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ESTIMATING REVENUE POTENTIAL FOR GAS VENTING AND FLARING ON NEW MEXICO STATE LANDS

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Executive Summary

The recent surge in oil and gas production on State Lands in New Mexico, driven by technological advancements and large investments by oil and gas producers, has meant a recent upsurge to state budgets. A consequence of increased oil and gas production, however, is a commensurate increase in gas that is vented or flared into the atmosphere. Reasons for venting or flaring range from insufficient infrastructure to manage the high volumes of waste at the wellhead to low commodity price, making natural gas collections and sales sometimes economically unattractive. Nevertheless, as the vented or flared gas is not sent to market, the state is likely missing out on royalties that it would otherwise receive.

This report projects royalties that would be owed to the state (1) if all oil and gas producers were required to pay royalties on vented or flared gas and (2) if only production on prospective leases are required to pay royalties on vented or flared gas. Table 1 shows historical revenues already foregone as well as projected future revenue potential in both instances. Note that historical data begins January 2010 and extends through September 2019; therefore, the forecast window begins October 2019. For all wells, royalties gradually increase through the forecast window with revenue potential increasing from around $5.6 million in 2020 to over $7.0 million by 2025. For new wells, revenue potential increases from over $460,000 in 2020 to around $2.4 million by 2025.

Table 1. Revenue Potential 2017 through 2025; Historical Periods for All Wells Correspond to Revenues Already Foregone

	2017	2018	2019	2020	2021	2022	2023	2024	2025
All Wells	$3,636,304	$8,288,874	$3,697,827	$4,946,856	$5,242,250	$5,574,001	$5,879,220	$6,446,116	$7,054,117
Only New Wells*			$50,096	$465,227	$836,897	$1,206,723	$1,557,445	$1,964,008	$2,367,647

*Beginning October 2019

In addition to the baseline outcome shown in Table 1, this report also describes the use of a simple Microsoft Excel spreadsheet tool that allows for the development of high and low scenarios. The scenarios are based on adjusting the three factors in the royalty calculation for vented or flared gas: the volume of gas vented or flared, the market price of gas, and the effective royalty rate percentage. Use of the spreadsheet tool is discussed in Appendix 2.

It is important to note that the conclusions discussed in this report are contingent on several factors. First, the forecasts rely on the assumption that historical relationships, as estimated in the modeling process, persist into the future. Changes in the statistical relationships among variables will require model updates and re-estimation. In addition, the research assumes no behavioral response with regard to future drilling and production decisions by producers to (increased) costs associated with being required to pay royalties for vented or flared gas.

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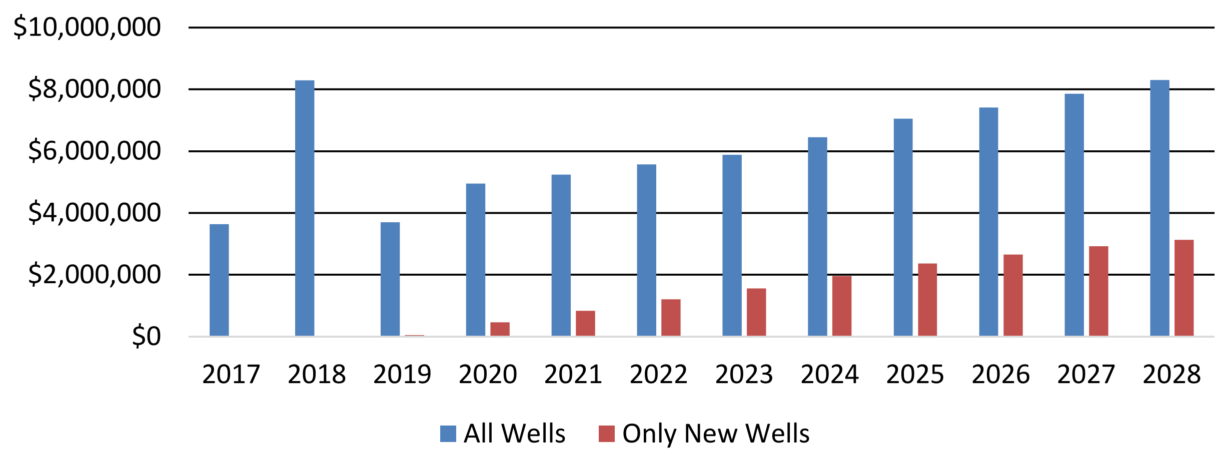
I. Introduction

The New Mexico State Land Office (SLO) assesses royalties on oil & gas produced on state trust lands with revenues going a variety of beneficiaries including schools, universities, and hospitals, as well as to the Land Grand Permanent Fund. As a key element to the state budget, accurate identification of oil and gas volumes produced as well as royalties payable is critical. While applying royalty rates to volumes of oil & gas sent to market is straightforward, the collection of royalties from excess gas that is vented or flared at the wellhead is less clear.

Although royalty collection on vented or flared gas has not been historically mandated, per NM Stat § 19-1-2 (2017), the SLO's Land Commissioner is authorized to make rules and regulations ensuring the control, management, and leasing of state lands. In concert with the Commissioner's fiduciary obligations to the State of New Mexico, her rulemaking capabilities may extend to regulating potentially wasteful activities by imposing royalties on vented and flared gas.

Given this backdrop, this research assesses the revenue potential: (1) assuming that royalties are assessed on all gas that is vented or flared and (2) assuming that royalties are assessed only on vented or flared gas coming from future wells. Over the period from 2017 to 2019, total revenues foregone have averaged over $5.0 million per year for all wells. From 2020 to 2028 projected royalty potential is expected to average over $6.5 million per year. For new wells, royalties are projected to increase from around $460,000 in 2020 to $3.1 million by 2028.

Figure 1. Revenue Potential 2017 through 2025; Historical Periods for All Wells Correspond to Revenues Already Foregone



This report is structured as follows: Section II begins by discussing relevant historical data series and sources. Section III describes the models used to project key variables including royalty revenue. Projections are developed for the three inputs to the royalty calculation: natural gas price, the effective royalty rate, and the volume vented or flared. Section IV presents final modeling results and analysis. Section V provides a brief conclusion and discussion of limitations. In addition to the baseline results discussed in the main body of the report, Section VII (Appendix 2) describes a simulation tool in Microsoft Excel that may be used by the SLO to create alternative (high and low) revenue scenarios. Sections VI and VIII provide model estimation results, diagnostics, and a brief discussion of forecast accuracy.

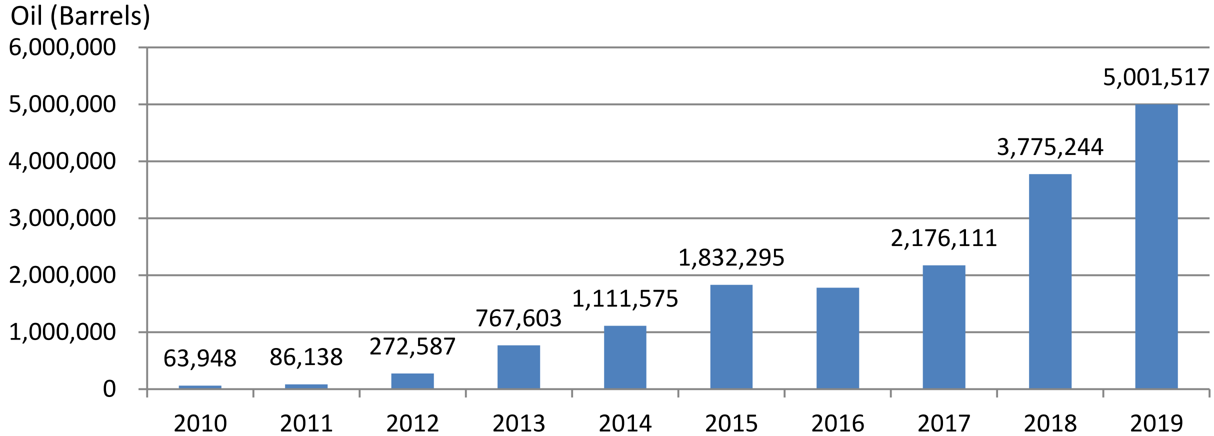
II. Data

This analysis seeks to investigate the royalty revenues that could be obtained if royalties were assessed on flared or vented natural gas. In order to estimate future royalty revenue potential, projections for key variables likely associated with flaring and venting are developed. This section discusses key variables and historical data trends.

A. Oil & gas production

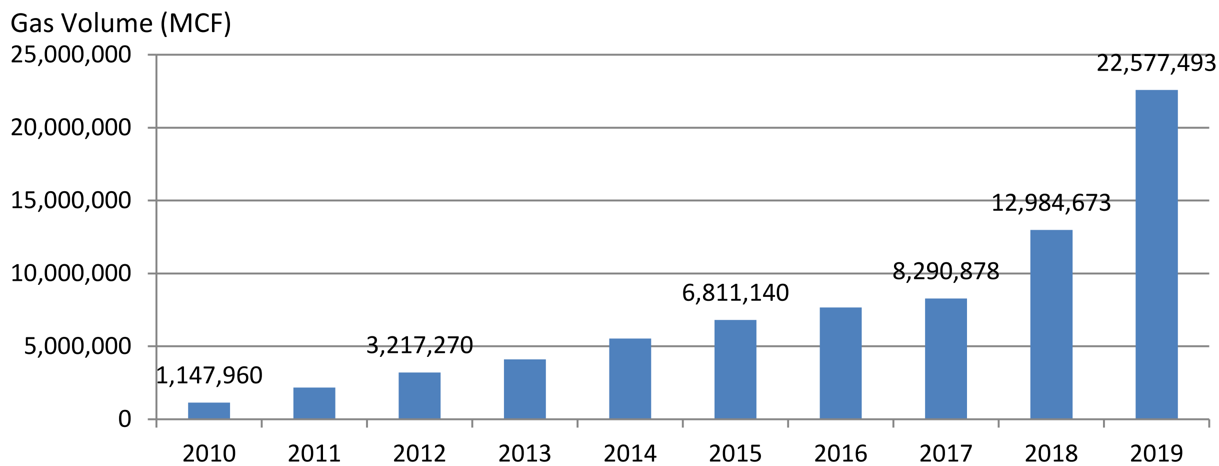
Data on oil production volumes are provided by the SLO. Data include oil produced on lands owned by the state of New Mexico over the period from January 2010 through September 2019. Over the past few years, oil production volumes have spiked with average monthly production increasing by 73% in 2018 over 2017 and by an additional 32% so far in 2019 over 2018. The rapid increase in production in New Mexico is due to recognition of the highly productive reserves in the southeastern portion of the state, improved technologies which are particularly well suited for exploiting formations in the state, and increased investment by large national and multinational oil producers.

Figure 2. Average Monthly Oil Produced on State Lands by Year



Data on gas production volumes are provided by the SLO over the period from January 2010 through September 2019. Like oil production, gas production has spiked over the last couple years, increasing by nearly 60% in 2018 over 2017 and by nearly another 75% in 2019 over a year earlier. High production levels, especially in 2019, are in spite of stubbornly low spot gas prices.

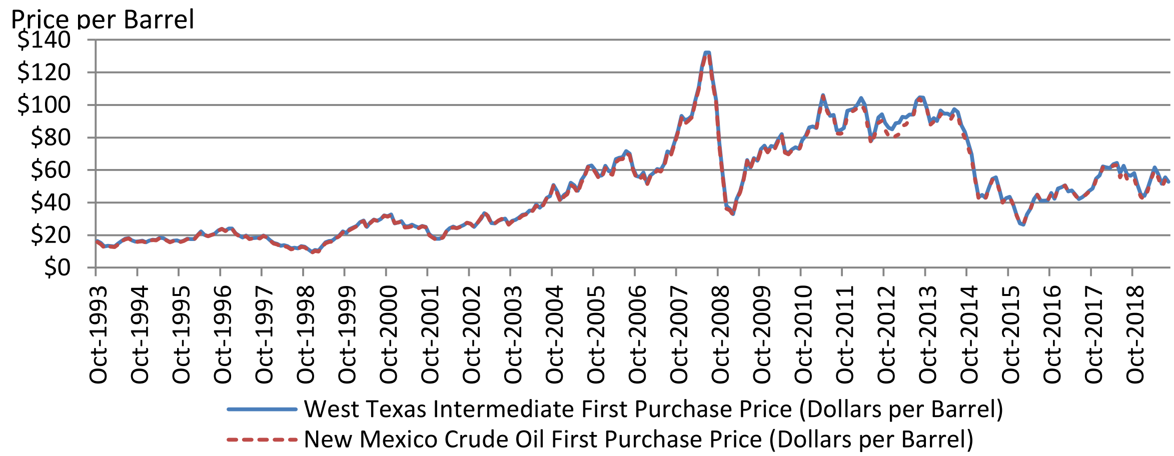
Figure 3. Average Monthly Gas Produced on State Lands by Year



B. Oil & gas price

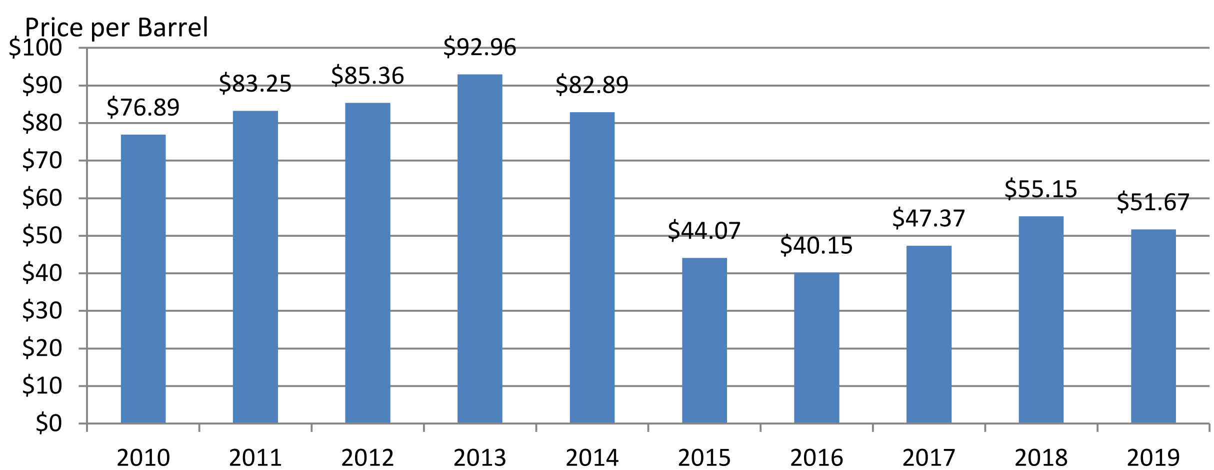
Oil and gas prices are subject to a wide variety of factors, many of which are hard to predict and geopolitical in nature. For oil price, this research relies on the West Texas Intermediate (WTI) crude price. While WTI is not the precise benchmark price for the New Mexico vintage of oil, as it often trades 1-3% lower than WTI, it generally follows WTI price trends with a correlation coefficient approaching 1. Using WTI price in this research is helpful as it is a commonly traded commodity with widely available historical and forecast prices.

Figure 4. WTI versus New Mexico Crude Oil First Purchase Price



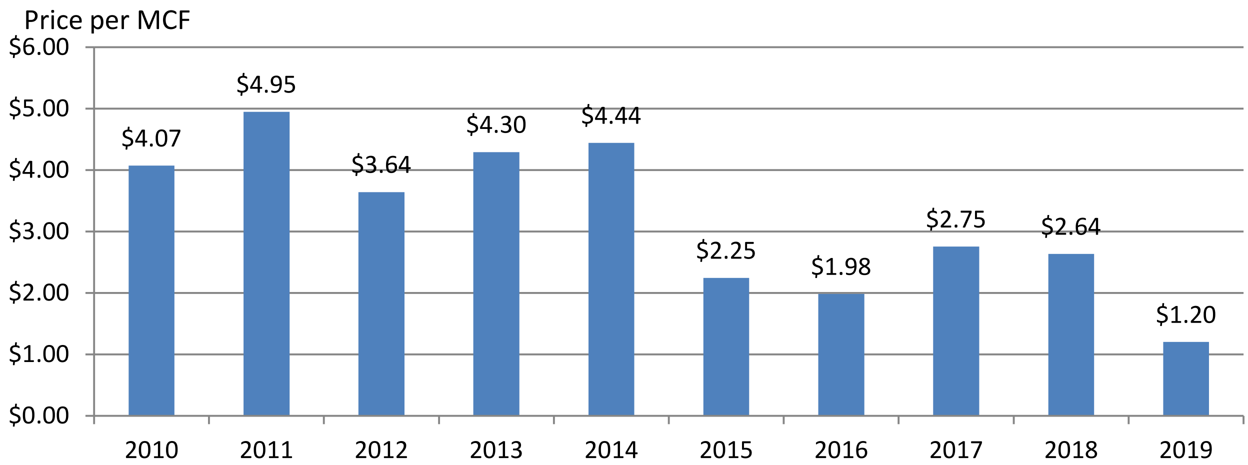
Consistent with price trends for WTI, price for New Mexico oil (per barrel) has generally remained low, typically averaging below $55/barrel since 2015. Figure 5 shows the average price per barrel of New Mexico oil implied by production volumes and royalties paid to the SLO.

Figure 5. Computed Average Oil per Barrel (per the SLO)



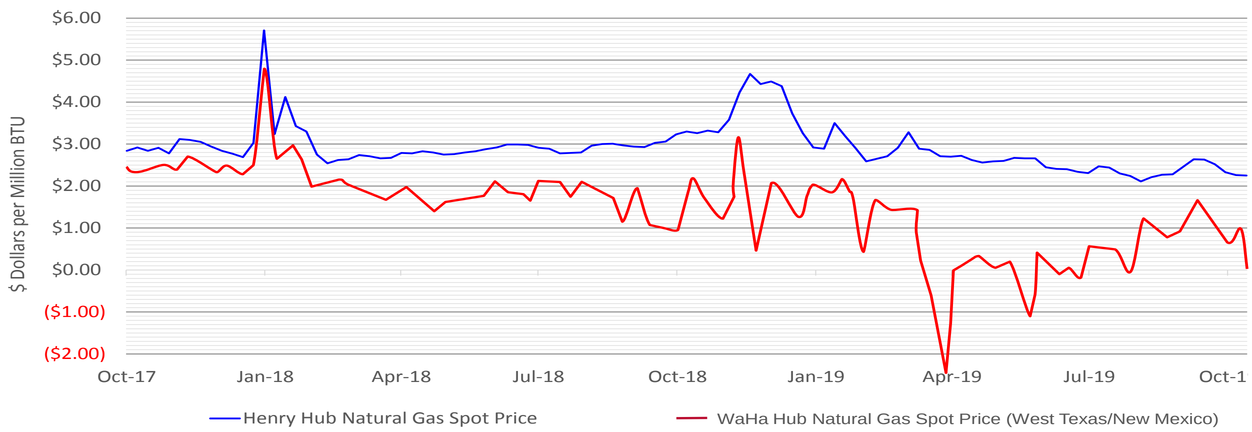
Similarly, the price for gas has been relatively low for the last several years, generally trading well below $3.00 per MCF since 2015. Figure 6 shows the implied average net gas price per MCF per the State Land Office.

Figure 6. Computed Average Net Gas Price per MCF (per the SLO)



The Henry Hub natural gas price is often used as the benchmark price; however, although New Mexico production has historically followed the Henry Hub price, prices began to diverge in 2018 with accelerating separation in 2019. Figure 7 shows a comparison of the benchmark Henry Hub price and the WaHa prices faced by New Mexico producers expressed in terms of Mbtu. The WaHa price stays lower than the Henry Hub price throughout the period with the WaHa price occasionally dropping below $0.00 per Mbtu. The implied negative prices are due to capacity constraints faced by New Mexico producers.

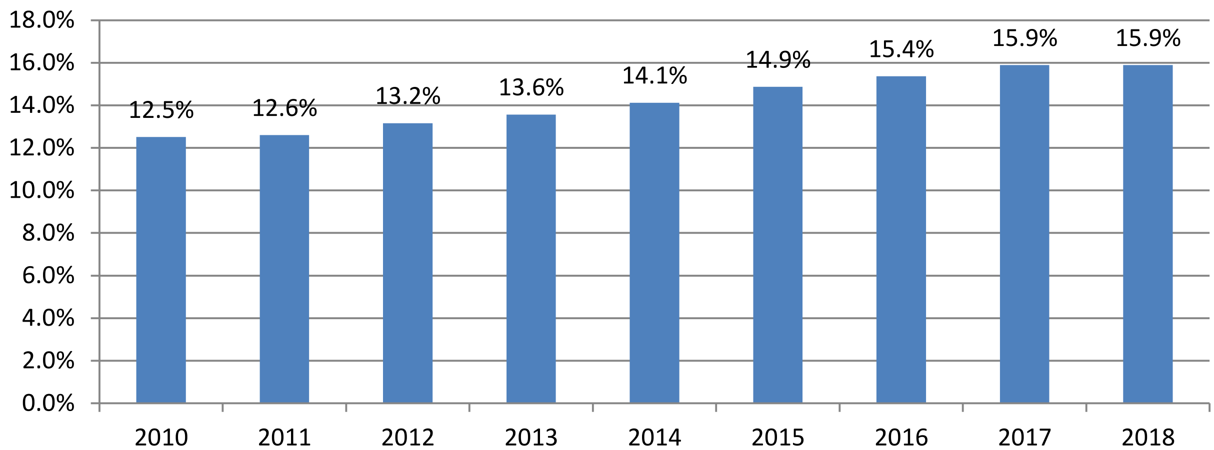
Figure 7. Gas Price per Mbtu – Henry Hub and WaHa



C. Royalty Rates

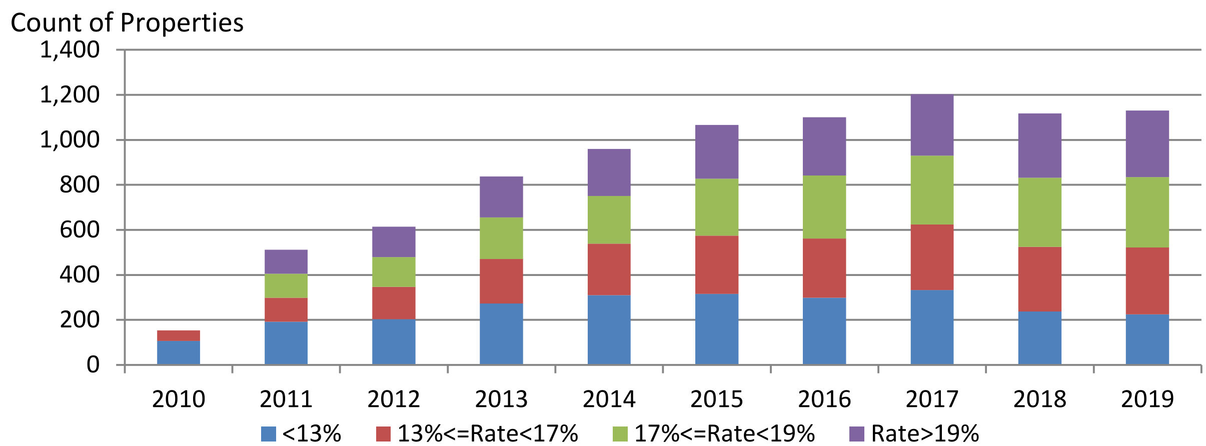
Historical data on royalty rates and royalties paid by producers are provided by the SLO. Average royalty rates have generally increased over the last several years as older wells have completed production and have been retired and as newer wells have come online that are often subject to relatively higher rates. As shown in Figure 8, for gas-producing wells that engaged in venting or flaring, computed average royalty rates have increased from 12.5% in 2010 to 15.9% in 2018.

Figure 8. Average Royalty Rates – Gas Producing Wells



Meanwhile, the proportion of properties subject to a royalty rate less than 13% to total properties has generally declined through time while properties subject to rates greater than or equal to 13% have increased. In 2010, the share of gas producing properties subject to royalty rates 13% or higher registered only about 30% of the total; however, the share increased to about 60% in 2011 and then to over 80% by 2018.

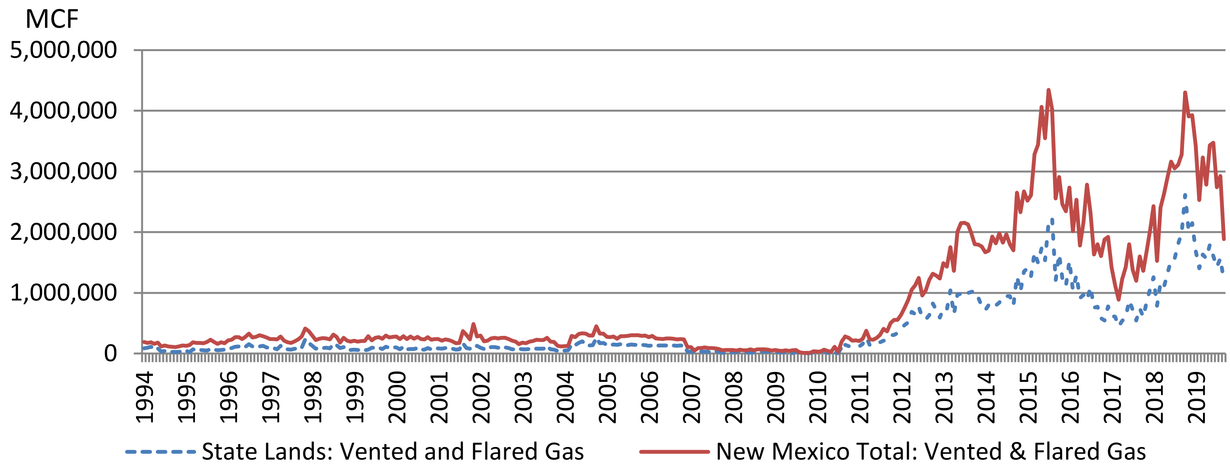
Figure 9. Count of Gas Producing Properties that Vented or Flared in at Least One Month in a Year by Computed Royalty Rate



D. Vented and flared gas volumes

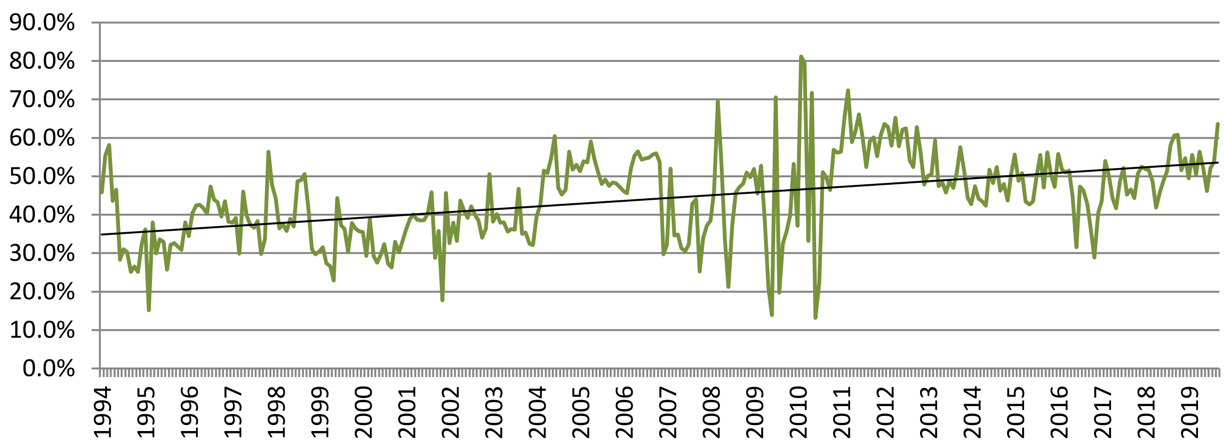
Data on volumes vented and flared are maintained by the SLO's Oil Conservation Division (OCD). For many New Mexico producers, natural gas is a byproduct of oil production and is a sometimes a nuisance product at low prices. Furthermore, producers in the Permian Basin who are typically focused on oil production may not have the infrastructure in place to collect gas thereby leading to venting or flaring at the wellhead. In addition, excess gas is sometimes produced by those who do not have the capacity to capture the entire volume with overage sometimes vented or flared. Figure 10 shows gas volumes vented or flared on New Mexico state lands and also the total volume vented or flared in New Mexico.

Figure 10. Gas Volumes Vented or Flared: New Mexico Total & State Lands



Over time, the share of total gas vented or flared in New Mexico has generally increased. In the mid- to late-1990's the share of vended or flared gas on state lands ranged between 30% and 40%. More recently, the share has generally ranged between 50% and 60%.

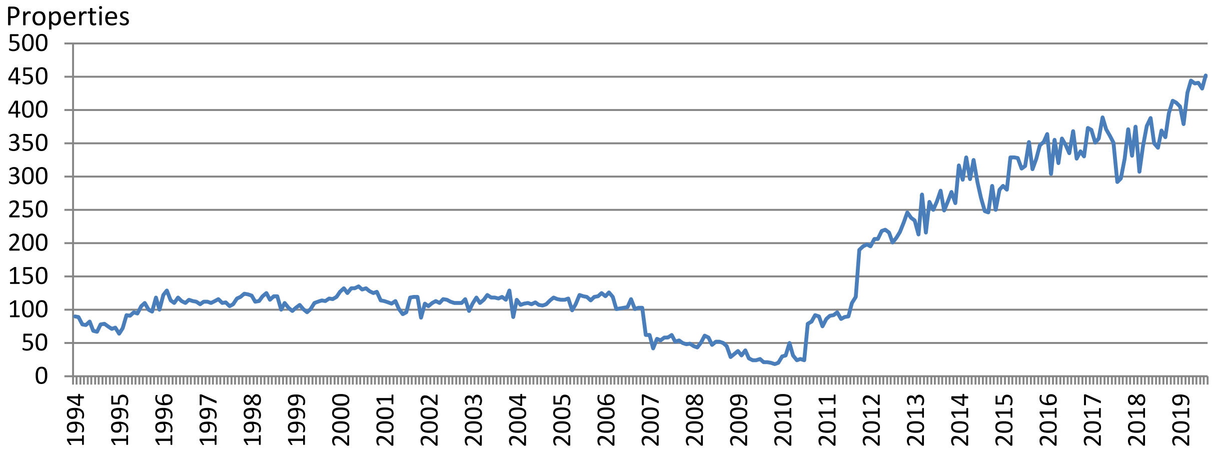
Figure 11. Share of Gas Flared in New Mexico on State Lands to Total Gas Flared in New Mexico (with trendline)



Although data extend back to 1994, the number distinct properties reported to be engaging in venting or flaring activities began to increase after 2010 – from below 50 properties in 2010 to around 450 properties by 2019. While a count of properties engaging in venting or flaring is not necessarily indicative of vented or flared volumes (as vented and flared volumes peaked in 2015-

2016 and again in 2018-2019), it speaks to the broad increase in popularity of the technique in oil and gas production.

Figure 12. Count of Properties Engaging in Flaring or Venting on State Lands by Month



E. Royalties from oil and gas production

Royalty revenues are a function of royalty rates, commodity prices, and commodity production volumes. Although royalties derived from oil and gas production is not the focus of this analysis (as this report is concerned with gas that is vented or flared), a description of royalties through the years is helpful for better highlighting how the royalty component factors operate together.

Figure 13 shows average monthly oil royalties by year broken down into royalty rate cohorts. While royalties were fairly evenly distributed between the less than 13%, 13% and 17%, and 17% and 19% royalty cohorts in 2013 and 2014, contribution from the lowest cohort began to wane in 2016 relative to the other two cohorts. Although contributions from all cohorts increased beginning in 2017, it was the 13% and 17%, and 17% and 19% royalty cohorts that saw the largest contributions. The share from highest royalty cohort (19% or higher) was low across the years – only contributing between 2% and 5% of the total in any given year – nevertheless, beginning in 2016, the low percentage still accounts for between \$5 million and \$10 million in royalties per year.

Figure 13. Average Monthly Oil Royalties by Royalty Rate Cohort

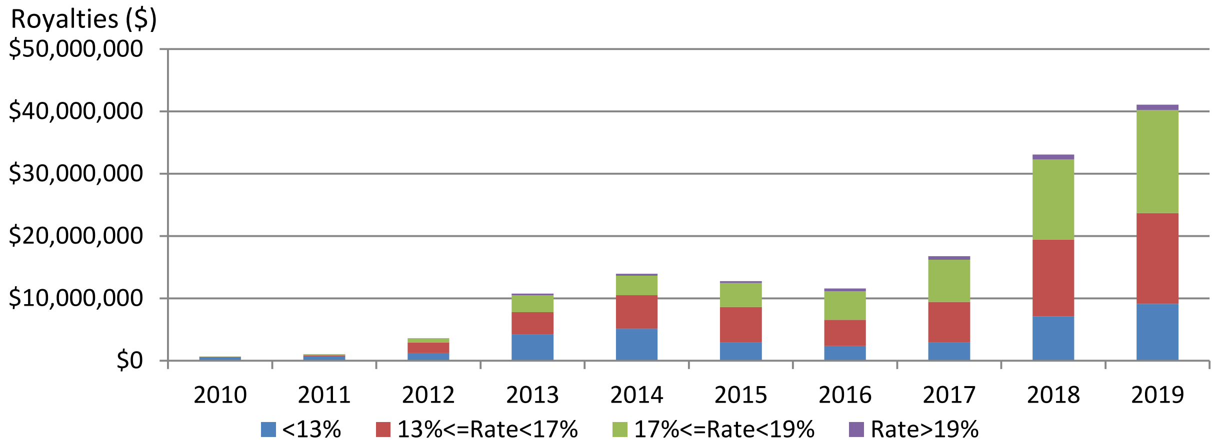
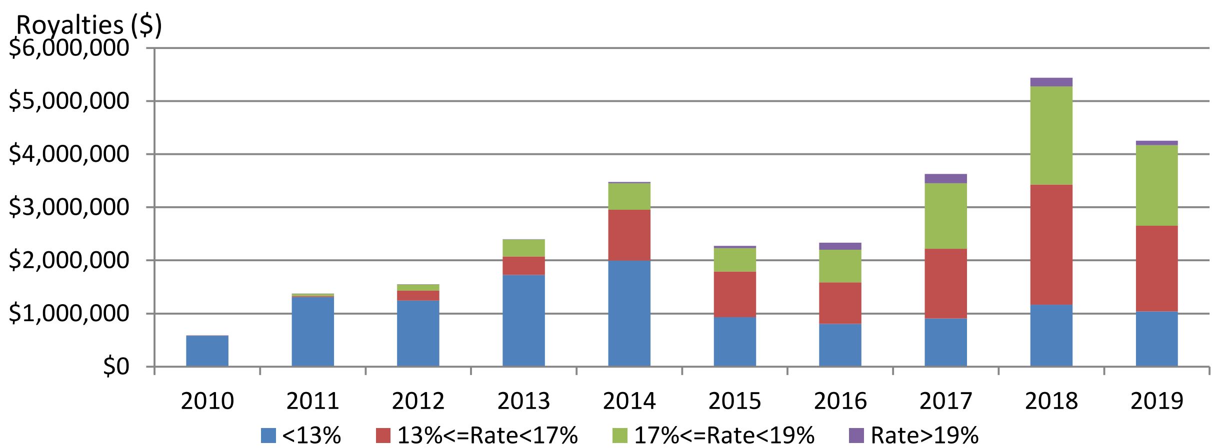


Figure 14 shows similar data for gas royalties. Royalties coming from properties assigned a royalty rate less than 13% increased from 2010 through 2014 before falling to about $1 million per month and remaining near that level until 2019. Beginning in 2012, royalties coming from higher royalty cohorts expanded with royalty contributions coming from the 13% to 17% and the 17% and 19% royalty cohorts exceeding contributions coming from the lowest royalty rate cohort.

Figure 14. Average Monthly Gas Royalties by Royalty Rate Cohort



III. Models & Projections

In this section, a model is developed to estimate revenue that could be obtained if all wells engaging in venting and flaring were subject to royalties. Royalty revenue from any given well or property (i) in any given period (t) is simply the product of the gas volume vented or flared, the market price for gas, and the royalty rate.

$$Royalty\ Revenue_{i,t} = Royalty\ Rate_i * Price_t * Volume\ Vented\ or\ Flared_{i,t}$$

Data used in this analysis are aggregated to monthly values because individual property-level data are sparse, making it difficult to perform statistical analysis and accurately assess data trends. Therefore, the royalty calculation becomes,

$$Royalty\ Revenue_t = Royalty\ Rate_t * Price_t * Volume\ Vented\ or\ Flared_t$$

Where $Royalty\ Revenue_t$ is total monthly revenue, $Royalty\ Rate_t$ is the average, or effective, monthly royalty rate, $Price_t$ is the average market price for natural gas, and $Volume\ Vented\ or\ Flared_t$ is the total monthly volume of vented or flared gas.

Since venting and flaring is typically a byproduct oil and gas production, it is necessary to produce models that statistically relate oil and gas production to venting and flaring volumes. Vented or flared volumes are then forecasted using simple forecasts for oil and gas production. Because the royalty calculation also requires gas price and royalty rate as inputs, those variables are also projected.

In addition to the models described in this section and the baseline royalty revenue projection, Appendix II contains results from alternative (low and high) scenarios and provides basic instructions for using a simple Microsoft Excel tool to adjust the alternative scenarios. Appendix I contains the statistical estimation results used as the basis for the forecasts and Appendix III includes a brief discussion of forecast accuracy.

A. Oil & gas price and production models

Over the last several years, oil production in New Mexico has been the key driver of gas production in the state; gas production has largely been a byproduct of oil production, particularly on state lands. Therefore, to estimate gas production a statistical relationship is developed between historical gas production and historical oil production. Because gas production is expected to retain at least a short term "memory," two lagged dependent variables $(t-1, t-2)$ are included in the statistical estimation.[1] Inclusion of lagged dependent variables also assists in mitigating the effects of serially correlated errors.

$$
\begin{aligned}
&Gas\ Production_t \\
&\qquad = \beta_0 + \beta_1 * Oil\ Production_t + \beta_2 * Gas\ Production_{t-1} \\
&\qquad + \beta_3 * Gas\ Production_{t-2} + u_{1t}
\end{aligned}
$$

In this model, the β's represent the estimated coefficients and u_{1t} is the error term.

To estimate gas price, statistical relationships are developed between historical data on average natural gas price (per the New Mexico State Land Office), historical data on the Henry Hub spot price, which is then projected by IHS Global Insight, a national forecasting service, and one lagged dependent variable.

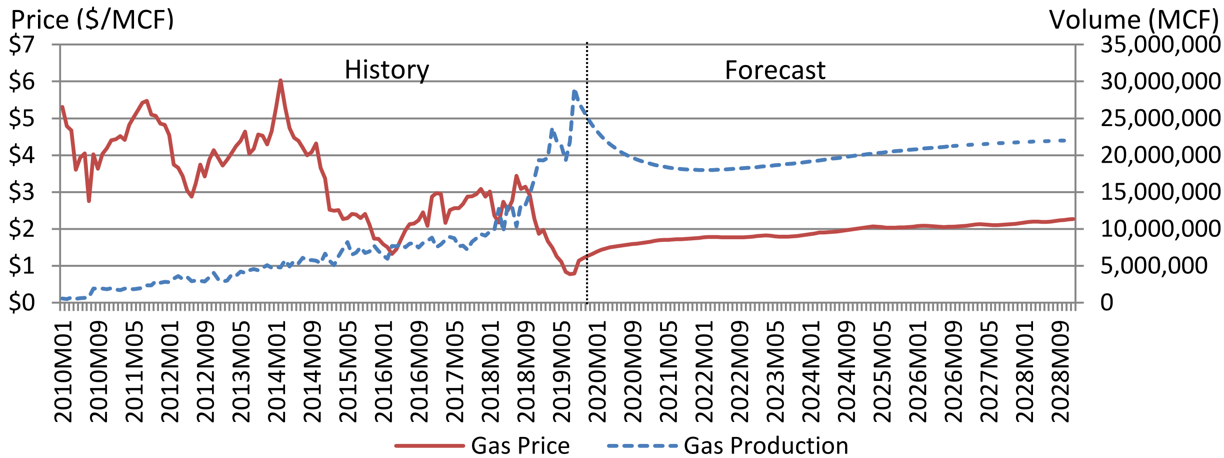
$$Gas\ Price_t = \alpha_0 + \alpha_1 * Henry\ Hub\ Price_t + \alpha_2 * Gas\ Price_{t-1} + u_{2t}$$

In this model, the α's represent the estimated coefficients and u_{2t} is the error term.

Figure 15 shows historical data for gas price and production as well as projections for each. Note the sharp increase in production and sharp decrease in price prior to the beginning of the forecast window. The rapid decrease in price is due in part to the oversupply conditions that were exacerbated by lack of infrastructure to manage excess gas.

[1] In some cases, indicator variables are used in econometric models to account for specific events or outliers. For simplicity, indicators are not shown in regression equations. See Appendix I for full models, coefficient estimates, and diagnostics. Unless otherwise noted, all models are estimated as log-log.

Figure 15. Price per MCF (left axis) and Gas Production Volume (right axis) – History and Forecast



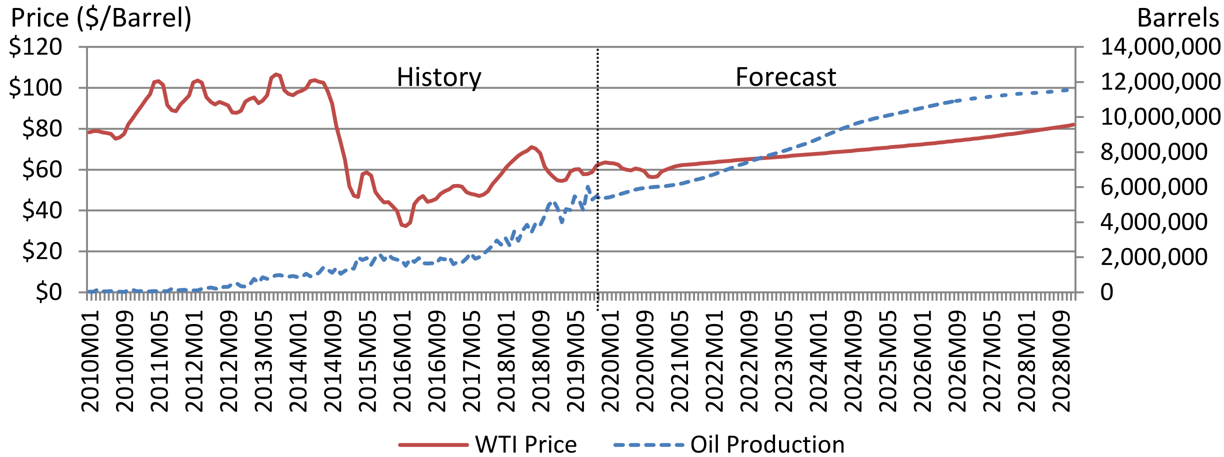
After gas production peaks in mid-2019, the projected series falls through early 2022 before slowly increasing for the remainder of the projection window. Gas price bounces back from below $1.00 per MCF in mid-2019 to about $1.25 near the beginning of the projection window and slowly increasing to just above $2.00 per MCF by the end of the projection.

To estimate oil production on state lands, oil production on state lands is statistically related to total oil produced in New Mexico and lagged oil production on state lands. A forecast for total oil produced in New Mexico is provided by the BBER quarterly forecasting model extended though the end of the forecast window. WTI price was tested as a possible explanatory variable; however, with the recent divergence between price and production (as price fell production increased), that explanatory variable was abandoned. Nevertheless, Figure 16 shows historical data for WTI and oil production and forecasts for each.

$$\begin{aligned} Oil\ Production_t &= \gamma_0 + \gamma_1 * Oil\ Production\ in\ NM_t + \gamma_2 * Oil\ Production_{t-1} \\ &+ \gamma_3 * Oil\ Production_{t-2} + u_{3t} \end{aligned}$$

In this model, the γ's represent the estimated coefficients and u_{3t} is the error term.

Figure 16. Price per Barrel (left axis) and Oil Production Volume (right axis) – History and Forecast



Despite continued low WTI prices throughout the projection window, oil production increases throughout. Production trends on state lands are generally consistent with expected trends in the state as well as industry forecasts for the region.

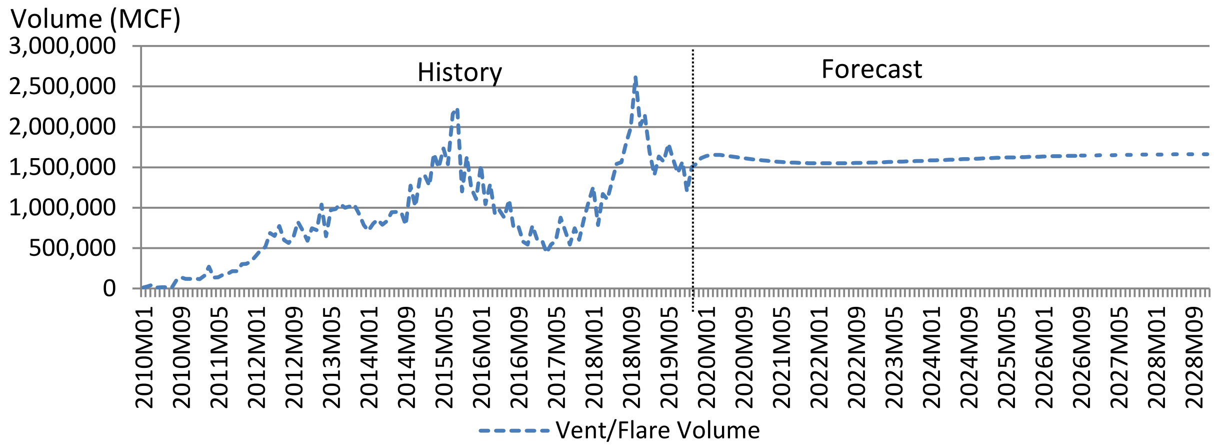
B. Models for volumes vented or flared

To estimate the volume of gas vented or flared, statistical relationships are developed between historical volumes of gas vented or flared, the volume of gas produced on state lands, the square of gas production, and two lagged dependent variables. The inclusion of gas production as an explanatory variable follows the logic that the volume vented and the volume produced are related, especially given the capacity constraints facing producers. The square of gas production is included to capture non-linearity between production and venting and flaring.

$$Vented_t = \delta_0 + \delta_1 * Gas\ Production_t + \delta_2 * Gas\ Production_t{}^2 + \gamma_3 * Vented_{t-1} + \gamma_3 * Vented_{t-2} + u_{4t}$$

In this model, the δ's represent the estimated coefficients and u_{4t} is the error term.

Figure 17. Volume Vented or Flared – History and Forecast



Projection of the volume vented or flared are generally flat throughout the forecast window and is likely conservative. However, given the low levels seen prior to 2013, and the peaks and valleys observed from 2015 through 2019, a conservative projection is warranted.

C. Model for royalty rate

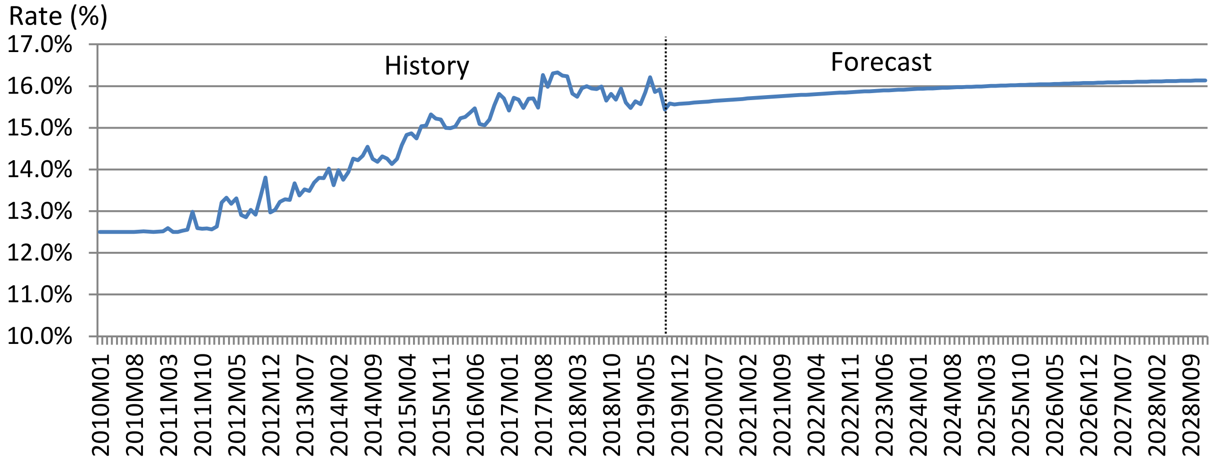
To forecast royalty revenue it is necessary to project the applicable royalty rate. Absent administrative or regulatory changes, the (average) royalty rate is expected to generally follow historical trend. Therefore, the royalty rate model utilizes two lags of the dependent variable. The coefficients from the model estimation are then used to project the average royalty rate.

$$Royalty\ Rate_t = \theta_0 + \theta_1 * Royalty\ Rate_{t-1} + \theta_1 * Royalty\ Rate_{t-2} + u_{5t}$$

In this model, the θ's represent the estimated coefficients and u_{5t} is the error term.

As shown in Figure 18, the (average) royalty rate is forecasted to slowly increase from about 15.5% at the beginning of the forecast period to around 16.2% by the end of the forecast. The increase in average royalty rate reflects the combined effect of old leases, which often have low royalty rates, retiring, and new leases, which often have relatively higher royalty rates, coming online.

Figure 18. Effective Gas Royalty Rate – History and Forecast



D. Revenue models

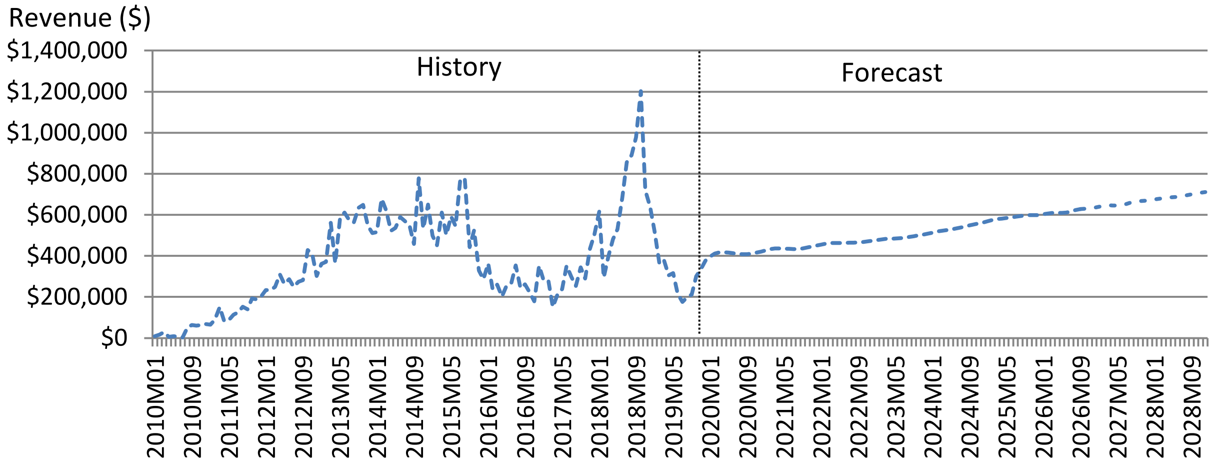
Oil and gas royalty revenues are the product of the commodity volume extracted and sold, the current commodity market price, and of the applicable royalty rate.

$$Royalty\ Revenue_t = Royalty\ Rate_t * Price_t * Volume\ Vented\ or\ Flared_t$$

In the case of vented and flared gas, royalty revenue is therefore a product of the gas volume vented or flared (shown in Figure 16), the price of gas at the time of venting or flaring (shown in Figure 14), and the average royalty rate (shown in Figure 17).

Figure 19 shows historical revenues and projected revenues could be available if royalties were assessed on (all) flared or vented gas using the forecasts developed for the three variables. Note that historical data extends through September 2019; therefore, forecasted royalty revenue begins October 2019.

Figure 19. Royalty Revenue Potential for Vented or Flared Gas (Baseline Model) – History and Forecast



The projection calls for royalty revenue potential to increase from around $400,000 per month at the beginning of the forecast window to around $800,000 per month near the end of the forecast window. Modeled results and forecasts for revenue potential are discussed in greater detail in the following section.

IV. Analysis & Discussion

A complete accounting of total royalties requires summing royalties paid from oil and gas production and the indirect royalties paid from vented or flared gas. This report, however, only focuses on the royalty revenue potential from gas that is vented or flared, which is likely to be a relatively small share of total royalties.

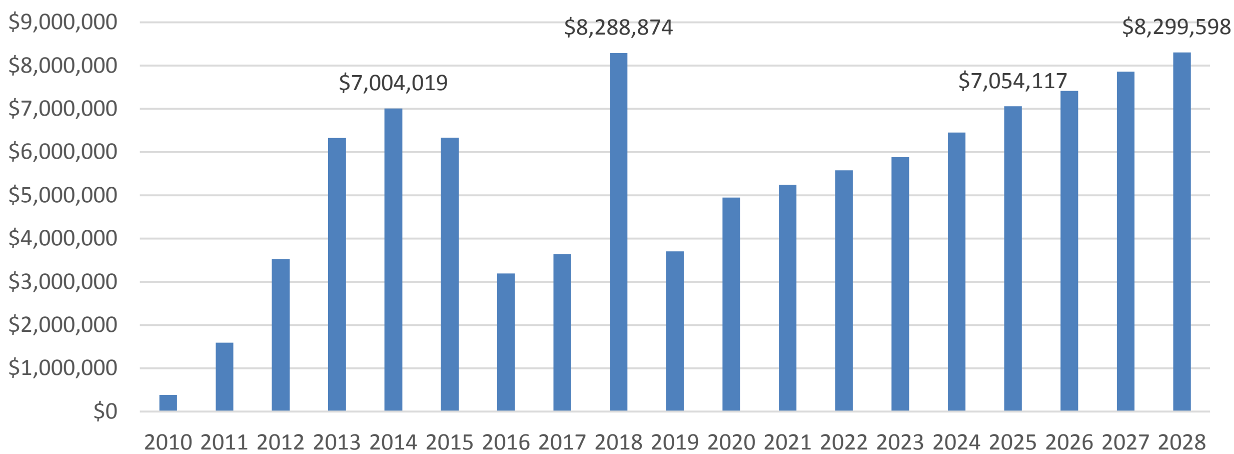
Discussed in the following subsection is the situation where all properties engaged in venting or flaring are required to pay royalties, regardless of when the lease began. In subsection B, estimated is the royalty potential for new leases only – or leases that have not started producing oil or gas as of September 2019. Therefore, this portion of the analysis considers only newly producing, or prospective, leases.

It is important to note that the projections require that regulations surrounding venting or flaring activity remain consistent through time. Forecast accuracy will be limited if there are changes in rules at state or federal levels (such as caps on venting or flaring). In addition, no attempt was made to assess whether requiring royalty payment on vented or flared gas, and thus increasing costs, will directly impact oil or gas production decisions. Rather, the models developed assume that due to the recent surge in investments by large oil and gas producers in New Mexico over the last several years, sufficient inertia exists over the relatively short forecast window, such that behavioral changes due to requiring payment for venting or flaring gas are likely to be minor.

A. Assuming all properties pay royalties for venting or flaring

The projections presented thus far assume that all gas vented or flared will be assessed royalties. For historical periods, royalty amounts correspond to revenues lost as a result of not assessing royalties on vented or flared volumes whereas royalty amounts in the forecast window correspond to revenues that would be available if royalties were assessed on all vented and flared volumes. Figure 20 shows annual royalty revenue by year.

Figure 20. Royalty Revenue for Vented or Flared Gas by Year



After peaking at above $8.2 million in foregone royalty revenue from vented or flared gas in 2018, only about $3.7 million in foregone royalties are projected for 2019. Thereafter, the model projects royalty revenue between $5.0 million and $6.5 million in each year from 2020 to 2024. Thereafter, revenue increases to above $7.0 million per year before ending at $8.3 million in 2028, slightly exceeding the 2018 peak.

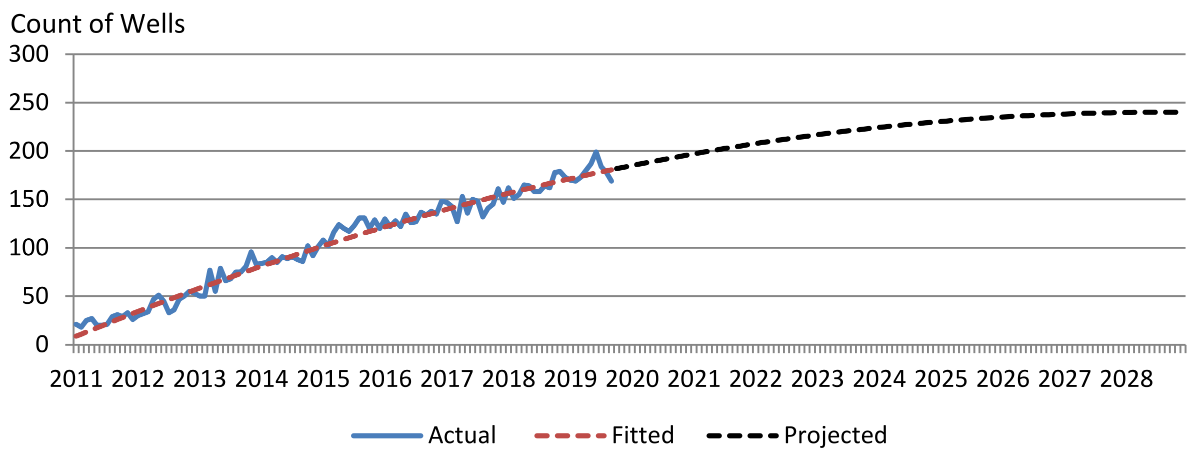
B. Royalties only from future wells engaging in venting or flaring

This scenario assumes that only future wells will pay royalties on vented and flared gas. In order to project the number of net new wells or properties producing in any given month, first the total number of wells is extrapolated forward using a simple second order time trend polynomial regression.

$$Wells_t = \pi_0 + \pi_1 * Time_t + \pi_2 * {Time_t}^2 + u_{6t}$$

In this model, the π's are the estimated coefficients and u_{6t} is the error term. A polynomial regression of order two is selected in this case not only because of high model fit ($R^2 = 0.97$), but also because of the likely nonlinear (specifically, concave) series behavior. This is due to expected constraints with regard to future lands available for oil and gas production.

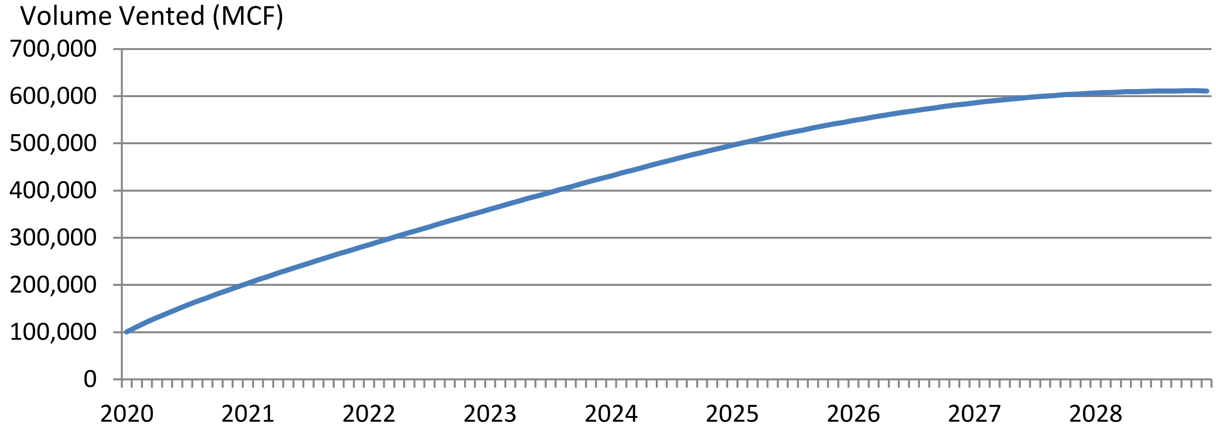
Figure 21. Extrapolation of Total Wells



Next, the projected series is compared against the average number of wells over the last twelve months of actual data (from October 2018 through September 2019). The count of wells in each month beyond the average over the twelve month period is assumed to be net new.

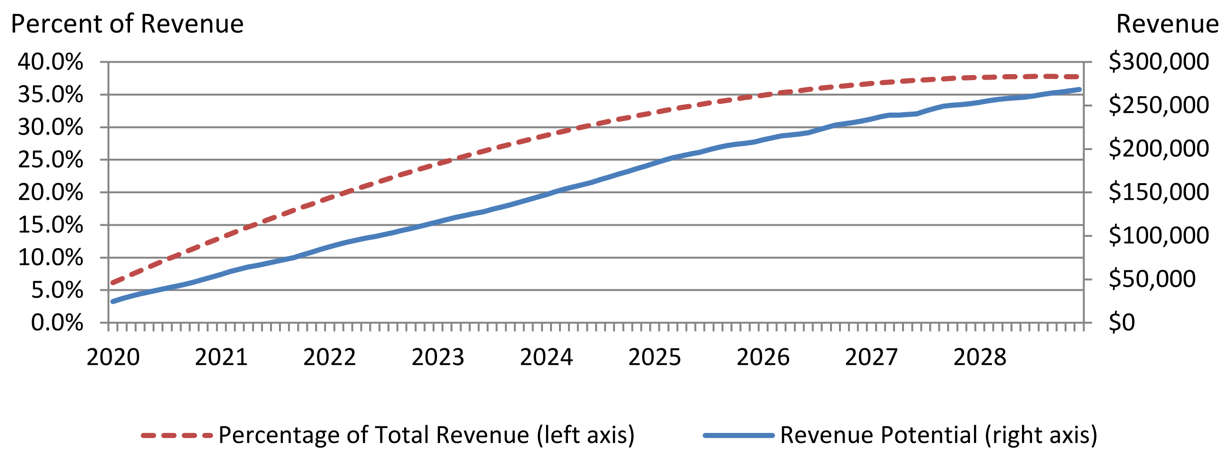
To estimate the volume vented or flared from net new wells, the share of net new wells to projected total wells is computed and applied to the projected vented and flared volume discussed earlier in the report. This calculation assumes that the average volume vented per well is the same for new and existing wells.

Figure 22. Volume Vented – Only New Wells



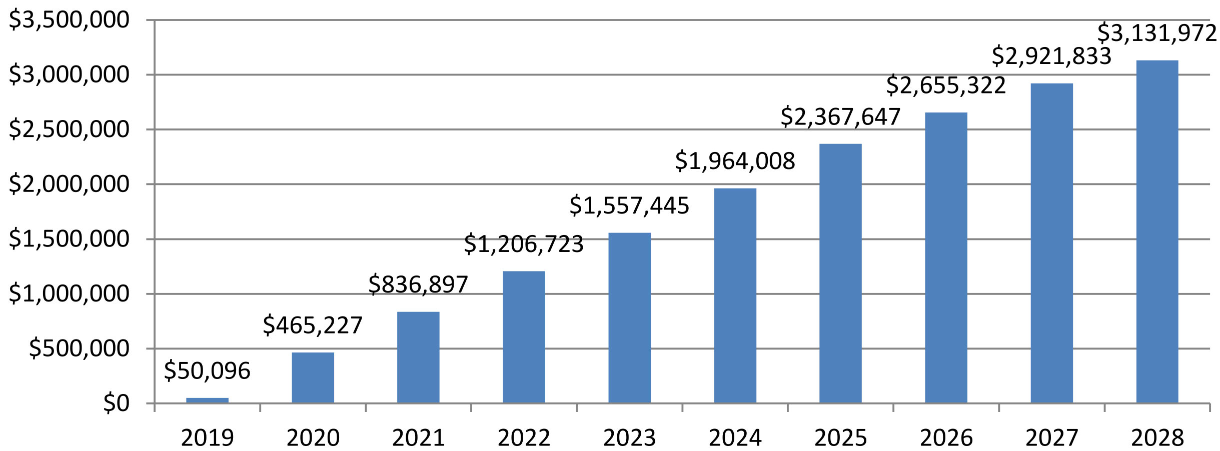
To compute royalty revenue, vented volume in each month for new wells is multiplied with the monthly gas price and royalty rate projections. As shown in Figure 23, the share of revenue from new wells to total increases from around 5% to around 35% by 2028. As a greater share of the total is represented by new wells, royalty revenue from venting and flaring increases from around $40,000 per month in the first year to an average over $250,000 per month by 2028.

Figure 23. Royalty Revenue for Vented or Flared Gas (monthly) – Only New Wells



Put in terms of annual revenues, assuming only new wells are subject to royalties on vented or flared gas, around $465,000 in revenue may be available by 2020 with that annual amount increasing to over $1.5 million by 2023 and then to over $2.3 million per year beginning in 2025.

Figure 24. Royalty Revenue for Vented or Flared Gas (annual) – New Wells



V. Conclusions and Limitations

This report estimated the likely revenue potential for assessing royalties on vented or flared gas assuming (1) royalties are captured from all wells engaged in venting or flaring, and (2) royalties are captured only on newly producing wells. In both cases, royalty revenue potential is notable. In the case of all wells, even excluding the outlier year 2018, where royalty revenue foregone totaled $8.3 million, royalty revenue foregone averaged about $4.0 million per year from 2010 to 2017. Given continued expansion in the oil industry, royalty revenue potential is projected to increase in the future to an average of about $6.5 million per year.

The general trend of increasing royalty revenue potential still holds if royalties are collected from only newly producing wells. As production slows on old and retiring wells, and as new lines of production are developed, venting and flaring activity from the new wells should constitute an increasing share of the total vented or flared volume. Royalty revenue potential from these new wells should total just under $500,000 in 2020, surpass $1.0 million in 2022, and then reach over $3.0 million by 2028.

It is important to note that the conclusions discussed in this report are contingent on several factors. Forecasts rely on the assumption that historical relationships, as estimated in the modeling process, persist into the future. Changes in the statistical relationships among variables will require model updates and re-estimation. In addition, the research assumes no behavioral response with regard to future drilling and production decisions by producers to (increased) costs associated with paying royalties for vented or flared gas. If it turns out that producers alter investment and production decisions, additional analysis will be required to uncover and control for those effects.

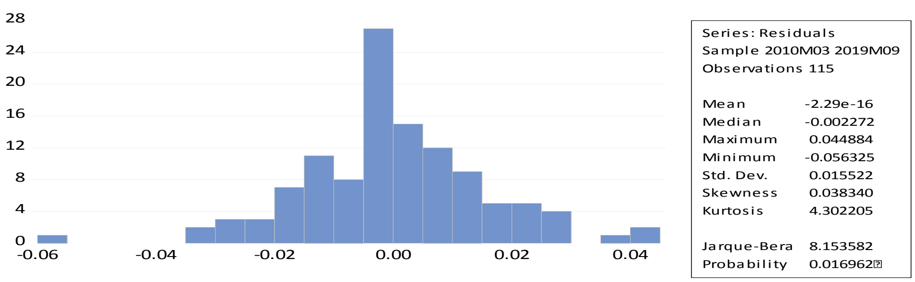
VI. Appendix 1. Regression Results & Diagnostics

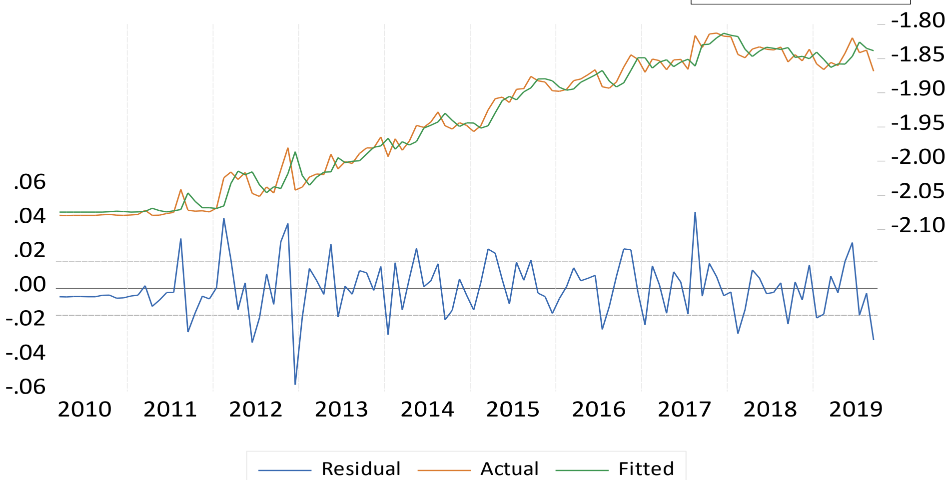
Royalty Rates

Dependent Variable: LOG(ROYALTYRATE)
Method: Least Squares
Date: 01/23/20 Time: 12:56
Sample (adjusted): 2010M03 2019M09
Included observations: 115 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.032778	0.031154	-1.052107	0.2950
LOG(ROYALTYRATE(-1))	0.709221	0.092440	7.672243	0.0000
LOG(ROYALTYRATE(-2))	0.272713	0.092214	2.957405	0.0038

R-squared	0.971239	Mean dependent var	-1.945757
Adjusted R-squared	0.970726	S.D. dependent var	0.091529
S.E. of regression	0.015660	Akaike info criterion	-5.449618
Sum squared resid	0.027468	Schwarz criterion	-5.378011
Log likelihood	316.3530	Hannan-Quinn criter.	-5.420553
F-statistic	1891.087	Durbin-Watson stat	2.045607
Prob(F-statistic)	0.000000		



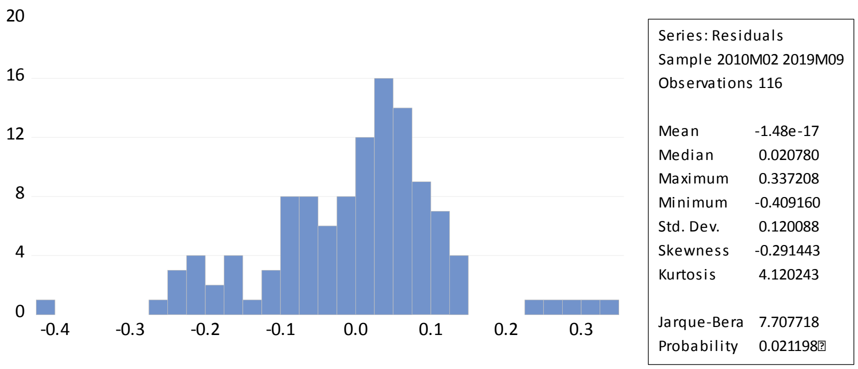


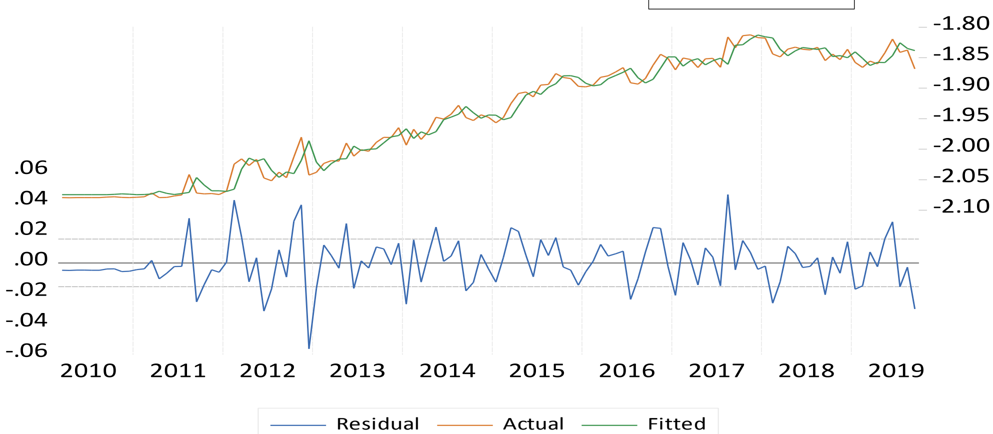
Gas Price

Dependent Variable: LOG(GAS_NETPRICE)
Method: Least Squares
Date: 01/23/20 Time: 13:30
Sample (adjusted): 2010M02 2019M09
Included observations: 116 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(PNGHH)	0.133177	0.074705	1.782688	0.0774
LOG(GAS_NETPRICE(-1))	0.779639	0.067814	11.49676	0.0000
C	0.027197	0.067245	0.404444	0.6867
A2014M02	0.108071	0.041568	2.599879	0.0106
A2019M08	-0.169182	0.087940	-1.923830	0.0569

R-squared	0.925581	Mean dependent var	1.099590
Adjusted R-squared	0.922899	S.D. dependent var	0.440209
S.E. of regression	0.122233	Akaike info criterion	-1.323627
Sum squared resid	1.658443	Schwarz criterion	-1.204938
Log likelihood	81.77038	Hannan-Quinn criter.	-1.275446
F-statistic	345.1376	Durbin-Watson stat	1.711480
Prob(F-statistic)	0.000000		





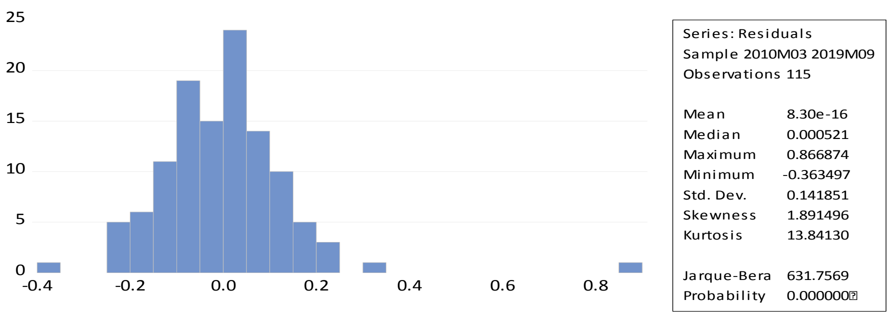
Gas Production

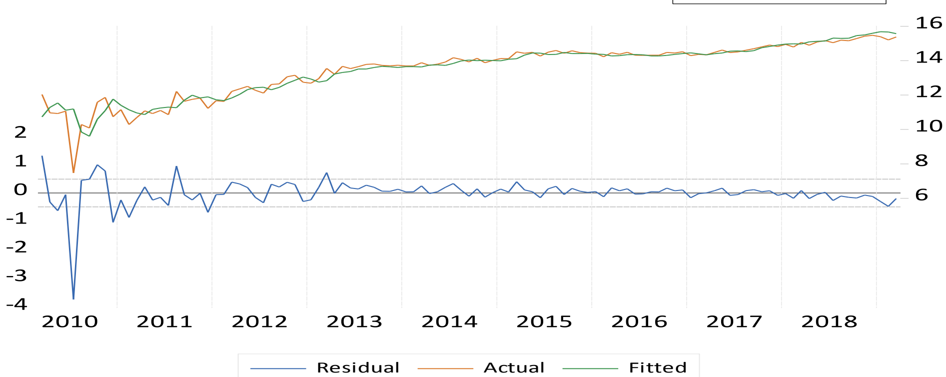
Dependent Variable: LOG(GASPROD)
Method: ARMA Maximum Likelihood (OPG - BHHH)
Date: 01/22/20 Time: 13:35
Sample: 2010M01 2019M09
Included observations: 117

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(OILPROD)	-0.275566	0.121236	-2.272976	0.0249
LOG(OILPROD)^2	0.020217	0.006554	3.084814	0.0026
C	15.28427	1.030448	14.83265	0.0000
AR(1)	0.991580	0.022114	44.84018	0.0000
SIGMASQ	0.017138	0.001568	10.92780	0.0000

R-squared	0.976821	Mean dependent var	15.44971
Adjusted R-squared	0.975993	S.D. dependent var	0.863572
S.E. of regression	0.133803	Akaike info criterion	-1.108155
Sum squared resid	2.005172	Schwarz criterion	-0.990113
Log likelihood	69.82706	Hannan-Quinn criter.	-1.060231
F-statistic	1179.984	Durbin-Watson stat	1.921815
Prob(F-statistic)	0.000000		

Inverted AR Roots	.99



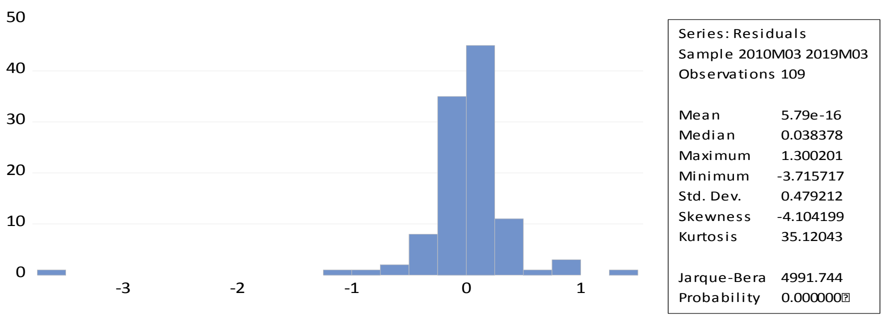


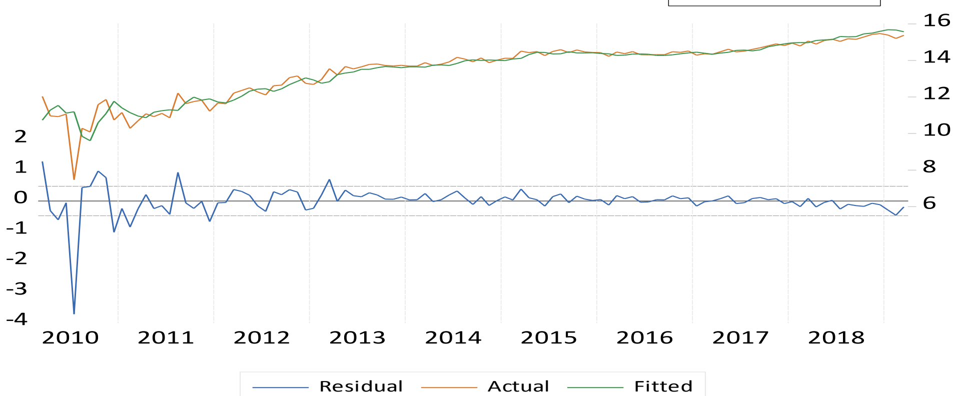
Oil Production

Dependent Variable: LOG(OILPROD)
Method: Least Squares
Date: 01/24/20 Time: 10:30
Sample (adjusted): 2010M03 2019M03

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(OILPROD_NM)	0.729895	0.188827	3.865425	0.0002
C	-8.513580	2.327365	-3.658033	0.0004
LOG(OILPROD(-1))	0.387627	0.086230	4.495263	0.0000
LOG(OILPROD(-2))	0.372379	0.085738	4.343204	0.0000

R-squared	0.902698	Mean dependent var	13.46423
Adjusted R-squared	0.899918	S.D. dependent var	1.536266
S.E. of regression	0.486010	Akaike info criterion	1.430830
Sum squared resid	24.80156	Schwarz criterion	1.529595
Log likelihood	-73.98025	Hannan-Quinn criter.	1.470883
F-statistic	324.7044	Durbin-Watson stat	1.897689
Prob(F-statistic)	0.000000	Wald F-statistic	163.6105
Prob(Wald F-statistic)	0.000000		



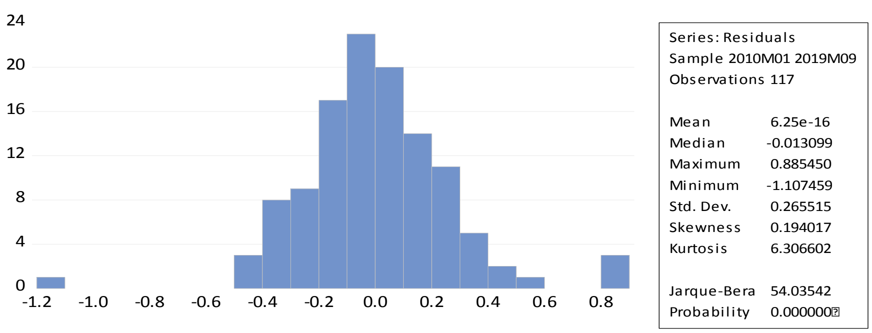


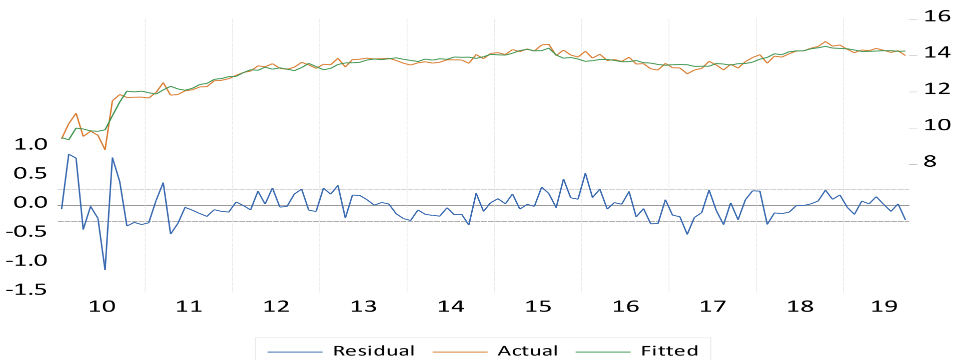
Vented Gas Model

Dependent Variable: LOG(VENT)
Method: Least Squares
Date: 01/23/20   Time: 13:05
Sample: 2010M01 2019M09
Included observations: 117

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(GASPROD)	5.892883	0.934248	6.307620	0.0000
LOG(GASPROD)^2	-0.170710	0.029668	-5.754012	0.0000
C	-43.82070	6.956264	-6.299458	0.0000
LOG(VENT(-1))	0.331738	0.074742	4.438458	0.0000
LOG(VENT(-2))	0.174980	0.065780	2.660086	0.0090
A2015M08	0.392138	0.086058	4.556690	0.0000
A2018M10	0.241097	0.106051	2.273400	0.0249

R-squared	0.948569	Mean dependent var	13.31382
Adjusted R-squared	0.945764	S.D. dependent var	1.170787
S.E. of regression	0.272660	Akaike info criterion	0.296785
Sum squared resid	8.177809	Schwarz criterion	0.462044
Log likelihood	-10.36195	Hannan-Quinn criter.	0.363878
F-statistic	338.1327	Durbin-Watson stat	1.740544
Prob(F-statistic)	0.000000		





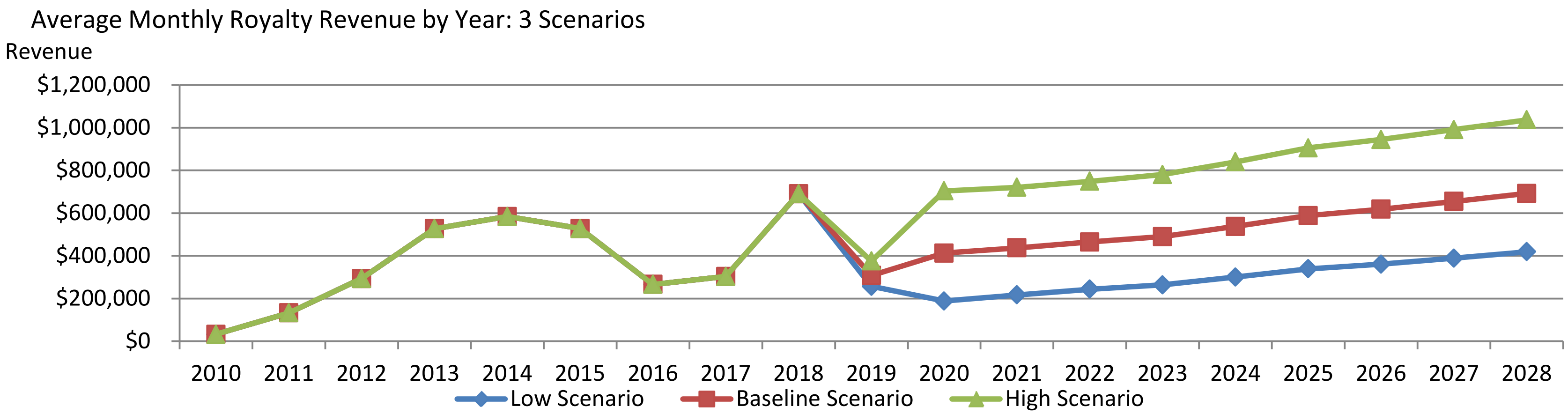
VII. Appendix 2. Updateable MS Excel Spreadsheet

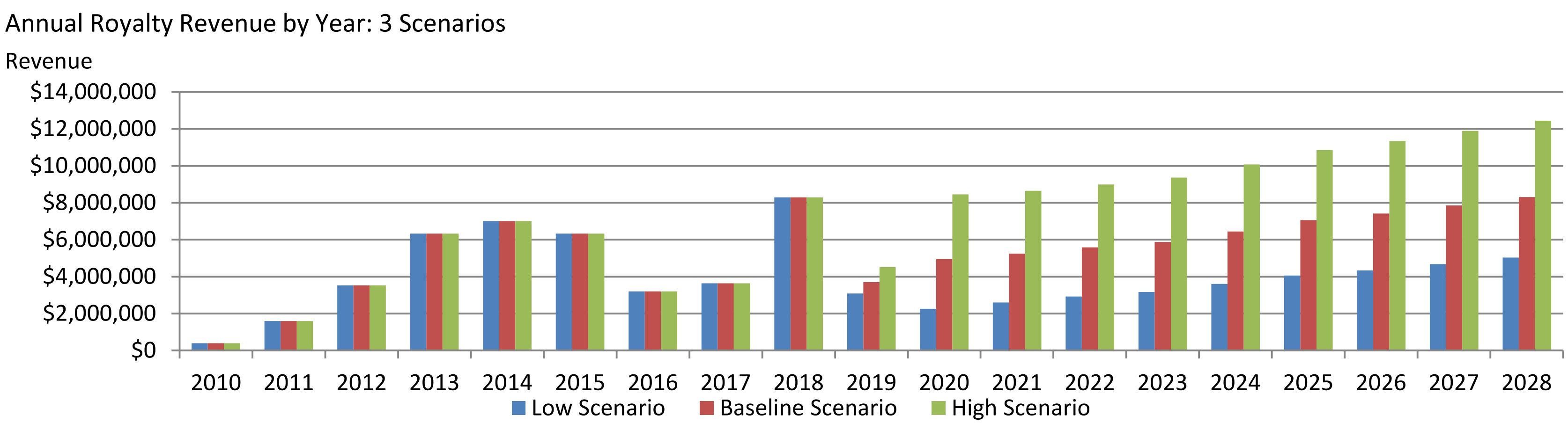
The key elements to the updatable spreadsheet are shown in the table and chart on this page and are discussed below.

Column B	Column C	Column D	Column E	Column F	Column G
-	Historical Values	Computed Forecast Values: October 2019 - December 2028			
Variable	January 2010 - September 2019 (Do Not Change)	Reference vs. Baseline	Change Y/N	Value (changed or computed)	Forecast Values (Do Not Change)
Royalty Rate (monthly average)	14.3%	Baseline Average --->			*15.9%*
		Percentage Points Higher than Baseline	**change -->**	**1.0%**	16.9%
		Percentage Points Lower than Baseline	**change -->**	**1.0%**	14.9%
Gas Price (monthly average)	$3.28	Baseline Average --->			*$2.17*
		Dollars Higher than Baseline	**change -->**	**$0.75**	$2.92
		Dollars Lower Baseline	**change -->**	**$0.75**	$1.42
Vented Volume (monthly average)	890,804	Baseline Average			*1,552,328*
		Percent Higher than Baseline	**change -->**	**10.0%**	1,707,561
		Percent Lower than Baseline	**change -->**	**10.0%**	1,397,095
Royalty Revenue (monthly average)	$367,214	Baseline Average --->			*$538,040*
		Percent Higher than Baseline (computed)	don't change -->	57%	$845,628
		Percent Lower than Baseline (computed)	don't change -->	45%	$297,551
Royalty Revenue (Sum over Period)	$42,963,984	Baseline Average --->			*$59,722,442*
		Percent Higher than Baseline (computed)	don't change -->	57%	$93,864,688
		Percent Lower than Baseline (computed)	don't change -->	45%	$33,028,176

Change **bolded** value(s) in **Column F** for the high scenario

Change **bolded** value(s) in **Column F** for the low scenario


Average Monthly Royalty Revenue by Year: 3 Scenarios
Revenue
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028
Low Scenario
Baseline Scenario
High Scenario


Annual Royalty Revenue by Year: 3 Scenarios
Revenue
$14,000,000
$12,000,000
$10,000,000
$8,000,000
$6,000,000
$4,000,000
$2,000,000
$0
2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028
Low Scenario
Baseline Scenario
High Scenario

The baseline scenario results are based on the estimations and forecasts for the variables already described in the text. The royalty revenue calculation is a function of the applicable royalty rate, the market price of gas, and the gas volume vented or flared. The updatable spreadsheet allows the user the modify any of the three variables to create simple low and high royalty revenue simulations that are referenced against the forecasted baseline. The elements of the spreadsheet are described according to the respective columns.

Column B describes the particular variables used in the simulation. The spreadsheet contains three input variables: Royalty Rate (monthly average), Gas Price (monthly average), and Vented Volume (monthly average), and two output variables: Royalty Revenue (monthly average) and Royalty Revenue (total sum over period). The royalty revenue variables are revenues that would be owed to the SLO if oil and gas producers were required to pay royalties for vented or flared gas.

The variables described as 'monthly average' correspond to the calculated average monthly value for the particular variable. The variable described 'total sum over period' is, as the name implies, a sum over a period.

Column C contains historical data over the period from January 2010 through September 2019. The monthly average variables are the average values for each variable in each month over the historical period whereas the total sum is the sum of royalty revenues that would have been owed over the historical period if producers were required to pay royalties for vented or flared gas.

Columns D through G are closely related because they all correspond to the forecast window beginning October 2019 through December 2028. **Column D** describes whether the variable comes from the baseline scenario (and therefore cannot be altered in the simulation) or whether the variable is from the low or high scenarios. Note that the table is color coded: grey cells correspond to values that cannot (or should not) be changed in the table whereas blue or peach cells correspond to values that can be changed.

Columns E, F and G are related as **Column E** describes whether the value in Column F can be changed in the simulation. Only change the values in Column F where Column E states "change →."

Column F shows how the variables can be changed in the high and low scenarios compared to the baseline scenario for the three input variables. The “higher” or “lower” scenarios are referenced to the baseline scenario for the two output variables. In the Royalty Rate rows, the values in Column F are the percentage points above or below the baseline. In the Gas Price rows, Column F is the price (in dollars) above or below the baseline scenario. In the Vented Volume rows, Column F shows the how much higher or lower the gas volume is projected to be over the forecast period compared to the baseline (in percent). Again, only change the bolded values in the blue or peach colored cells (and not the values in the grey cells).

Column G shows the baseline average (or sum) values over the forecast period and the user-inputted values from the high or low scenarios. For example, the baseline value for Royalty Rate is 15.9% (which cannot be changed). The value in the high scenario in Column F is 1%, meaning that the average monthly value in the high scenario is one percentage points higher, or 16.9%. The low scenario works in the same manner. The baseline average gas price is $2.17; the high scenario adds $0.75 to that calculation making it $2.92. The baseline average monthly vented volume is 1.55 million; the high scenario adds 10% making it 1.71 million.

The results of the simulation produce the output values which correspond to estimated royalty revenues. In the baseline scenario, average royalty revenue is computed as roughly $538,000 per month. The combined effect of the changes in the high scenario produces royalty revenue that is 57% higher than the baseline of $846,000 million per month. Although not explicitly discussed, the combined effect of the analogous changes in the low scenario produces royalty revenue that is 45% lower than the baseline scenario of $298,000 per month.

In the MS Excel spreadsheet, the results from each of the scenario is shown in the chart below the table and will automatically update when changes are made to the assumptions in the table.

Though not discussed, the spreadsheet tab includes additional useful data and output. Columns K though N show the data that make the charts that begin in Column B as well as calculated annual growth rates (beginning in row 49). Column S shows the data series for the input variables (royalty rate, gas price, and vent volume) with an associated chart to the right of each series.

Note that the baseline scenarios cannot be updated without re-estimating the underlying econometric forecasting model. Periodic updating of the model is advised.

VIII. Appendix 3. Prediction Accuracy

Model accuracy is assessed in terms of in-sample performance. The revenue model developed in this report is composed of three elements: gas price, royalty rate, and the volume vented or flared and is denoted as "Composite Model." An alternative modeling strategy is to model royalty revenues directly. Three additional models are assessed. The first is a simple one period lagged dependent variable model.

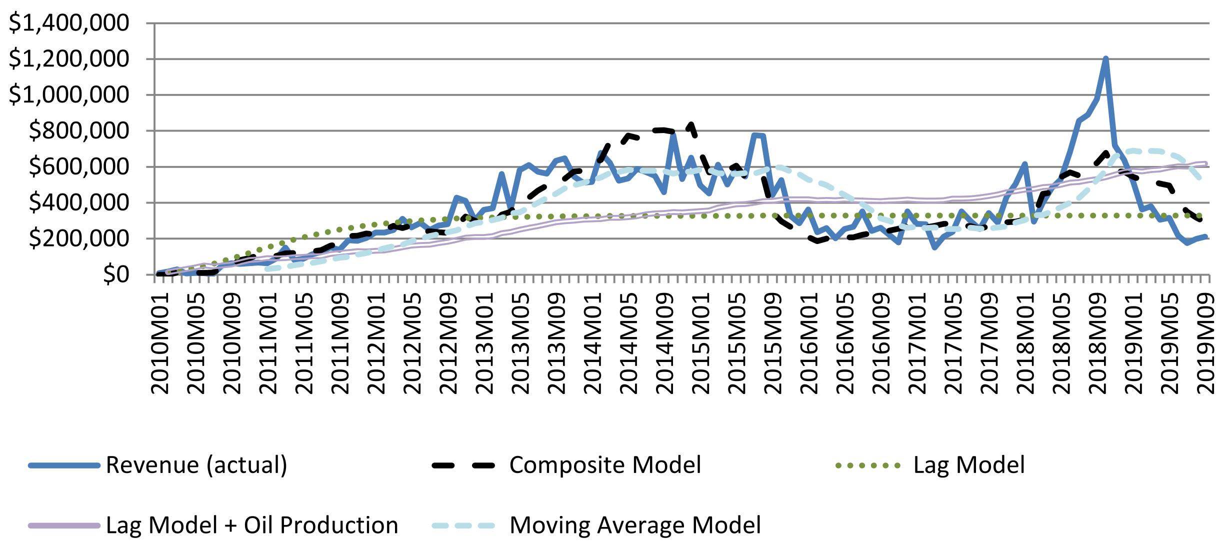
$$Revenue_t = \tau_0 + \tau_1 * Revenue_{t-1} + u_{7t}$$

Since oil production likely drives venting and flaring, the next model adds oil production on state lands.

$$Revenue_t = \varphi_0 + \varphi_1 Revenue_{t-1} + u_{8t}$$

Also considered is a simple moving average of royalty revenues. In this case, a twelve month moving average is selected. In-sample predictions are shown graphically in Figure A3.1 and are referenced against actual revenue.

Figure A3.1 In-sample Prediction Comparison



Over the in-sample period from January 2010 through September 2019, the Composite Model out-performs the other models as it has the lowest mean squared error (MSE). Perhaps surprisingly, the simple Moving Average Model has the next lowest MSE; however, the value is still about 75% above the Composite Model.

Table A3.1 Mean Squared Error: Model Comparison

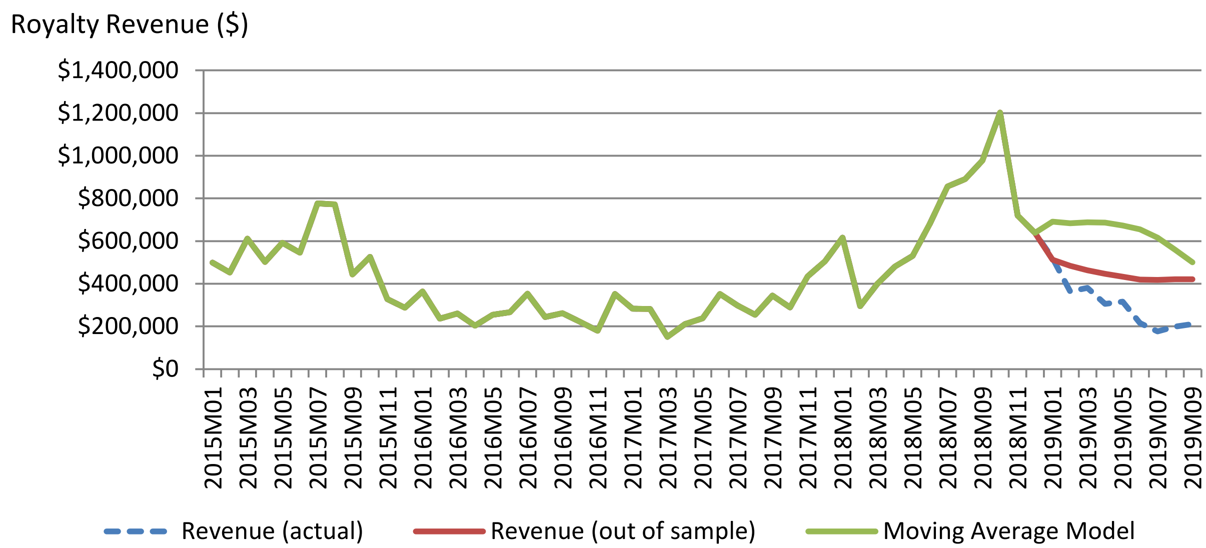
Composite Model*	Lag Model**	Lag Model + Oil Production**	Moving Average Model**
19,318,157,034	47,283,105,008	47,369,011,575	33,864,745,304

* Created by combining forecasts for gas price, royalty rate, and vent/flare volume

** Dependent variable is royalty

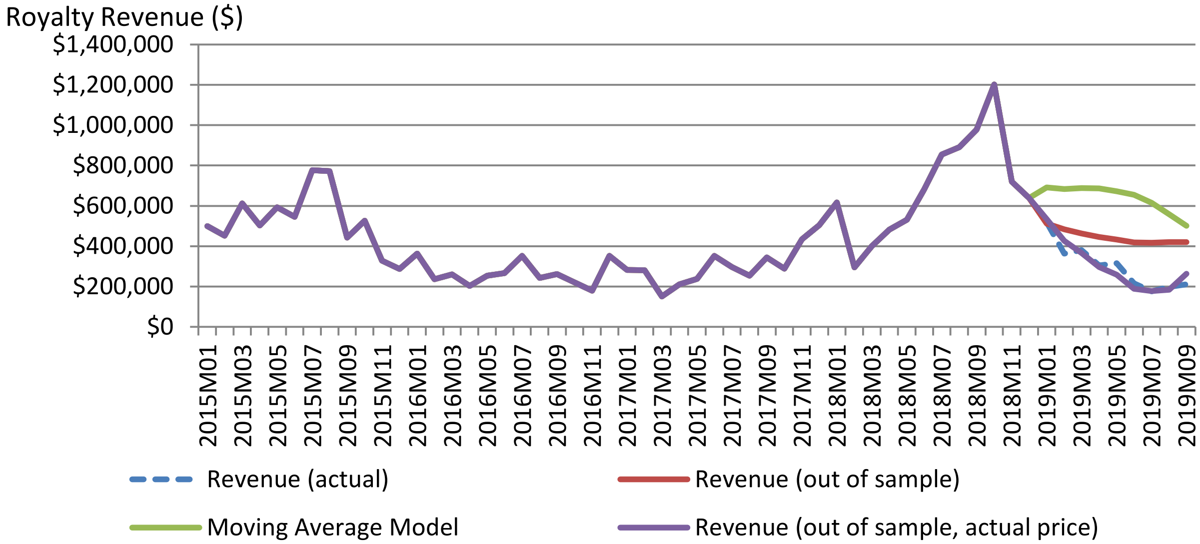
Because the Composite Model and the Moving Average models outperformed the other two models, they are used for (in-sample) out-of-sample prediction. All of the Composite Model's equations are re-estimated only through December 2018. The Moving Average model takes data prior to January 2019 as given. The prediction window begins January 2019 and ends September 2019. As shown in Figure A3.2, the Moving Average model is again out-performed by the Composite Model (with a MSE more than 4 times larger). In this case, the Composite Model's over-projection can be explained largely by the historically low gas prices faced by New Mexico producers.

Figure A3.2 Out-of-sample Prediction Comparison



To visualize the effect of the gas price over-prediction, Figure A3.3 includes an additional revenue series that is created by taking the out-of-sample projections for vented or flared gas and royalty rate but applies the actual gas price. Notice that the new series closely mirrors the actual series.

Figure A3.3 Out-of-sample Prediction Comparison



This result highlights the usefulness of the simulation tool discussed in Section VII; if a key variable in the revenue calculation is not behaving in an expected manner, it is possible to adjust the that variable to more closely mirror current conditions.