Note

November 1, 2023 Methane update

1 Upcoming

Next week, I will present this project at the US Association for Energy Economics annual conference. Toren and I will also present at the Salata Institute Climate Workshop Series. Following that, our main objective will be to complete a draft by December 15.

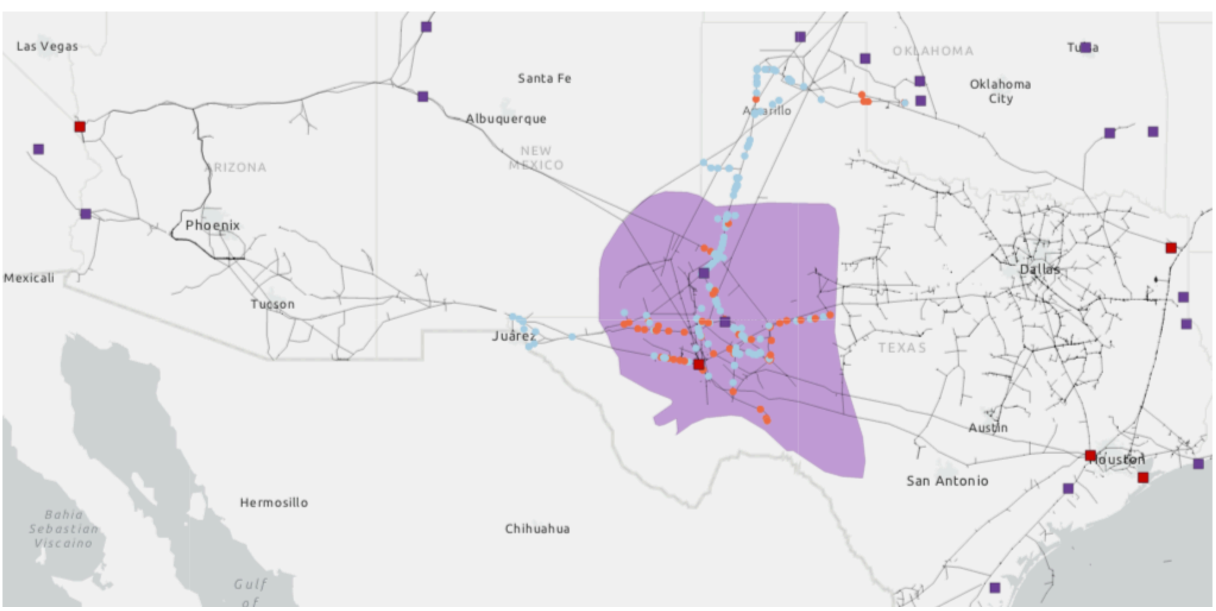
2 Overview

We have anecdotal evidence that the Henry-Waha price gap is a good proxy for pipeline congestion, and suggestive evidence (Figure 1, Table 2) that this price gap is related to emissions.

Previously, we've struggled to explain why the Waha price doesn't capture all relevant information for producers. Recently, we spoke with someone with more knowledge of the industry, who pointed out that not all infrastructure out of the Permian passes through Waha Hub. Nevertheless, congestion going east will affect more than just transactions that occur at Waha. In summary:

1. Not all Permian gas passes through Waha Hub
    - Marketers often send gas directly to buyers or to other, further hubs
    - Gap reflects congestion that is relevant even for non-Waha Hub transactions
2. Congestion b/w Henry-Waha might correlate with congestion w/in Permian
    - Difficulty moving gas east from the basin could cause backups on local pipelines
    - Permian producers unable to move gas to Waha → Waha price won't clear market

Figure 1: Permian Pipelines and Connected Hubs



3 Model

We propose a simple model of firm behavior. Oil and gas are co-produced. Production is costly, as are gas capture and transmission. Firms choose production intensity and how much of their gas to capture based on costs and commodity prices.

State variables: p^o, p^g (prices), u (pipeline utilization rate)

Control variables: q^o (oil production), e (emissions rate)

$$\max_{q^o, e \in [0,1]} \underbrace{p^o q^o - c^o(q^o)}_{\text{oil profit}} + \underbrace{p^g[(1-e)q^g(q^o)]}_{\text{gas revenue}} - \underbrace{c_a(1-e)q^g(q^o)}_{\text{capture cost}} - \underbrace{c_t(u)[(1-e)q^g(q^o)]}_{\text{transmission cost}}$$

$$\text{FOC:} \quad \underbrace{p^g - c_t(u)}_{\text{shadow price}} = \underbrace{c_a'(1-e)}_{\text{MACC}}$$

Our goal is to use a flexible function f to estimate inverse marginal abatement cost curve (MACC):

$$e = f(p^g - c_t) + \varepsilon$$

4 Estimating MACCS

We've tried several different approaches to estimating MACCs. On the price side, we've tried using each of the following as our $p^g - c_t$:

1. **Wellhead-level prices:** Previously, we gathered firm-level data (from tax records) on average sales and marketing figures at the month level (see Figure 5). We decided not to move forward with these data because we thought the sales data represented average prices and so was not a good representation of marginal prices. But, these prices still might be relevant for the firm decision.

2. **Waha prices:** Even though we know that not all gas passes through Waha, the Waha price still approximates the commodity value net of transport costs for some share of Permian gas.

3. **Henry-Waha basis:** It's not clear how this variable makes sense for an MACC, since it's a proxy for c_t rather than $p^g - c_t$. But, we wanted to try it anyway.

For all estimates, we measure e at the subbasin-month level. We calculate e to be the ratio of emissions to production for each subbasin-month. c_t is measured as the sub-basin average of wellhead-level prices, but is uniform across sub-basins for the Waha price and Henry-Waha basis variations. In all estimates, we run the following regression:

$$e = f(p)$$

where $f()$ is a polynomial of degree 3 and p is each of the three options detailed above.

The results are shown in Figure 2.

5 Simulations

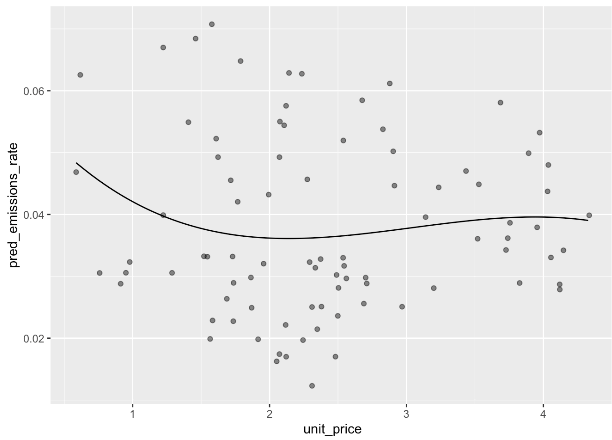
We wanted to run some model simulations to demonstrate the impact of changing various parameters. To do this, we specified the following cost curves:

$$c_o = (\beta q_o)^2$$
$$c_a = -\gamma \log(e)$$
$$c_m = \frac{1}{1-u}$$

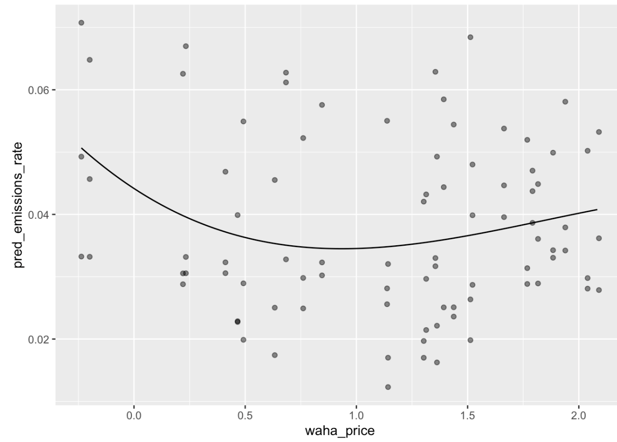
We set $\beta = 0.1$ and $\gamma = 0.1$ at baseline. We then solve numerically for the firm's optimal e, given first order conditions. Results are shown in Figure 3.

Figure 2: MACC estimates

(a) Wellhead prices



(b) Waha price



(c) Henry-Waha Basis

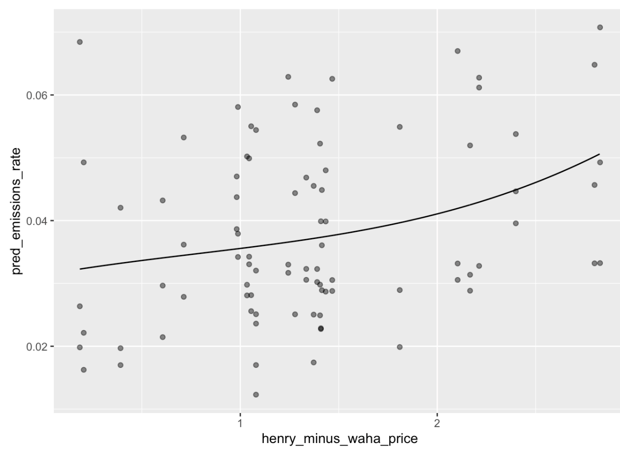
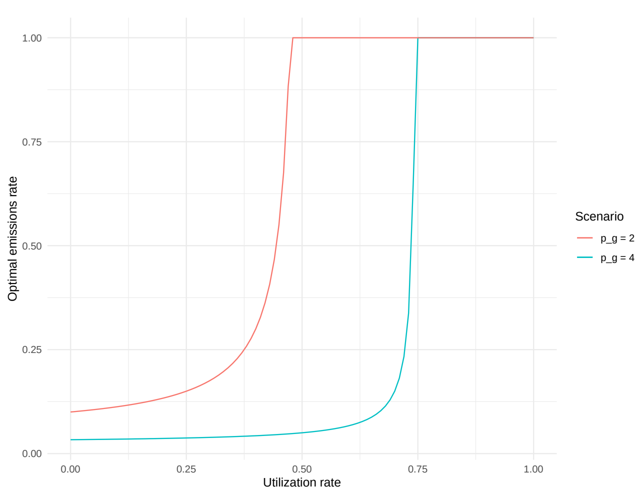
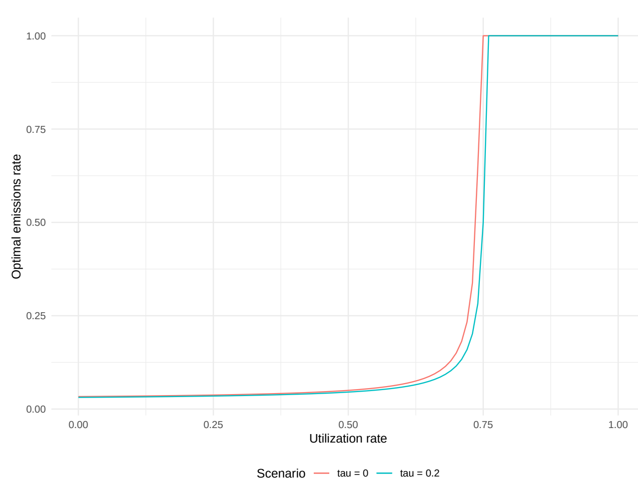


Figure 3: Simulations

(a) Varying p_g



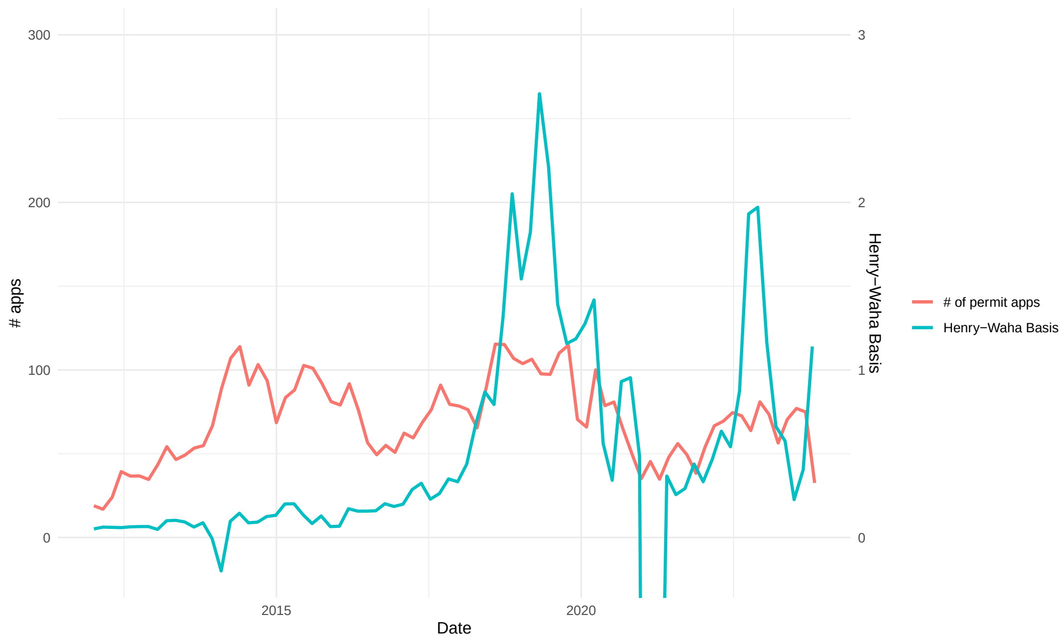
(b) Varying τ



6 New Data

This week, we obtained data on 1) flaring permit requests and 2) lease-level flared/vented volumes. We're still exploring this data. Figure 4 shows that there is some correlation between the timing of flaring permit requests and the Henry-Waha basis (both series are smoothed). This dataset also includes several text fields in which applicants describe justifications for flaring (e.g. "no market for gas with gas purchasers", "new well with no connection immediately available", "processing plant issues")

Figure 4: Flaring permit requests and Henry-Waha basis



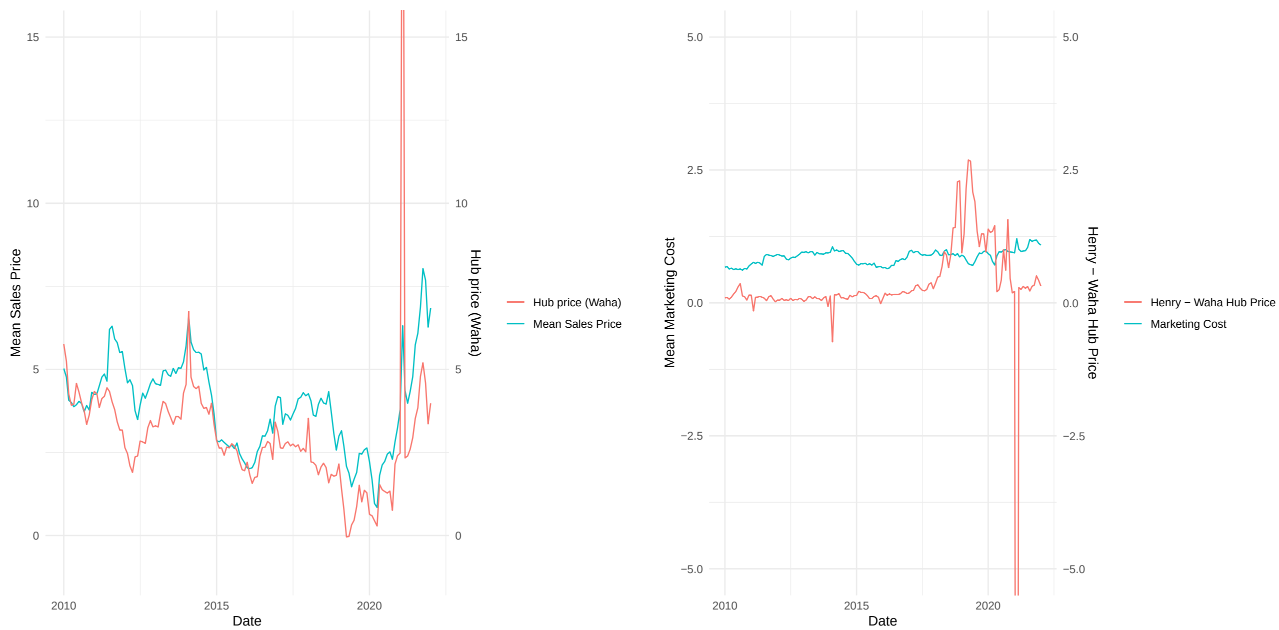
A Appendix: Decomposing wellhead prices

What if we could split wellhead prices into a firm-specific component (representing contracted sales) vs. a marginal component?

Figure 5: Producer-reported sales prices and marketing costs

(a) Sales prices

(b) Marketing costs



Suppose the average sales price is a weighted average of hub prices (say, p_w and p_h) in each period, as well as the firm's contracted price p_i, which we assume does not vary month-to-month.

$$p_{i,t} = \alpha p_{w,t} + \beta p_{h,t} + (1 - \alpha - \beta) p_i$$
$$p_{i,t+1} = \alpha p_{w,t+1} + \beta p_{h,t+1} + (1 - \alpha - \beta) p_i$$

Taking first differences yields:

$$p_{i,t+1} - p_{i,t} = \alpha(p_{w,t+1} - p_{w,t}) + \beta(p_{h,t+1} + p_{h,t})$$

We can try doing this regression:

Table 1: Decomposing Gas Prices and Marketing costs

	Dependent variable:			
	Price diffs	Prices	Cost diffs	Costs
	(1)	(2)	(3)	(4)
waha_diff	0.044***			
	(0.001)			
henry_diff	0.443***			
	(0.007)			
mean_waha		0.059		
		(0.039)		
mean_henry		1.029***		
		(0.097)		
basis_henry_waha_diff			−0.010***	
			(0.002)	
mean_basis_henry_waha				−0.014**
				(0.006)
Constant	0.004	0.396	−0.011*	0.871***
	(0.002)	(0.270)	(0.006)	(0.011)
Observations	4,280,007	145	4,280,007	145
R^2	0.005	0.606	0.00000	0.041
Adjusted R^2	0.005	0.601	0.00000	0.034
Residual Std. Error	4.846 (df = 4280004)	0.854 (df = 142)	12.818 (df = 4280005)	0.129 (df = 143)
F Statistic	10,111.330*** (df = 2; 4280004)	109.336*** (df = 2; 142)	16.711*** (df = 1; 4280005)	6.055** (df = 1; 143)

Notes: An observation is a month.
$^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

B Appendix: Figures and Tables

Figure 6: Production by basin

(a) Gas production

(b) Oil production

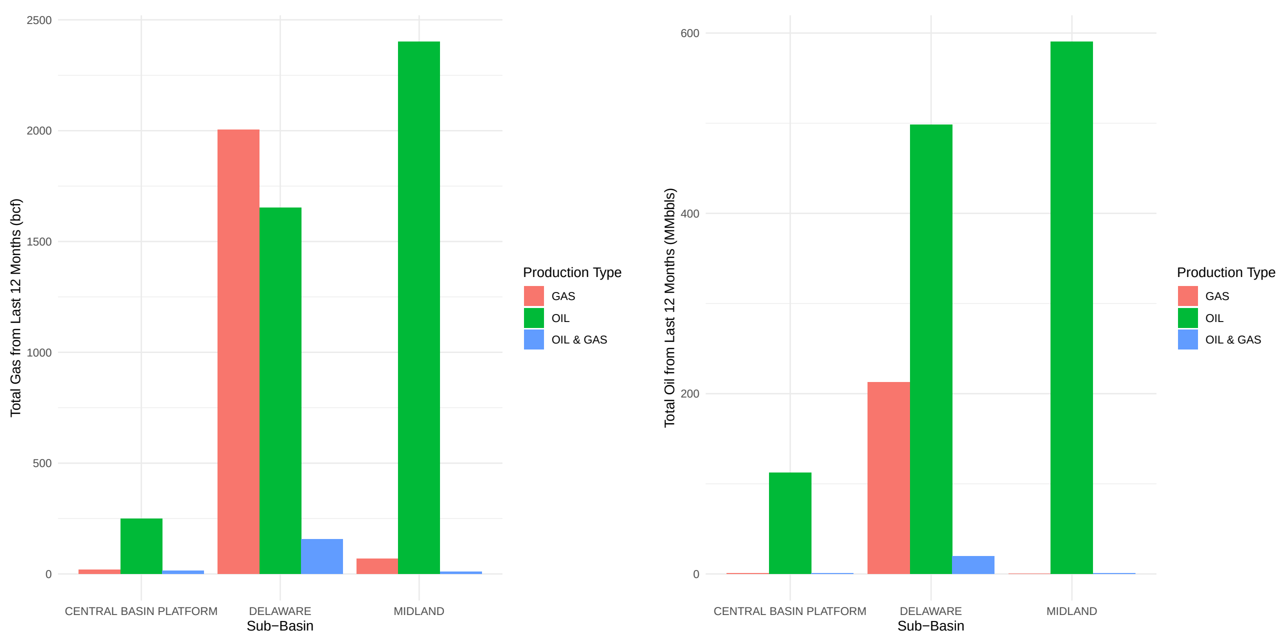


Table 2: Methane Emissions, Prices, and Production

	Dependent variable:			
	log(emissions)			
	All	Midland	Central	Delaware
	(1)	(2)	(3)	(4)
Waha Hub Price	0.040	0.005	0.005	0.069
	(0.049)	(0.059)	(0.034)	(0.058)
Henry - Waha Hub Price	0.090^{*}	0.147^{**}	0.091^{**}	0.034
	(0.050)	(0.057)	(0.039)	(0.060)
Cushing Spot Oil Price	-0.004^{**}	-0.004	0.002	-0.009^{***}
	(0.002)	(0.002)	(0.002)	(0.003)
log(Oil Production)	1.004	-1.582^{*}	-0.492	3.589^{**}
	(1.205)	(0.810)	(0.753)	(1.390)
log(Gas Production)	-0.974	1.198	1.468	-3.269^{**}
	(1.018)	(0.758)	(0.904)	(1.278)
log(New Wells)	0.216	0.124	0.005	0.604^{**}
	(0.160)	(0.342)	(0.069)	(0.269)
log(Lagged New Wells)	0.035	0.313	-0.041	-0.244
	(0.162)	(0.348)	(0.070)	(0.271)
Constant	0.466	3.854	-16.474^{**}	-2.594
	(5.075)	(5.491)	(7.460)	(4.619)
Observations	125	125	125	125
R^2	0.320	0.286	0.247	0.339
Adjusted R^2	0.279	0.244	0.202	0.300
Residual Std. Error (df = 117)	0.212	0.243	0.183	0.266
F Statistic (df = 7; 117)	7.859^{***}	6.707^{***}	5.481^{***}	8.577^{***}

Notes: An observation is a week. Emissions are in log teragrams per annum (Tg/a). Prices reflect the average of prices over the week. Oil and gas production and new wells are measured monthly. Oil and gas production are in sbarrels and thousands of cubic feet (Mcf), respectively. Flared volume is measured in billions of cubic feet.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 3: Methane Flares, Prices, and Production

	Dependent variable:		
	log(num_flares)		
	All	Midland	Delaware
	(1)	(2)	(3)
Waha Hub Price	0.009	0.073^{***}	-0.0004
	(0.020)	(0.025)	(0.020)
Henry - Waha Hub Price	0.042^{**}	0.094^{***}	0.031
	(0.020)	(0.024)	(0.020)
Cushing Spot Oil Price	0.004^{***}	0.001	0.004^{***}
	(0.001)	(0.001)	(0.001)
log(Oil Production)	1.623^{***}	2.557^{***}	0.513
	(0.487)	(0.346)	(0.468)
log(Gas Production)	-0.662	-0.822^{**}	0.024
	(0.412)	(0.323)	(0.430)
log(New Wells)	0.017	0.119	0.023
	(0.065)	(0.146)	(0.090)
log(Lagged New Wells)	-0.031	-0.115	0.052
	(0.066)	(0.149)	(0.091)
Constant	-10.799^{***}	-23.933^{***}	-4.524^{***}
	(2.053)	(2.342)	(1.555)
Observations	125	125	125
R^2	0.572	0.669	0.530
Adjusted R^2	0.546	0.649	0.502
Residual Std. Error (df = 117)	0.086	0.103	0.090
F Statistic (df = 7; 117)	22.296^{***}	33.727^{***}	18.864^{***}

Notes: An observation is a week. Outcome variable is the number of clustered VIIRS flaring object detections. Prices reflect the average of prices over the week. Oil and gas production and new wells are measured monthly and interpolated to the week level. Oil and gas production are in barrels and thousands of cubic feet (Mcf), respectively.
$^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table 4: Methane Emissions, Prices, and Production: Hubs

	Dependent variable:				
	log(emissions)				
	(1)	(2)	(3)	(4)	(5)
Waha Hub Price	0.042	0.056	0.044	0.052	−0.025
	(0.050)	(0.052)	(0.050)	(0.051)	(0.032)
Henry - Waha Hub Price	0.092^{*}				
	(0.051)				
Katy - Waha Hub Price		0.107^{**}			
		(0.051)			
Ship - Waha Hub Price			0.094^{*}		
			(0.050)		
NGPL - Waha Hub Price				0.104^{**}	
				(0.053)	
SoCal - Waha Hub Price					0.013
					(0.020)
Cushing Spot Oil Price	-0.004^{**}	-0.004^{**}	-0.004^{**}	-0.004^{**}	-0.004^{*}
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Log(Oil Production)	0.922	0.909	0.974	0.823	1.865^{*}
	(1.226)	(1.192)	(1.202)	(1.224)	(1.106)
Log(Gas Production)	−0.897	−0.816	−0.921	−0.777	-1.841^{**}
	(1.036)	(1.016)	(1.016)	(1.040)	(0.884)
Log(New Wells)	0.224	0.219	0.221	0.246	0.187
	(0.162)	(0.161)	(0.161)	(0.162)	(0.164)
Log(Lagged New Wells)	0.032	0.042	0.040	0.020	0.033
	(0.164)	(0.163)	(0.164)	(0.163)	(0.167)
Constant	0.438	−0.832	−0.041	−0.072	1.580
	(5.133)	(5.194)	(5.154)	(5.144)	(5.192)
Observations	123	123	123	123	123
R^2	0.319	0.325	0.321	0.323	0.302
Adjusted R^2	0.278	0.284	0.279	0.282	0.260
Residual Std. Error (df = 115)	0.214	0.213	0.213	0.213	0.216
F Statistic (df = 7; 115)	7.699^{***}	7.897^{***}	7.755^{***}	7.829^{***}	7.116^{***}

Notes: An observation is a week. Emissions are in log teragrams per annum (Tg/a). Prices reflect the average of prices over the week. Oil and gas production and new wells are measured monthly. Oil and gas production are in sbarrels and thousands of cubic feet (Mcf), respectively. Flared volume is measured in billions of cubic feet.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 5: Oil prices, drilling, and production

	Dependent variable:		
	log(sum_spuds) Spuds	log(Firstprod) First Prod	log(SUM.Monthly.Oil.) Bbl Oil
	(1)	(2)	(3)
Log(Cushing, Forward contract)	2.711^{***}	2.564^{***}	-1.731^{*}
	(0.810)	(0.534)	(0.881)
Log(Cushing, 3 month contract)	-2.443^{***}	-2.423^{***}	1.778
	(0.861)	(0.567)	(1.124)
Log(Henry spot price)	-0.226	-0.190^{*}	-0.210
	(0.163)	(0.109)	(0.194)
Basin = Midland	0.333^{***}	0.643^{***}	-1.147^{***}
	(0.081)	(0.053)	(0.087)
Production type = Oil			3.673^{***}
			(0.087)
Constant	4.105^{***}	4.414^{***}	12.527^{***}
	(0.601)	(0.395)	(1.319)
Observations	320	318	396
R^2	0.099	0.358	0.836
Adjusted R^2	0.088	0.350	0.834
Residual Std. Error	0.721 (df = 315)	0.474 (df = 313)	0.862 (df = 390)
F Statistic	8.665^{***} (df = 4; 315)	43.678^{***} (df = 4; 313)	396.896^{***} (df = 5; 390)

Notes: An observation is a month. Prices reflect the average of prices over the month.
$^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$