper dependent variable. This method takes on a double difference approach containing a time component (*RRRP*) and a categorical component (*Federal*).

Equation 8 contains property fixed effects (δ_p), in order to account for differences between properties that are constant over time, as well as three control variables: Wyoming First Purchase Price (*FPP*), Wyoming Oil Reserve Base (*Reserves*) and Operating Cost (*Cost*). Equation 9 omits the three control variables and includes both

[26] Box-Cox Test provided theta values equal to 0.290 (0 acre), 0.370 (40 acre), and 0.479 (160 acre), resulting in the use of a level-level specification. The critical values for these tests are 1,324.11 (0 acre), 1,648.41 (40 acre), and 1,965.88 (160 acre). The Box-Cox test analyzes the normality of a given distribution. Non-normal distributions can be transformed in order to achieve the normality desired for an empirical analysis.

year (δ_y) and month of year (δ_m) fixed effects along with the property fixed effects. Finally, equation 10 contains month-by-year fixed effects and property fixed effects. The *Federal* indicator has been omitted from equations 8, 9 and 10 because it is perfectly correlated with the property fixed effects. The *RRRP* indicator has been omitted from equation 10 because it is perfectly correlated with the month-by-year fixed effects.

$$Percent\ Stripper_{p,ym} = \beta_0 + \beta_1 RRRP_{ym} + \beta_2 RRRP \times Federal_{p,ym} + \beta_3 FPP_{ym} + \beta_4 Reserves_y + \beta_5 Cost_y + \delta_p + \mu \quad (8)$$

$$Percent\ Stripper_{p,ym} = \beta_0 + \beta_1 RRRP_{ym} + \beta_2 RRRP \times Federal_{p,ym} + \delta_p + \delta_y + \delta_m + \mu \quad (9)$$

$$Percent\ Stripper_{p,ym} = \beta_0 + \beta_1 RRRP \times Federal_{p,ym} + \delta_p + \delta_{ym} + \mu \quad (10)$$

The coefficient of primary interest in equations 8 and 9 (β_2) and equation 10 (β_1) represents the average impact of the program on the percentage of wells on a federal property that qualify as stripper wells after netting out the change in means of all non-federal properties. This regression is conducted on property levels with an area greater than zero (i.e. 0 acre properties are omitted from this regression). The results for equations 8, 9, and 10 are found in table 7.

These specifications are useful because they provide a broad measure for the impact of the existence of the RRRP on the intensive and extensive production margins of federal stripper oil production.

Continuous Impact

The next step is to take into account the magnitudes of the royalty rate reductions and their impacts on production. For these models, the fixed effects double- and triple-difference methods are replaced by a more traditional multiple regression model.

Log(Barrels per Day). The first continuous empirical model uses *log(Barrels per Day)* as the dependent variable. These multiple regression models interact a discrete royalty rate variable (*Royalty Rate*), that varies by property (*p*) and time (*ym*), with both the stripper property binary variable and the federal property binary variable.

Equation 11 contains property fixed effects (δ_p) as well as the three control variables: Wyoming First Purchase Price (*FPP*), Wyoming Oil Reserve Base (*Reserves*) and Operating Cost (*Cost*). Equation 12 omits the three control variables and includes both year (δ_y) and month of year (δ_m) fixed effects along with the property fixed effects. Finally, Equation 13 contains month-by-year fixed effects and property fixed effects.

$$Log(Barrels\ per\ Day)_{p,ym} = \beta_0 + \beta_1 Royalty\ Rate \times Stripper \times Federal_{p,ym} + \beta_2 FPP_{ym} + \beta_3 Reserves_y + \beta_4 Cost_y + \delta_p + \mu \quad (11)$$

$$Log(Barrels\ per\ Day)_{p,ym} = \beta_0 + \beta_1 Royalty\ Rate \times Stripper \times Federal_{p,ym} + \delta_p + \delta_y + \delta_m + \mu \quad (12)$$

$$Log(Barrels\ per\ Day)_{p,ym} = \beta_0 + \beta_1 Royalty\ Rate \times Stripper \times Federal_{p,ym} + \delta_p + \delta_{ym} + \mu \quad (13)$$

These regressions are conducted on all three property levels. The results for equations 11, 12, and 13 are found in table 8.

<u>Percent Stripper</u>. The last continuous empirical model uses *Percent Stripper* as the dependent variable. These multiple regression models interact a discrete royalty rate variable (*Royalty Rate*), which varies by property (*p*) and time (*ym*), with federal property binary variable.

Equation 14 contains property fixed effects (δ_p) as well as the three control variables: Wyoming First Purchase Price (*FPP*), Wyoming Oil Reserve Base (*Reserves*) and Operating Cost (*Cost*). Equation 15 omits the three control variables and includes both year (δ_y) and month of year (δ_m) fixed effects along with the property fixed effects. Lastly, equation 16 contains month-by-year fixed effects and property fixed effects.

$$Percent\ Stripper_{p,ym} = \beta_0 + \beta_1 Royalty\ Rate \times Federal_{p,ym} + \beta_2 FPP_{ym} + \beta_3 Reserves_y + \beta_4 Cost_y + \delta_p + \mu \qquad (14)$$

$$Percent\ Stripper_{p,ym} = \beta_0 + \beta_1 Royalty\ Rate \times Federal_{p,ym} + \delta_p + \delta_y + \delta_m + \mu \qquad (15)$$

$$Percent\ Stripper_{p,ym} = \beta_0 + \beta_1 Royalty\ Rate \times Federal_{p,ym} + \delta_p + \delta_{ym} + \mu \qquad (16)$$

These regressions are conducted on property levels with an area greater than zero (i.e. 0 acre properties are omitted from this regression). The results for equations 14, 15, and 16 are found in table 9. The royalty rates associated with private and state wells are coded as a flat 15.33 and 16.67 percent, respectively.

These specifications are useful because they provide a more detailed measure of the impact of the RRRP than the binary specifications by introducing the magnitudes of the royalty rate reductions. While the binary results provide an average impact of the program, the continuous results provide the average impact of the program given a one percentage point decrease in the royalty rate. These results would be more pertinent to policy analysis and future policy planning because they give policymakers an insight into the responsiveness of operators to the slope of the royalty rate schedule implicit in the RRRP. Any future royalty rate reduction programs may need a steeper or flatter royalty rate schedule.

It is important to note that, because the properties in this thesis are estimated, the standard errors associated with the regressions may be inflated. This would deflate the significance of the results.

RESULTS

Binary Impact

Log(Barrels per Day)

Table 5 displays the results for the binary impact of the RRRP on the intensive production margin, *log(barrels per day)* for each well. It is important to note that, because this first specification is represented by a semi-logarithmic equation containing binary variables, the coefficients for this specification need to be transformed to obtain their true values. The proper transformation is $e^{\beta} - 1$. The percentage effect is then represented by $\left(e^{\beta} - 1\right) \times 100$.[27] The transformed coefficients, which will be used for the remainder of this analysis, can be found in appendix B.

The first specification (equation 2 on page 45), which includes property fixed effects and other time-varying controls, is displayed in columns 1-3 for a range of estimated property sizes. As mentioned previously, the *Federal* indicator is omitted from these specifications because it is perfectly correlated with the property fixed effects. The coefficients for the *Stripper* binary variable are negative, as expected. The coefficients for the *RRRP* binary variable are insignificant and near-zero in magnitude.

No predictions were made for the three first-order interaction variables. The coefficients for *RRRP*×*Federal* and *RRRP*×*Stripper* are consistent across property size. The coefficients for *Federal*×*Stripper* are consistent for the 0 and 40 acre property level, but the coefficient changes sign at the 160 acre property level. This may signal the

[27] For more information on the proper interpretation of dummy variables in semi-logarithmic equations, see Halvorsen & Palmquist (1980).

inclusion of high-producing wells on these larger stripper properties, or it could reflect statistical noise introduced by the manner in which properties were estimated. The estimated properties include the maximum number of wells in a given acreage.

The coefficients for the second-order interaction variable, *RRRP×Stripper×Federal*, provide estimates of the impact of the RRRP on targeted federal stripper properties. If the program has an effect, we would expect it to be strongest for this group. The magnitudes are large relative to the previous five coefficients, positive in sign, and statistically significant. These effects persist across the three property sizes—ranging from 52 to 67 percent. That suggests that the RRRP achieved its intended effects.

The results for the second specification (equation 3 on page 45), containing property, month-of-year, and year fixed effects, found in columns 4-6, are similar to those from the first specification. The largest difference between the first and second specification is in the coefficients for the *RRRP* variable. Despite still being small in magnitude, these coefficients are now statistically significant. The estimated coefficient on the second-order interaction variable, *RRRP×Stripper×Federal*, for the second specification is slightly higher in magnitude and still highly significant—ranging from 58 to 72 percent.

The third specification (equation 4 on page 45), contains property and month-by-year fixed effects—the most specific controls for time-varying unobservables. These results are reported in columns 7-9. The *RRRP* binary variable is omitted from this specification because it is perfectly correlated with the month-by-year fixed effects.

Therefore, the impact of the RRRP can only be identified through the first- and second-order interactions. Relative to the results for the previous two specifications, the coefficients are larger for all included variables. I attribute this to the omission of the *RRRP* variable as the impact previously attributed to the RRRP is now distributed amongst the remaining variables and the month-by-year fixed effects.

The marginal effects of each specification are reported in table 6. These marginal effects are calculated using the Halvorsen & Palmquist (1980) transformed coefficients (table B1). These coefficients are used, as opposed to the uncorrected coefficient values, because it is important to undo the log transformation in order to obtain the correct interpretation. The average marginal effects reflect the marginal impact of the RRRP on non-federal, non-stripper properties.[28] The federal stripper marginal effects reflect the marginal impact of the RRRP on federal stripper properties.[29]

In the first panel, the first specification shows statistically insignificant program effects across all types of properties. The marginal impacts for federal stripper properties, however, display positive and statistically significant marginal impacts—ranging from a 32 to 38 percent increase on the intensive production margin. The marginal impacts for the second specification display relatively small, statistically significant average marginal impacts—ranging from about 9 to 11 percent. The marginal impacts for federal stripper properties decrease in magnitude, relative to the first specification—ranging from about

[28] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 2, 3 and 4) with respect to *RRRP*, given that the federal and stripper binary variables both equal 0.
[29] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 2, 3 and 4) with respect to *RRRP*, given that the federal and stripper binary variables both equal 1.

35 to 41 percent. These marginal effects confirm the intuition from the coefficient estimates that the RRRP had intended impacts on the intensive margin.

Because the *RRRP* variable is omitted from the month-by-year specification, the average impact of the RRRP across all groups is not identified. However, the marginal impact of the RRRP for federal stripper properties is statistically insignificant. This may be attributed to the month-by-year fixed effects taking on a large portion of the temporal effect of the program that is of interest.

To assess the responsiveness of production to the RRRP, the marginal effects are used to construct intensive production effects with respect to changes in the royalty rate. These arc elasticities, displayed in table 7, are calculated by dividing the marginal impact of the RRRP on *log(barrels per day)* by the average percent change in the royalty rate.[30] This process is shown in the following equation:

$$\frac{\frac{\partial(Log\frac{BBL}{Day})}{\partial(RRRP)}}{\%\Delta Royalty\ Rate} = \frac{Marginal\ Effects\ of\ RRRP\ on\ Log(\frac{BBL}{Day})}{\%\Delta Royalty\ Rate}$$

These elasticities indicate the impact on production of a one percent change in the royalty rate —not a one percentage point change in the royalty rate. Production is inelastic with respect to changes in the royalty rate. The elasticity measure from column 1 indicates that a 1 percent decrease in the royalty rate leads to a 0.561 percent increase in production. Because a 1 percentage point reduction in the royalty rate reflects an 8 percent decrease in the royalty rate, a one percentage point decrease in the royalty rate (i.e., going from 12.5 to 11.5) results in about a 4.5 percent increase in production. The 0

[30] The 0, 40 and 160 acre federal stripper properties experienced 63.2, 62.5 and 63 percent decreases in the royalty rate during the RRRP, respectively.

acre federal stripper properties averaged a royalty rate of 4.6 percent during the RRRP—a decrease of 7.9 percentage points. This equates to about a 35.5 percent increase in production.

In the all three specifications, the elasticities display the largest magnitude at the 40 acre property level. Estimating the properties may contribute to this because high-producing wells may not actually be on these properties. A second explanation could be operators include high-producing wells on their stripper properties in an attempt to decrease the royalty for those wells. Because the exact allocation of wells to properties is not known, a test between these alternative explanations is not feasible.

Active Property Count

Table 8 displays the results for the binary impact of the RRRP on the extensive production margin, *Active Property Count*. The first specification (equation 5 on page 46), which includes group fixed effects and other time-varying controls, is displayed in columns 1-3 for three estimated property sizes. As mentioned previously, the *Federal*, *Stripper*, and *Federal×Stripper* indicators are omitted from these specifications because they are perfectly correlated with the group fixed effects. The coefficients for the *RRRP* binary variable are significant and negative. No predictions were made for this variable.

Again, no predictions were made for the two first order interaction variables. The coefficients for *RRRP×Federal* are negative and significant across property size, while the coefficients for *RRRP×Stripper* are positive and significant across property size. The coefficients for the previous two variables decrease in magnitude as the property size increases.

The coefficients for the second-order interaction variable, *RRRP×Stripper×Federal*, provide estimates of the impact for the targeted federal stripper properties. If the RRRP has an effect, we would expect it to be strongest for this group as operators resume production on shut-in wells that were previously economically unprofitable. The magnitudes are much larger relative to the previous three coefficients, positive in sign, and statistically significant. These effects persist across the three property sizes—ranging from about 721 to 334 additional producing properties. These magnitudes decrease as the property size increases. This makes sense because as the size of the property increases, the total number of properties decreases given the fixed boundaries of the state of Wyoming.

The results for the second specification (equation 6 on page 46), containing group, month-of-year, and year fixed effects, found in columns 4-6, are similar to those from the previous specification. The estimated coefficient of the second-order interaction variable, *RRRP×Stripper×Federal*, for the second specification is nearly identical to the first specification—ranging from about 721 to 334 additional producing properties.

The third specification (equation 7 on page 47), contains group and month-by-year fixed effects. These results are reported in columns 7-9. The RRRP binary variable is omitted from this specification because it is perfectly correlated with the month-by-year fixed effects. Therefore, the impact of the RRRP can only be identified through the first- and second-order interactions. Similar to the results of *log(barrels per day)*, the coefficients are larger for all included variables, relative to the results for the previous two specifications. I attribute this to the lack of the *RRRP* variable as the impact previously attributed to the RRRP is now distributed among the remaining variables and the month-by-year fixed effects.

The marginal effects of each specification are reported in table 6. The average marginal effects reflect the marginal impact of the RRRP on non-federal, non-stripper properties.[31] The federal stripper marginal effects reflect the marginal impact of the RRRP on federal stripper properties.[32]

The first specification shows a negative, statistically significant impact for the average marginal effect of the RRRP across all types of properties. The marginal impacts for federal stripper properties, however, display positive, statistically significant impacts—ranging from about a 541 to 280 property increase on the extensive production margin. Again, the marginal impact of the RRRP on *Active Property Count* decreases as the size of the property increases. The average marginal impacts for the second specification display slightly smaller, but still negative and significant impacts. These range from about 170 to 133 fewer producing properties. The marginal impacts for federal stripper properties decrease in magnitude across specifications for the 0 acre properties and increase in magnitude for the 40 and 160 acre properties, relative to the first specification. These marginal effects confirm the intuition from the coefficient estimates that the RRRP had real intended impacts on the extensive margin.

Because the *RRRP* variable is omitted from the third specification, the average impact of the RRRP across all groups is not identified. For federal stripper properties, the

[31] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 5, 6 and 7) with respect to *RRRP*, given that the federal and stripper binary variables both equal 0.
[32] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 5, 6 and 7) with respect to *RRRP*, given that the federal and stripper binary variables both equal 1.

marginal impact of the RRRP is positive and statistically significant across all property levels. The magnitudes of these impacts are smaller, relative to the marginal impacts of the first and second specifications—ranging from 446 to 258 property increases.

To assess the responsiveness of production on the extensive margin, elasticities are calculated. These arc elasticities, displayed in table 7, are calculated by first dividing the marginal impact of the RRRP on *Active Property Count* by the average of *Active Property Count* to get the estimated percent change in the *Active Property Count* variable.[33] This value is then divided by the percent change in the royalty rate.[34] This process is shown in the following equation:

$$\frac{\frac{\Delta Active\ Property\ Count}{Active\ Property\ Count}}{\%\Delta Royalty\ Rate} = \frac{\frac{Marginal\ Effects\ of\ RRRP\ on\ Active\ Property\ Count}{Active\ Property\ Count}}{\%\Delta Royalty\ Rate}$$

These elasticities indicate the impact on the active property count of a 1 percent change in the royalty rate—not a 1 percentage point change in the royalty rate. The active property count is inelastic with respect to changes in the royalty rate. But these are smaller than the intensive elasticities. Because of this, we would expect to see a larger impact on the intensive margin. The elasticity measure from column 1 indicates that a 1 percent decrease in the royalty rate leads to a 0.372 percent increase in the active property count. Because a 1 percentage point reduction in the royalty rate reflects an 8 percent decrease in royalty, a one percentage point decrease in the royalty rate (i.e., going from 12.5 to 11.5) results in about a 3 percent increase in the active property count. The 0 acre

[33] The *Active Property Count* average is 2,302.506, 1,666.574 and 1,121.573 for the 0, 40 and 160 acre properties, respectively.

[34] The 0, 40 and 160 acre federal stripper properties experienced 63.2, 62.5 and 63 percent decreases in the royalty rate during the RRRP, respectively.

properties averaged a royalty rate of 4.6 percent during the RRRP—a decrease of 7.9 percentage points. This implies about a 24 percent increase in the active property count.

The elasticities remain consistent across property sizes and specifications. However, the third specification does display slightly smaller magnitudes than the first and second specifications. This is because, as stated previously, the month-by-year fixed effects may be taking on a large portion of the temporal effect of the RRRP that is of interest.

Percent Stripper

Table 9 displays the results for the binary impact of the RRRP on a second extensive production margin, *Percent Stripper* for each property. The first specification (equation 8 on page 48), which includes controls and property fixed effects, is displayed in columns 1 and 2 for a range of estimated property sizes. As mentioned previously, the *Federal* indicator is omitted from these specifications because it is perfectly correlated with the property fixed effects. The coefficients for the *RRRP* binary variable are negative and significant. Again, no predictions were made for this variable.

The coefficients for the first-order interactions variable, *RRRP*×*Federal*, focus on the impact for federal properties. If the RRRP has an effect, we would expect it to be strongest for this group. The magnitudes are large relative to the previous coefficient, positive in sign, and statistically significant. These effects persist across the two property sizes—ranging from about 9 to 11 percentage points. Again, these regressions are only run on properties with areas greater than 0 (i.e., 40 and 160 acre properties). This suggests that the RRRP has achieved its intended effects.

The results for the second specification (equation 9 on page 48), containing property, month-of-year, and year fixed effects, found in columns 3 and 4, are similar to those from the first specification. However, these coefficients are roughly the same in magnitude—ranging from about 9 to 10 percentage points for federal properties.

The third specification (equation 10 on page 48), contains property and month-by-year fixed effects. These results are reported in columns 5 and 6. The *RRRP* binary variable is omitted from this specification because it is perfectly correlated with the month-by-year fixed effects. Therefore, the impact of the RRRP can only be identified through the first-order interaction variable. Relative to the results of the first two specifications, the coefficients for the third specification are nearly twice as large—ranging from about 15 to 16 percentage points.

The marginal effects of each specification are reported in table 6. The average marginal effects reflect the marginal impact of the RRRP on non-federal, non-stripper properties.[35] The federal stripper marginal effects reflect the marginal impact of the RRRP on federal stripper properties.[36]

The first specification shows negative, moderately significant impacts for the average marginal effect of the RRRP across all property types. The marginal impacts for federal properties, however, are positive and statistically significant—ranging from about 6 to 8 percentage points. The marginal impacts for the second specification display slightly smaller, significant average marginal impacts. The marginal impacts for federal

[35] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 8, 9 and 10) with respect to *RRRP*, given that the federal and stripper binary variables both equal 0.
[36] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 8, 9 and 10) with respect to *RRRP*, given that the federal and stripper binary variables both equal 1.

properties increase in magnitude, relative to the first specification—ranging from about 7 to 8 percentage points. These marginal effects confirm the intuition from the coefficient estimates that the RRRP had real intended impacts on this extensive margin.

Because the *RRRP* variable is omitted from the month-by-year specification, the average impact of the RRRP across all groups is not identified. Because of this, the marginal impact of the RRRP on federal properties is identical to the regression coefficients.

Table 5: Estimated impact of the RRRP on Log(Barrels per Day) (Binary Regression).

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Stripper	-1.731*** (0.057)	-1.864*** (0.055)	-1.858*** (0.051)	-1.542*** (0.034)	-1.697*** (0.033)	-1.673*** (0.031)	-1.996*** (0.045)	-2.068*** (0.042)	-2.055*** (0.039)
RRRP	0.103 (0.070)	0.053 (0.064)	0.052 (0.063)	0.107*** (0.032)	0.083*** (0.031)	0.089*** (0.031)			
Federal x Stripper	-0.088*** (0.023)	-0.071*** (0.025)	0.033 (0.021)	-0.112*** (0.025)	-0.087*** (0.026)	0.021 (0.020)	-0.149*** (0.019)	-0.138*** (0.020)	-0.033** (0.016)
RRRP x Federal	-0.272*** (0.021)	-0.182*** (0.020)	-0.068*** (0.020)	-0.306*** (0.021)	-0.213*** (0.020)	-0.108*** (0.018)	-0.425*** (0.033)	-0.372*** (0.029)	-0.262*** (0.028)
RRRP x Stripper	-0.180*** (0.045)	-0.193*** (0.042)	-0.204*** (0.041)	-0.206*** (0.038)	-0.219*** (0.035)	-0.245*** (0.034)	-0.280*** (0.043)	-0.337*** (0.038)	-0.358*** (0.038)
RRRP x Stripper x Federal	0.500*** (0.025)	0.513*** (0.024)	0.419*** (0.023)	0.539*** (0.026)	0.540*** (0.023)	0.457*** (0.022)	0.672*** (0.037)	0.731*** (0.033)	0.635*** (0.032)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.160	0.186	0.188	0.131	0.164	0.167	0.201	0.215	0.215
N	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table 6: Marginal Impacts of the RRRP (Binary)

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Log(Barrels per Day)									
Average	0.108	0.054	0.053	0.113***	0.087***	0.093***			
Federal Stripper	0.354***	0.383***	0.324***	0.377***	0.414***	0.353***	0.368	0.480	0.356
Active Property Count									
Average	-180.905***	-203.230***	-157.182***	-139.850***	-170.125***	-132.592***			
Federal Stripper	541.364***	430.222***	279.626***	517.889***	463.327***	304.216***	446.174***	406.494***	257.812***
Percent Stripper									
Average		-3.092**	-3.284**		-1.920**	-1.659**			
Federal		7.575***	5.936***		8.064***	7.066***		16.320***	15.041***

Notes: Average marginal impacts represent non-federal, non-stripper properties. Federal stripper marginal impacts represent federal stripper properties. Federal marginal impacts represent federal properties.

Table 7: Elasticities of the RRRP (Binary)

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Log(Barrels per Day)									
Federal Stripper	-0.561	-0.612	-0.514	-0.597	-0.662	-0.560	-0.582	-0.769	-0.564
Active Property Count									
Federal Stripper	-0.372	-0.413	-0.395	-0.356	-0.445	-0.430	-0.307	-0.390	-0.365

Notes: Elasticities represent a percent change in the dependent variable given a one percent change in the royalty rate.

Table 8: Estimated impact of the RRRP on Active Property Count (Binary Regression)

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RRRP	-180.905***	-203.230***	-157.182***	-139.850***	-170.125***	-132.592***			
	(20.284)	(26.230)	(20.828)	(20.353)	(26.312)	(20.018)			
RRRP x Federal	-357.662***	-252.031***	-108.613***	-357.662***	-252.031***	-108.613***	-638.757***	-478.989***	-287.609***
	(13.078)	(8.085)	(5.919)	(13.191)	(8.154)	(5.969)	(39.874)	(28.229)	(17.389)
RRRP x Stripper	358.824***	290.560***	211.456***	294.294***	291.280***	211.718***	82.729***	63.876**	32.529
	(39.666)	(49.662)	(39.289)	(36.704)	(50.218)	(39.685)	(17.516)	(25.923)	(20.322)
RRRP x Stripper x Federal	721.107***	594.923***	333.965***	721.107***	594.203***	333.703***	1002.202***	821.607***	512.892***
	(28.368)	(22.212)	(15.790)	(28.611)	(22.394)	(15.961)	(51.004)	(36.251)	(20.152)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean Active Property Count for Federal Strippers RRRP=0	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32
R^2	0.114	0.098	0.078	0.096	0.098	0.078	0.071	0.063	0.049
N	2,487	2,517	2,519	2,487	2,517	2,519	2,487	2,517	2,519

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table 9: Estimated impact of the RRRP on Percentage Stripper (Binary Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
RRRP	-3.092** (1.353)	-3.284** (1.404)	-1.920** (0.835)	-1.659** (0.805)		
RRRP x Federal	10.667*** (0.335)	9.220*** (0.266)	9.984*** (0.341)	8.725*** (0.264)	16.320*** (1.169)	15.041*** (1.144)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.041	0.042	0.087	0.093	0.007	0.008
N	3,320,651	2,507,921	3,320,651	2,507,921	3,320,651	2,507,921

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal properties outside of the RRRP.

<u>Continuous</u>

<u>Log(Barrels per Day)</u>

Table 10 displays the results for the continuous impact of the RRRP on the intensive production margin, *log(barrels per day)* for each well. The first specification (equation 11 on page 49), which includes property fixed effects and other time-varying controls, is displayed in columns 1-3 for a range of estimated property sizes. The coefficients for the *Royalty Rate*×*Stripper*×*Federal* variable are negative and significant—ranging from -4.8 to -5.7 percent.

The results for the second specification (equation 12 on page 49), containing property, month-of-year, and year fixed effects, found in columns 4-6, are similar to those from the first specification. The coefficients for the *Royalty Rate×Stripper×Federal* are negative and significant—ranging from -3.5 to -4.6 percent. Overall, these coefficients are smaller in magnitude than the coefficients from the first specification.

The results from the third specification (equation 13 on page 49), contains property and month-by-year fixed effects—the most specific controls for time-varying unobservables. These results are reported in columns 7-9. These coefficients mirror those of the previous two specifications in terms of significance and sign. These coefficients fall in the middle of the first and second specification, in terms of magnitude—ranging from -4.2 to -5.1 percent.

The marginal effects of all specifications are reported in table 11.[37] The marginal impacts across all property types are equal to the *Royalty Rate×Stripper×Federal* coefficient for each specification.

To assess the responsiveness of production to changes in the royalty rate, the marginal effects are used to construct intensive production effects with respect to changes in the royalty rate. These arc elasticities, displayed in table 12, are calculated by dividing the marginal impact of a change in the royalty rate on *log(barrels per day)* by the average percent change in the royalty rate, in absolute value.[38] The absolute value of the average percent change in the royalty rate is used because, unlike the binary regressions, the direction of the change in the royalty rate is taken into account in the continuous

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[37] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 11, 12 and 13) with respect to *Royalty Rate*, given that the federal and stripper binary variables both equal 1.

[38] The 0, 40 and 160 acre federal stripper properties experienced 63.2, 62.5 and 63 percent decreases in the royalty rate during the RRRP, respectively.

regression. Consequently, it is reflected in the marginal impacts. Not using the absolute value would be redundant and would incorrectly change the sign of the elasticity. This process is shown in the following equation:

$$\frac{\frac{\partial(Log\frac{BBL}{Day})}{\partial(Royalty\ Rate)}}{|\%\Delta Royalty\ Rate|} = \frac{Marginal\ Effects\ of\ Royalty\ Rate\ on\ BBL/Day}{|\%\Delta Royalty\ Rate|}$$

These elasticities indicate the impact on production of a 1 percent change in the royalty rate—not a 1 percentage point change in the royalty rate. Production is inelastic with respect to changes in the royalty rate. The elasticity measure from column 1 indicates that a 1 percent decrease in the royalty rate leads to a 0.076 percent increase in production. Because a 1 percentage point reduction in the royalty rate reflects an 8 percent decrease in the royalty rate, a one percentage point decrease in the royalty rate (i.e., going from 12.5 to 11.5) results in about a 0.61 percent increase in production. The 0 acre federal stripper properties averaged a royalty rate of 4.6 percent during the RRRP—a decrease of 7.9 percentage points. This equates to about a 4.8 percent increase in production.

<u>Percent Stripper</u>

Table 13 displays the results for the continuous impact of the RRRP on the extensive production margin, *Percent Stripper*. The first specification (equation 14 on page 50), which includes property fixed effects and other time-varying controls, is displayed in columns 1 and 2 for the 40 and 160 acre estimated property sizes. The coefficients for the *Royalty Rate*×*Federal* variable are negative and significant. The magnitudes of these coefficients are -1.544 and -1.087.

The results for the second specification (equation 15 on page 50), containing property, month-of-year, and year fixed effects, found in columns 3 and 4, display negative, statistically significant coefficients for the *Royalty Rate*×*Federal* variable. The magnitudes of the coefficients are -1.529 and -1.093.

The results for the third specification (equation 16 on page 50), contains property and month-by-year fixed effects—the most specific controls for time-varying unobservables. These results are reported in columns 5 and 6. The coefficients for the *Royalty Rate*×*Federal* variable are both negative and statistically significant. The magnitudes for the 40 and 160 acre properties are -2.354 and -1.924, respectively. These magnitudes of these coefficients are the largest out of the three specifications.

The marginal effects of all specifications are reported in table 11.[39] The marginal impacts across all property types are equal to the *Royalty Rate*×*Federal* coefficient for each specification.

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[39] These marginal impacts are formed by taking the partial derivative of the regression equation (equations 14, 15 and 16) with respect to *Royalty Rate*, given that the federal and stripper binary variables both equal 1.

The coefficients of the control variables for tables 5, 8, 9, 10 and 13 can be found in Appendix C. The primary reason this has been done is to ensure a proper fit of the regression tables within the paper.

Robustness checks can be found in Appendices D, E and F. Appendix D contains standard error robustness tests in which the regressions are run with the standard errors clustered at the year level instead of the year-month level. Tables D1-D5 display significant results, albeit not quite as significant as the main paper results. Appendix E contains counterfactual robustness tests in which the regressions are run twice more—once omitting private properties and once omitting state properties. Tables E1-E5, which omit the private properties, experience a large drop in observation numbers. Still, the results remain significant and similar in magnitude to the main paper results. Tables E6-E10, which omit the state properties, experience a much smaller drop in observation numbers, leading to near identical results as the main paper tables. Finally, appendix F contains royalty rate robustness checks in which all state owned properties are assigned a royalty rate of 12.5 percent—the rate assigned to a number of state owned wells in Wyoming. The continuous regression results remain unchanged despite the adjustment to the state royalty rate.

Table 10: Estimated impact of the RRRP on Log(Barrels per Day) (Continuous Regression)

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Royalty Rate x Stripper x Federal	-0.048*** (0.003)	-0.057*** (0.004)	-0.056*** (0.003)	-0.035*** (0.003)	-0.046*** (0.003)	-0.044*** (0.003)	-0.042*** (0.005)	-0.051*** (0.005)	-0.049*** (0.004)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.007	0.009	0.011	0.008	0.011	0.013	0.005	0.006	0.007
N	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table 11: Marginal Impacts of the RRRP (Continuous)

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Log(Barrels per Day)									
Federal Stripper	-0.048***	-0.057***	-0.056***	-0.035***	-0.046***	-0.044***	-0.042***	-0.051***	-0.049***
Percent Stripper									
Federal		-1.544***	-1.087***		-1.529***	-1.093***		-2.354***	-1.924***

Notes: Federal stripper marginal impacts represent federal stripper properties. Federal marginal impacts represent federal properties.

Table 12: Elasticities of the RRRP (Continuous)

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Log(Barrels per Day)									
Federal Stripper	-0.076	-0.091	-0.089	-0.055	-0.074	-0.070	-0.066	-0.082	-0.078

Notes: Elasticities represent a percent change in the dependent variable given a one percent change in the royalty rate.

Table 13: Estimated impact of the RRRP on Percentage Stripper (Continuous Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
Royalty Rate x Federal	-1.544*** (0.091)	-1.087*** (0.090)	-1.529*** (0.048)	-1.093*** (0.050)	-2.354*** (0.107)	-1.924*** (0.107)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.042	0.037	0.088	0.087	0.009	0.002
N	3,320,651	2,507,921	3,320,651	2,507,921	2,507,921	2,507,921

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal properties outside of the RRRP.

<u>Discussion of Results</u>

Overall, the results display a much stronger and significant impact for the binary regressions than the continuous regressions, for both the intensive and extensive production margins. Consequently, this could signal that stripper property operators were much more responsive to the existence of the program than they were the exact royalty rate reduction they received. This could also signal that operator production decisions occur at the binary level, with little to no control over the degree of the result. One example is that if a well is abandoned, the operator may make the decisions to reenter the well, but may have no control over the amount of oil that is produced by the well. A second example is that an operator may decide to conduct a workover on a well, but has no control over the exact increase in well production resulting from the workover.

To evaluate the RRRP in a broader context, the results from the 0 acre property level regressions containing the control variables (equations 2 and 5) are used to make some back-of-the-envelope calculations. These results are chosen for analysis because they are fairly conservative (i.e, inelastic). Finally, because the binary regressions displayed a better fit than the continuous regressions, the RRRP will be evaluated using the results obtained from the binary regressions.

Table 14 contains all of the parameters necessary for these calculations. The averages during the RRRP are observed. The estimated averages without the RRRP are calculated using the elasticity estimates from table 7. The federal stripper operator cost margin is calculated by dividing the average monthly operating cost (*Cost*) for a single well by the monthly revenue of a single well (taken from the data). This calculation is performed for the time period during the RRRP as well as the time period before and after the RRRP to get an estimated cost margin in the absence of the RRRP. The equation is represented by:

$$Cost\ Margin = \left(\frac{Operating\ Cost}{Total\ Revenue}\right)$$

First, calculations quantify the impact of the RRRP to two groups: the federal government and the Wyoming federal stripper well operators. The overall impact of the RRRP consists of two effects. The first is the increase in production from existing wells (intensive effect) and the second is the increase in production from additional wells (extensive effect). The overall effect of the RRRP on federal stripper production can be represented as:

$$(\Delta\ Barrels\ per\ well\ per\ day\ \times Existing\ Wells) + (\Delta\ Wells\ \times Barrels\ per\ well\ per\ day)$$

Table 15, which contains these calculations, reports the intensive effect as 4,793.94 barrels per day and the extensive effect as 4,310.42 barrels per day. This results in an overall impact of 9,104.35 barrels per day with the intensive and extensive effects being responsible for about 53 and 47 percent of the total effect, respectively. This percentage allocation makes sense because the intensive margin is less inelastic than the intensive margin (table 7).

Next, table 16 displays the calculation of federal stripper royalty revenue. Column 1 represents these values under the RRRP. Column 2 represents the estimated values in the absence of the RRRP. Finally, column 3 represents the difference between the two columns. It is estimated that the federal government lost a total of almost $70 million in royalty while the RRRP was in place. This is about a 38 percent decrease in federal stripper royalty revenue. Table 17 uses the same format as table 16 to display the calculation for federal stripper operator profit. It is estimated that federal stripper operators gained over $260 million while the RRRP was in place. This is about an 84 percent increase in federal stripper operator profit.

Finally, table 18 displays the total revenue generated by Wyoming stripper properties. The RRRP increased this revenue measure by about $193 million, or about a 39 percent increase.

One additional consideration is severance tax returns to the state of Wyoming. The Wyoming state severance tax rate for stripper wells was 4 percent during the RRRP period.[40] This tax applied to stripper wells producing less than 10 barrels per day if the

[40] Aside from January 1, 1999 to November 30, 1999 in which it dropped to 3 percent.

price of oil was greater than $20 per barrel. This tax applied to stripper wells producing less than 15 barrels per day if the price of oil was less than $20 per barrel.

It is estimated that the state of Wyoming received about $65.8 million in severance tax revenue from federal stripper properties during the RRRP. Because federal stripper production increased by about 66 percent during the RRRP, it is estimated that the state of Wyoming gained about $26 million in severance tax revenue from federal stripper properties during the RRRP. This suggests that the state of Wyoming was better off during the RRRP.

However, one additional factor must be taken into consideration in order to evaluate the impact of the RRRP on the state of Wyoming—Payment in Lieu of Taxes (PILT). PILT payments are made by the federal government to local governments (counties or states) that lose tax revenue due to the existence of federally-owned land within their borders. The federal government is required to give 50 percent of revenue generated from mineral leasing back to the state or county from which it came (30 U.S. Code § 191). Consequently, 50 percent of the federal royalty revenue lost due to the RRRP (almost $70 million) can be thought of as PILT loss to the state of Wyoming. This translates to about $34 million in lost PILT payments.

Comparing the gain in severance tax revenue to the loss in PILT payments will yield the overall net impact of the RRRP to the state of Wyoming. It is estimated that Wyoming loses almost $8 million ($26 million - $34 million) during the RRRP due to the lost PILT payments outweighing the gained severance tax revenue.

Table 14: Calculation Parameters

	Average During RRRP (1)	Impact of RRRP (2)	Estimated Value without RRRP (3)
Active Federal Stripper Production (bbl/day)	8.80	+35.4%	6.50
Federal Stripper Well Count	2,574.14	+23.50%	2,084.32
Active Federal Stripper Royalty Rate	4.6%	-7.9	12.5%*
Federal Stripper Operator Cost Margin	71.43%	-	65.75%
WY First Purchase Price	$21.63	-	$21.63
Length of Program (days)	4,871	-	4,871

Note: Column 1 is observed. Percent change (column 2) equal to the binary elasticity estimate (table 7) multiplied by percent change in the royalty rate (63.2%). *As federal royalty rates remain at 12.5 percent outside of the RRRP, this would be an actual value, not an estimated value. Estimated value without RRRP (column 3 - bbl/day and well count) equal to column 1 minus the percent impact.

Table 15: Intensive and Extensive Effects of the RRRP

Δ Barrels per well per day × Existing Wells	2.3 × 2,084.32	4,793.94 barrels per day
Δ Wells × Barrels per well per day	489.82 × 8.80	4,310.42 barrels per day
Overall Impact	(2.3 × 2,084.32) + (489.82 × 8.80)	9,104.35 barrels per day

Note: Δ Barrels per well per day and Δ Wells equal to the difference between columns 1 and 3 of table 14. Existing wells equal to value in column 3 of table 14. Barrels per well per day equal to value in column 1 of table 14.

Table 16: Federal Stripper Royalty Revenue

	During RRRP (1)	Estimated Value without RRRP (2)	Difference (1)-(2)
Active Federal Stripper Production (bbl/day)	22,652.43	13,548.08	9,104.35 (+67%)
Federal Stripper Property Revenue (per day)	$489,972.06	$293,044.97	$196,927.09 (+67%)
Stripper Property Federal Royalty Revenue (per day)	$22,538.71	$36,630.62	-$14,091.91 (-38%)
Total Stripper Property Federal Royalty Revenue	$109,786,056.40	$178,427,756.10	-$68,641,699.70 (-38%)

Notes: Row 1=(bbl/day)×(well count). Row 2=(Row 1)×(Price). Row 3=(Row 2)×(Royalty Rate). Row 4=(Row 3)×(Length of RRRP).

Table 17: Federal Stripper Operator Profit

	During RRRP (1)	Estimated Value without RRRP (2)	Difference (1)-(2)
Active Federal Stripper Production (bbl/day)	22,652.43	13,548.08	9,104.35 (+67%)
Federal Stripper Property Revenue (per day)	$489,972.06	$293,044.97	$196,927.09 (+67%)
Stripper Property Operator Profit (per day)	$117,446.30	$63,737.28	$53,709.02 (+84%)
Total Stripper Property Operator Profit	$572,080,927.30	$310,464,290.90	$261,616,636.40 (+84%)

Notes: Row 1=(bbl/day)×(well count). Row 2=(Row 1)×(Price). Row 3=(Row 2)×(1-Royalty Rate-Cost Margin). Row 4=(Row 3)×(Length of RRRP).

Table 18: Total Revenue Generated by Wyoming Stripper Properties

	During RRRP (1)	Estimated Value without RRRP (2)	Difference (1)-(2)
Total Stripper Property Revenue (Federal Royalty Revenue + Stripper Operator Profit)	$681,866,983.70	$488,892,047	$192,974,936.70 (+39%)

Notes: Equal to (Table 16 Row 4)+(Table 17 Row 4).

CONCLUSION

This thesis investigates the impact of royalty rate reductions on the intensive and extensive production margins of federal, marginally producing oil wells. Although many papers have investigated the impact of taxation on oil production, this thesis is the first, to my knowledge, to single out the extensive stripper well population for analysis.

The econometric analysis, conducted as a fixed effects, double- and triple-difference model, of the binary impact of the RRRP suggests a substantial and significant effect of the RRRP on barrels of oil produced per day, the number of producing stripper well properties and the percentage of wells on a property that qualify as stripper wells.

The econometric analysis, conducted as a multiple regression model, of the continuous impact of the RRRP suggests a less substantial effect of the exact magnitude of the royalty reduction on barrels of oil produced per day and the percentage of wells on a property that qualify as stripper wells.

Based on the previously discussed back-of-the-envelope calculations, these results signal that the RRRP was effective in increasing stripper well production on both the intensive and extensive production margins. However, this program also resulted in the decrease in federal stripper royalty revenue by about 38 percent in the state of Wyoming—leading to the eventual stoppage of the program. A less steep, and therefore less generous, royalty rate reduction schedule may have resulted in both parties experiencing positive returns. Finally, it was determined that the state of Wyoming also lost as the result of the program as the gain from increase severance tax revenue could not overcome the loss in PILT payments.

An interesting continuation of this analysis would be to use these results to run simulations under various royalty rate reduction schedules in order to establish the possible existence of a pareto-optimal royalty rate reduction schedule, given the required existence of a royalty rate reduction. These results could be used to improve the RRRP for possible future programs—as the number of stripper properties will inevitably continue to increase as the reserve levels and reservoir pressures decrease over time.

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APPENDICIES

APPENDIX A

EIA PRODUCTION RATE CLASSES

Table A1 displays the EIA production rate class schedule. The EIA uses this to group wells together by production levels, in average barrels per day. Consequently, wells that qualify as stripper wells would fall into rate classes 8 and below.

Table A1: EIA Production Rate Class Schedule

Average BBL/Day	Rate Class	Average BBL/Day	Rate Class
0-1	1	30-40	12
1-2	2	40-50	13
2-4	3	50-100	14
4-6	4	100-200	15
6-8	5	200-400	16
8-10	6	400-800	17
10-12	7	800-1600	18
12-15	8	1600-3200	19
15-20	9	3200-6400	20
20-25	10	6400-12800	21
25-30	11	>12800	22

Note: For more information on the EIA Production Rate Class Schedule, visit the EIA's website.

APPENDIX B

HALVORSEN & PALMQUIST TRANSFORMED COEFFICIENTS

Table B1: Halvorsen & Palmquist Transformed Coefficients – *Log(Barrels per Day)* (Binary)

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Stripper	-0.823***	-0.845***	-0.844***	-0.786***	-0.817***	-0.812***	-0.864***	-0.874***	-0.872***
RRRP	0.108	0.054	0.053	0.113***	0.087***	0.093***			
Federal x Stripper	-0.084***	-0.069***	0.034	-0.106***	-0.083***	0.021	-0.138***	-0.129***	-0.030**
RRRP x Federal	-0.238***	-0.166***	-0.066***	-0.264***	-0.192***	-0.102***	-0.346***	-0.311***	-0.230***
RRRP x Stripper	-0.165***	-0.176***	-0.185***	-0.186***	-0.197***	-0.217***	-0.244***	-0.286***	-0.301***
RRRP x Stripper x Federal	0.649***	0.670***	0.520***	0.714***	0.716***	0.579***	0.958***	1.077***	0.887***

Notes: Transformation is equal to $(e^{\beta} - 1)$. Percent change equal to $(e^{\beta} - 1) \times 100$.

APPENDIX C

CONTROL COEFFICIENTS TABLES

The following tables contain the coefficient estimates for the control variables for the main paper regression tables. The regressions that do not contain the three control variables have been omitted from these tables. As mentioned in the main paper, these coefficients take on values close to zero.

Table C1: Estimated impact of the RRRP on *Log(Barrels per Day)* (Binary Regression).

	0 acre	40 acre	60 acre
	(1)	(2)	(3)
Reserves	0.003***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)
FPP	-0.011***	-0.008***	-0.007***
	(0.001)	(0.001)	(0.010)
Cost	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Property FE	Yes	Yes	Yes
Month FE	No	No	No
Year FE	No	No	No
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60
R^2	0.160	0.186	0.188
N	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table C2: Estimated impact of the RRRP on *Active Property Count* (Binary Regression).

	0 acre	40 acre	60 acre
	(1)	(2)	(3)
Reserves	0.729***	0.245***	0.186***
	(0.105)	(0.030)	(0.021)
FPP	-1.742***	-0.873***	-0.402***
	(0.328)	(0.146)	(0.106)
Cost	-0.001	-0.002***	-0.003***
	(0.001)	(0.001)	(0.000)
Property FE	Yes	Yes	Yes
Month FE	No	No	No
Year FE	No	No	No
Mean Active Property Count for Federal Strippers RRRP=0	2,127.96	1,511.72	1,023.32
R^2	0.114	0.098	0.078
N	2,487	2,517	2,519

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table C3: Estimated impact of the RRRP on *Percentage Stripper* (Binary Regression).

	40 acre	60 acre
	(1)	(2)
Reserves	-0.073***	-0.074***
	(0.007)	(0.007)
FPP	0.199***	0.194***
	(0.034)	(0.035)
Cost	0.000	0.000
	(0.000)	(0.000)
Property FE	Yes	Yes
Month FE	No	No
Year FE	No	No
Mean Percent Stripper for Federal RRRP=0	63.11	67.53
R^2	0.041	0.042
N	3,320,651	2,507,921

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table C4: Estimated impact of the RRRP on *Log(Barrels per Day)* (Continuous Regression).

	0 acre (1)	40 acre (2)	60 acre (3)
Reserves	0.004***	0.004***	0.004***
	(0.000)	(0.000)	(0.000)
FPP	-0.012***	-0.009***	-0.009***
	(0.002)	(0.001)	(0.001)
Cost	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Property FE	Yes	Yes	Yes
Month FE	No	No	No
Year FE	No	No	No
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60
R^2	0.007	0.009	0.011
N	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table C5: Estimated impact of the RRRP on *Percentage Stripper* (Continuous Regression).

	40 acre	60 acre
	(1)	(2)
Reserves	-0.067***	-0.069***
	(0.005)	(0.005)
FPP	0.225***	0.219***
	(0.027)	(0.028)
Cost	0.000	0.000
	(0.000)	(0.000)
Property FE	Yes	Yes
Month FE	No	No
Year FE	No	No
Mean Percent Stripper for Federal RRRP=0	63.11	67.53
R^2	0.042	0.037
N	3,320,651	2,507,921

Notes: S.E. clustered by year-month. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

APPENDIX D

STANDARD ERROR ROBUSTNESS

The following regression tables, D1-D5, duplicate the five regression tables, found in the main body of the paper, with the standard errors clustered at the year level instead of the year-month level. This is done in order to ensure that the main paper results are not solely driven by ideal clustering of the standard errors. The following results remain significant, albeit slightly less so than the main paper results.

Table D1: Estimated impact of the RRRP on *Log(Barrels per Day)* (Binary Regression).

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Stripper	-1.731*** (0.180)	-1.864*** (0.172)	-1.858*** (0.161)	-1.542*** (0.078)	-1.697*** (0.091)	-1.673*** (0.090)	-1.996*** (0.142)	-2.068*** (0.132)	-2.055*** (0.119)
RRRP	0.103 (0.224)	0.053 (0.207)	0.052 (0.208)	0.107 (0.085)	0.083 (0.080)	0.089 (0.078)			
Federal x Stripper	-0.088 (0.074)	-0.071 (0.079)	0.033 (0.063)	-0.112 (0.081)	-0.087 (0.082)	0.021 (0.061)	-0.149** (0.063)	-0.138** (0.063)	-0.033 (0.048)
RRRP x Federal	-0.272*** (0.056)	-0.182*** (0.052)	-0.068 (0.052)	-0.306*** (0.057)	-0.213*** (0.051)	-0.108** (0.048)	-0.425*** (0.094)	-0.372*** (0.081)	-0.262*** (0.078)
RRRP x Stripper	-0.180 (0.142)	-0.193 (0.135)	-0.204 (0.132)	-0.206* (0.107)	-0.219** (0.104)	-0.245** (0.104)	-0.280* (0.147)	-0.337** (0.131)	-0.358*** (0.129)
RRRP x Stripper x Federal	0.500*** (0.074)	0.513*** (0.067)	0.419*** (0.063)	0.539*** (0.075)	0.540*** (0.065)	0.457*** (0.060)	0.672*** (0.108)	0.731*** (0.096)	0.635*** (0.094)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.160	0.186	0.188	0.131	0.164	0.167	0.201	0.215	0.215
N	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table D2: Estimated impact of the RRRP on *Active Property Count* (Binary Regression).

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RRRP	-180.905**	-203.230**	-157.182**	-139.850**	-170.125*	-132.592*			
	(67.045)	(89.340)	(71.463)	(56.378)	(88.187)	(68.426)			
RRRP x Federal	-357.662***	-252.031***	-108.613***	-357.662***	-252.031***	-108.613***	-638.757***	-478.989***	-287.609***
	(44.359)	(26.965)	(19.928)	(44.739)	(27.193)	(20.097)	(136.821)	(97.065)	(59.788)
RRRP x Stripper	358.824**	290.560*	211.456	294.294**	291.280*	211.718	82.729	63.876	32.529
	(137.163)	(169.535)	(135.163)	(116.289)	(171.478)	(136.500)	(57.403)	(85.623)	(69.117)
RRRP x Stripper x Federal	721.107***	594.923***	333.965***	721.107***	594.203***	333.703***	1002.202***	821.607***	512.892***
	(94.917)	(69.444)	(53.229)	(95.732)	(70.210)	(53.855)	(173.209)	(120.167)	(68.072)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean Active Property Count for Federal Strippers RRRP=0	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32
R^2	0.114	0.098	0.078	0.096	0.098	0.078	0.071	0.063	0.049
N	2,487	2,517	2,519	2,487	2,517	2,519	2,487	2,517	2,519

Notes: S.E. clustered by year. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table D3: Estimated impact of the RRRP on *Percentage Stripper* (Binary Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
RRRP	-3.092 (4.461)	-3.284 (4.636)	-1.920* (1.063)	-1.659* (0.925)		
RRRP x Federal	10.667*** (1.125)	9.220*** (0.890)	9.984*** (1.148)	8.725*** (0.892)	16.320*** (4.031)	15.041*** (3.942)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.041	0.042	0.087	0.093	0.007	0.008
N	3,320,651	2,507,921	3,320,651	2,507,921	3,320,651	2,507,921

Notes: S.E. clustered by year. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table D4: Estimated impact of the RRRP on *Log(Barrels per Day)* (Continuous Regression).

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Royalty Rate x Stripper x Federal	-0.048*** (0.011)	-0.057*** (0.012)	-0.056*** (0.011)	-0.035*** (0.010)	-0.046*** (0.011)	-0.044*** (0.009)	-0.042** (0.017)	-0.051*** (0.017)	-0.049*** (0.015)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.007	0.009	0.011	0.008	0.011	0.014	0.005	0.006	0.007
N	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table D5: Estimated impact of the RRRP on *Percentage Stripper* (Continuous Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
Royalty Rate x Federal	-1.544*** (0.303)	-1.087*** (0.299)	-1.529*** (0.163)	-1.093*** (0.170)	-2.354*** (0.364)	-1.924*** (0.365)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.042	0.037	0.088	0.087	0.009	0.002
N	3,320,651	2,507,921	3,320,651	2,507,921	2,507,921	2,507,921

Notes: S.E. clustered by year. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

APPENDIX E

COUNTERFACTUAL ROBUSTNESS

The main paper regressions are replicated twice more under two different counterfactuals. These robustness checks are run in order to ensure that the main paper results are not being driven by state or private properties alone.

Regression tables E1-E5 duplicate the five regression tables, found in the main body of the paper, omitting private properties—leaving only federal and state properties. Because private properties greatly outnumber state properties, the observation numbers for the *barrels per day* and *percentage stripper* regressions drop substantially. Despite this, the results remain both significant and similar in magnitude to the main paper regressions.

Regression tables E6-E10 duplicate the five regression tables, found in the main body of the paper, omitting state properties—leaving only federal and private properties. Because private properties greatly outnumber state properties, the observation numbers for the *barrels per day* and *percentage stripper* regressions more closely resemble those of the main paper regressions. Because of this the results in the following tables are nearly identical to the main paper results.

Table E1: Estimated impact of the RRRP on *Log(Barrels per Day)* (Binary Regression).

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Stripper	-1.632***	-1.816***	-1.764***	-1.517***	-1.732***	-1.638***	-1.842***	-1.962***	-1.926***
	(0.066)	(0.065)	(0.058)	(0.035)	(0.036)	(0.034)	(0.053)	(0.050)	(0.044)
RRRP	0.069	-0.028	0.056	0.082*	-0.030	0.053			
	(0.073)	(0.067)	(0.068)	(0.042)	(0.042)	(0.046)			
Federal x Stripper	-0.211***	-0.139***	-0.078***	-0.180***	-0.100***	-0.050**	-0.303***	-0.241***	-0.157***
	(0.029)	(0.030)	(0.026)	(0.025)	(0.024)	(0.022)	(0.023)	(0.022)	(0.019)
RRRP x Federal	-0.276***	-0.125***	-0.090***	-0.287***	-0.128***	-0.113***	-0.425***	-0.372***	-0.262***
	(0.026)	(0.028)	(0.028)	(0.024)	(0.025)	(0.025)	(0.033)	(0.029)	(0.027)
RRRP x Stripper	-0.297***	-0.226***	-0.359***	-0.285***	-0.212***	-0.377***	-0.415***	-0.440***	-0.497***
	(0.053)	(0.054)	(0.052)	(0.042)	(0.043)	(0.043)	(0.038)	(0.036)	(0.037)
RRRP x Stripper x Federal	0.625***	0.549***	0.575***	0.627***	0.535***	0.586***	0.807***	0.832***	0.774***
	(0.031)	(0.031)	(0.030)	(0.029)	(0.027)	(0.028)	(0.035)	(0.031)	(0.031)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.151	0.178	0.175	0.125	0.161	0.157	0.188	0.203	0.199
N	2,551,280	1,840,555	1,218,366	2,551,280	1,840,555	1,218,366	2,551,280	1,840,555	1,218,366

Notes: S.E. clustered by year-month. Federal and State Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E2: Estimated impact of the RRRP on *Active Property Count* (Binary Regression).

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
RRRP	8.021 (12.479)	-29.603*** (6.329)	-24.039*** (4.730)	49.543*** (13.144)	-9.038 (5.533)	-16.401*** (4.340)			
RRRP x Federal	-590.785*** (34.606)	-436.956*** (23.561)	-255.166*** (13.768)	-590.785*** (35.055)	-436.956*** (23.863)	-255.166*** (13.945)	-638.757*** (39.886)	-478.989*** (28.237)	-287.609*** (17.395)
RRRP x Stripper	27.543*** (7.657)	36.991*** (10.289)	28.839*** (7.921)	-12.719 (14.358)	37.409*** (10.478)	29.013*** (8.045)	-17.711*** (3.957)	-4.864 (5.505)	-3.548 (4.209)
RRRP x Stripper x Federal	1054.669*** (50.804)	848.492*** (43.368)	516.583*** (25.233)	1054.669*** (51.463)	848.074*** (43.835)	516.408*** (25.515)	1102.642*** (55.547)	890.347*** (48.109)	548.969*** (28.923)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean Active Property Count for Federal Strippers RRRP=0	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32
R^2	0.197	0.242	0.287	0.193	0.243	0.287	0.181	0.223	0.261
N	1,658	1,678	1,679	1,658	1,678	1,679	1,658	1,678	1,679

Notes: S.E. clustered by year-month. Federal and State Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E3: Estimated impact of the RRRP on *Percentage Stripper* (Binary Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
RRRP	-3.406*** (1.271)	-3.147** (1.310)	-4.968*** (1.478)	-4.271*** (1.389)		
RRRP x Federal	10.708*** (0.360)	9.202*** (0.271)	10.084*** (0.357)	8.615*** (0.267)	16.294*** (1.167)	15.000*** (1.141)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.065	0.063	0.110	0.119	0.024	0.022
N	1,261,867	869,254	1,261,867	869,254	1,261,867	869,254

Notes: S.E. clustered by year-month. Federal and State Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E4: Estimated impact of the RRRP on *Log(Barrels per Day)* (Continuous Regression).

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Royalty Rate x Stripper x Federal	-0.053***	-0.061***	-0.060***	-0.048***	-0.058***	-0.055***	-0.042***	-0.051***	-0.048***
	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)	(0.005)	(0.005)	(0.004)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.014	0.021	0.022	0.013	0.022	0.023	0.019	0.020	0.020
N	2,551,280	1,840,555	1,218,366	2,551,280	1,840,555	1,218,366	2,551,280	1,840,555	1,218,366

Notes: S.E. clustered by year-month. Federal and State Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E5: Estimated impact of the RRRP on *Percentage Stripper* (Continuous Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
Royalty Rate x Federal	-1.447*** (0.111)	-0.978*** (0.107)	-1.424*** (0.090)	-0.874*** (0.084)	-2.346*** (0.107)	-1.925*** (0.107)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.010	0.080	0.138	0.133	0.055	0.037
N	1,261,867	869,254	1,261,867	869,254	1,261,867	869,254

Notes: S.E. clustered by year-month. Federal and State Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E6: Estimated impact of the RRRP on *Log(Barrels per Day)* (Binary Regression).

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Stripper	-1.742***	-1.872***	-1.871***	-1.541***	-1.695***	-1.676***	-2.013***	-2.081***	-2.070***
	(0.056)	(0.053)	(0.051)	(0.034)	(0.034)	(0.031)	(0.045)	(0.042)	(0.038)
RRRP	0.100	0.052	0.039	0.104***	0.082***	0.078**			
	(0.070)	(0.063)	(0.063)	(0.032)	(0.032)	(0.032)			
Federal x Stripper	-0.074***	-0.062**	0.047**	-0.104***	-0.084***	0.029	-0.131***	-0.125***	-0.018
	(0.024)	(0.025)	(0.021)	(0.026)	(0.027)	(0.021)	(0.020)	(0.020)	(0.016)
RRRP x Federal	-0.273***	-0.189***	-0.065***	-0.309***	-0.221***	-0.107***	-0.425***	-0.372***	-0.262***
	(0.021)	(0.020)	(0.020)	(0.021)	(0.020)	(0.019)	(0.033)	(0.029)	(0.028)
RRRP x Stripper	-0.167***	-0.187***	-0.184***	-0.198***	-0.218***	-0.228***	-0.265***	-0.324***	-0.339***
	(0.044)	(0.042)	(0.040)	(0.037)	(0.035)	(0.034)	(0.044)	(0.039)	(0.038)
RRRP x Stripper x Federal	0.487***	0.508***	0.399***	0.529***	0.538***	0.440***	0.657***	0.718***	0.617***
	(0.026)	(0.024)	(0.023)	(0.026)	(0.024)	(0.022)	(0.038)	(0.033)	(0.032)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.161	0.188	0.190	0.132	0.166	0.169	0.201	0.216	0.216
N	5,809,453	4,437,864	3,206,016	5,809,453	4,437,864	3,206,016	5,809,453	4,437,864	3,206,016

Notes: S.E. clustered by year-month. Federal and Private Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E7: Estimated impact of the RRRP on *Active Property Count* (Binary Regression).

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RRRP	-379.936***	-385.025***	-299.364***	-321.713***	-336.284***	-262.146***			
	(37.372)	(46.707)	(37.215)	(36.282)	(47.010)	(36.277)			
RRRP x Federal	-124.539***	-67.105***	37.939*	-124.539***	-67.105***	37.939*	-638.757***	-478.989***	-287.609***
	(20.460)	(20.920)	(20.827)	(20.726)	(21.188)	(21.094)	(39.886)	(28.237)	(17.395)
RRRP x Stripper	690.307***	544.141***	394.101***	599.946***	544.798***	394.101***	183.169***	132.515***	68.552*
	(72.216)	(89.451)	(70.967)	(65.688)	(90.683)	(71.875)	(31.898)	(46.827)	(36.731)
RRRP x Stripper x Federal	387.544***	341.342***	151.320***	387.544***	340.684***	151.320***	901.762***	752.968***	476.869***
	(34.740)	(47.730)	(43.258)	(35.191)	(48.376)	(43.812)	(50.394)	(34.619)	(22.773)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean Active Property Count for Federal Strippers RRRP=0	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32	2,127.96	1,511.72	1,023.32
R^2	0.197	0.242	0.287	0.193	0.243	0.287	0.213	0.160	0.112
N	1,658	1,678	1,679	1,658	1,678	1,679	1,658	1,678	1,679

Notes: S.E. clustered by year-month. Federal and Private Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E8: Estimated impact of the RRRP on *Percentage Stripper* (Binary Regression).

	40 acre	160 acre	40 acre	160 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)
RRRP	-3.079**	-3.269**	-2.020**	-1.726**		
	(1.354)	(1.409)	(0.863)	(0.820)		
RRRP x Federal	10.655***	9.214***	9.972***	8.736***	16.318***	15.033***
	(0.335)	(0.270)	(0.342)	(0.268)	(1.169)	(1.143)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.043	0.044	0.089	0.094	0.008	0.009
N	3,085,845	2,315,216	3,085,845	2,315,216	3,085,845	2,315,216

Notes: S.E. clustered by year-month. Federal and Private Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E9: Estimated impact of the RRRP on *Log(Barrels per Day)* (Continuous Regression).

	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre	0 acre	40 acre	160 acre
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Royalty Rate x Stripper x Federal	-0.048***	-0.056***	-0.055***	-0.035***	-0.046***	-0.044***	-0.042***	-0.051***	-0.049***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)	(0.005)	(0.004)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.008	0.011	0.013	0.009	0.013	0.015	0.005	0.007	0.008
N	5,809,453	4,437,864	3,206,016	5,809,453	4,437,864	3,206,016	5,809,453	4,437,864	3,206,016

Notes: S.E. clustered by year-month. Federal and Private Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table E10: Estimated impact of the RRRP on *Percentage Stripper* (Continuous Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
Royalty Rate x Federal	-1.543*** (0.092)	-1.085*** (0.091)	-1.528*** (0.050)	-1.091*** (0.052)	-2.356*** (0.107)	-1.925*** (0.107)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.044	0.037	0.090	0.088	0.009	0.002
N	3,085,845	2,315,216	3,085,845	2,315,216	3,085,845	2,315,216

Notes: S.E. clustered by year-month. Federal and Private Properties only. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

APPENDIX F

STATE ROYALTY RATE ROBUSTNESS

This appendix contains royalty rate robustness checks in which all state owned properties are assigned a royalty rate of 12.5 percent—the rate assigned to a portion of state owned wells in Wyoming. The continuous regression results remain unchanged despite the adjustment to the state royalty rate.

Table F1: Estimated impact of the RRRP on *Log(Barrels per Day)* (Continuous Regression).

	0 acre (1)	40 acre (2)	160 acre (3)	0 acre (4)	40 acre (5)	160 acre (6)	0 acre (7)	40 acre (8)	160 acre (9)
Royalty Rate x Stripper x Federal	-0.048*** (0.003)	-0.057*** (0.004)	-0.056*** (0.003)	-0.035*** (0.003)	-0.046*** (0.003)	-0.044*** (0.003)	-0.042*** (0.005)	-0.051*** (0.005)	-0.049*** (0.004)
Controls	Yes	Yes	Yes	No	No	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	No	Yes	Yes	Yes	No	No	No
Year FE	No	No	No	Yes	Yes	Yes	No	No	No
Month × Year FE	No	No	No	No	No	No	Yes	Yes	Yes
Mean bbl/day (level) for Federal Strippers RRRP=0	3.29	2.95	2.60	3.29	2.95	2.60	3.29	2.95	2.60
R^2	0.007	0.009	0.011	0.008	0.011	0.014	0.005	0.006	0.007
N	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420	6,231,324	4,799,736	3,489,420

Notes: S.E. clustered by year-month. State royalty rate equal to 12.5 percent. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.

Table F2: Estimated impact of the RRRP on *Percentage Stripper* (Continuous Regression).

	40 acre (1)	160 acre (2)	40 acre (3)	160 acre (4)	40 acre (5)	160 acre (6)
Royalty Rate x Federal	-1.544*** (0.091)	-1.087*** (0.090)	-1.529*** (0.048)	-1.093*** (0.050)	-2.354*** (0.107)	-1.924*** (0.107)
Controls	Yes	Yes	No	No	No	No
Property FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes	No	No
Year FE	No	No	Yes	Yes	No	No
Month × Year FE	No	No	No	No	Yes	Yes
Mean Percent Stripper for Federal RRRP=0	63.11	67.53	63.11	67.53	63.11	67.53
R^2	0.042	0.037	0.088	0.087	0.009	0.002
N	3,320,651	2,507,921	3,320,651	2,507,921	2,507,921	2,507,921

Notes: S.E. clustered by year-month. State royalty rate equal to 12.5 percent. * Statistically significant at the 10% level, ** at 5% level, *** at 1% level. Mean of the dependent variable representative of federal stripper properties outside of the RRRP.