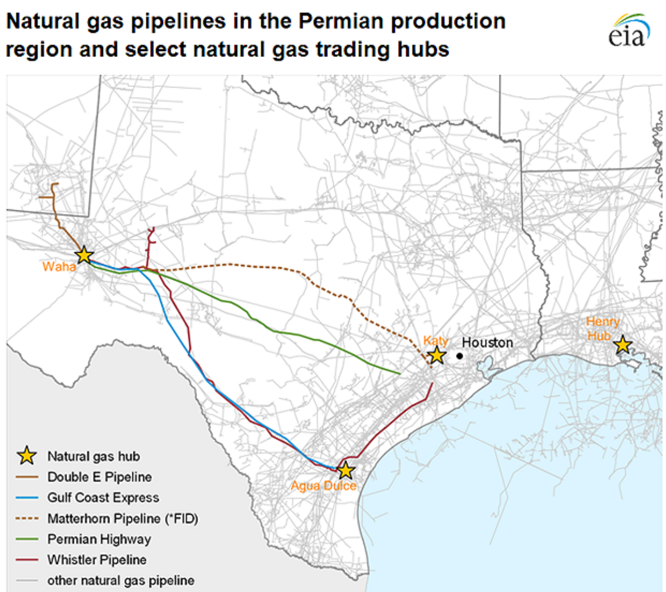
1 Introduction

Methane is both a commodity (as the primary component of natural gas) and a potent greenhouse gas. In this project, we study producer decisions about whether to a) capture and sell or b) emit/flare the gas they produce. Our results indicate that capacity constraints are an important determinant of what producers decide to do.

Natural gas is traded at many hubs. The Waha Hub is the primary hub for the Permian Basin, a major oil-gas producing region and the focus of our study. Henry Hub is particularly well-connected, and prices there are the industry benchmark.

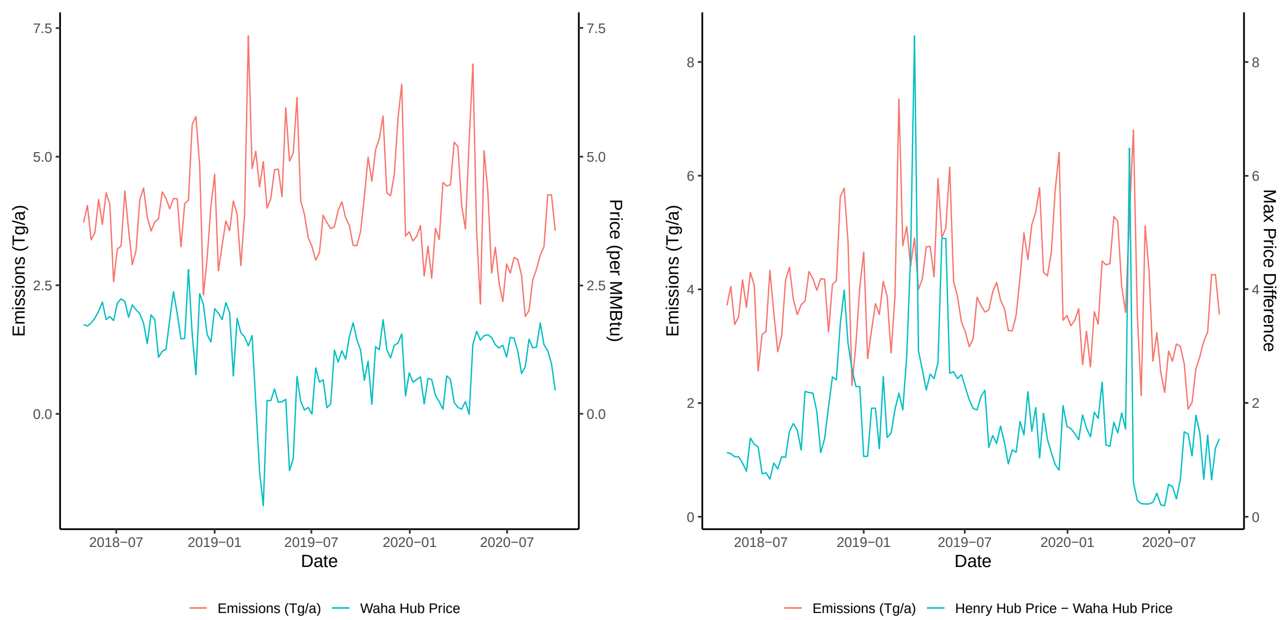


Natural gas can only be transported long-distance via pipeline, and pipelines have fixed capacities. As a result, prices at different hubs can diverge. The price gap differential with Henry Hub is a proxy for capacity constraints. We plot weekly methane emissions estimates against prices at Waha, and against the Henry-Waha price differential. We observe that emissions spikes are tightly linked with upticks in the price differential (Figure 1).

Figure 1: Emissions and prices

(a) Waha Price

(b) Henry-Waha Gap



When we regress flaring and emissions on the price gap, we find that increases in the price gap (which correspond to increases in congestion) are associated with increases in emissions and increases in flaring (Tables 1, 2). These relationships appear most prominently in the sub-basins of the Permian in which gas is produced mostly from oil wells (5). We infer that congestion leads producers to flare rather than sell their gas, resulting in higher emissions, and that this behavior is linked to more oil-centric production.

2 Model

We propose a simple model of firm behavior. Oil and gas are co-produced. Production is costly, as is 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):

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

We can also use a flexible function g to estimate transport costs:

$$c_t = g(u)$$

We can instrument for utilization using unexpected pipeline outages (or changes in the oil price- see section B.2). Together, these estimates should allow us to do a rough calculation of the social cost of insufficient capacity.

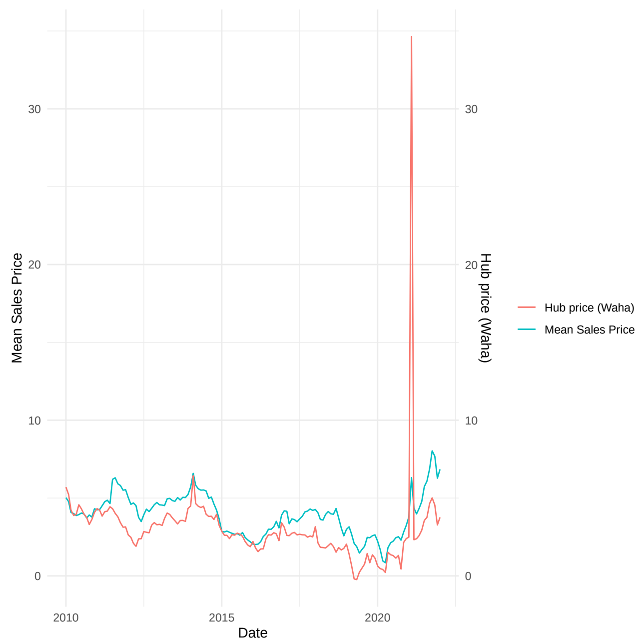
3 Bringing model to data

The main challenge we're facing is that it is not clear how to match the concepts from the model to our data. For each concept, I will walk through our data and related issues.

3.1 Gas prices

Waha Hub spot prices (as in Figure 1a) are considered to be the regional gas benchmark. However, producers tend to negotiate long-term contracts for some of their gas, in part because spot prices are so volatile. When we compare Waha Hub spot prices to the mean of lease-level sales prices (from tax data), we see that sales prices track spot prices but are somewhat less volatile (Figure 2). Sales prices are also higher than spot prices, though it's not clear if this is due to higher contracted prices or other terms of sale that are not captured in this reporting.

Figure 2: Lease-level sales prices



3.2 Transmission costs

We can interpret the Henry-Waha price differential as an approximation of the cost of transporting gas between hubs. Since natural gas is a homogeneous commodity, traders can arbitrage spot prices until the difference in prices equals the transport costs.

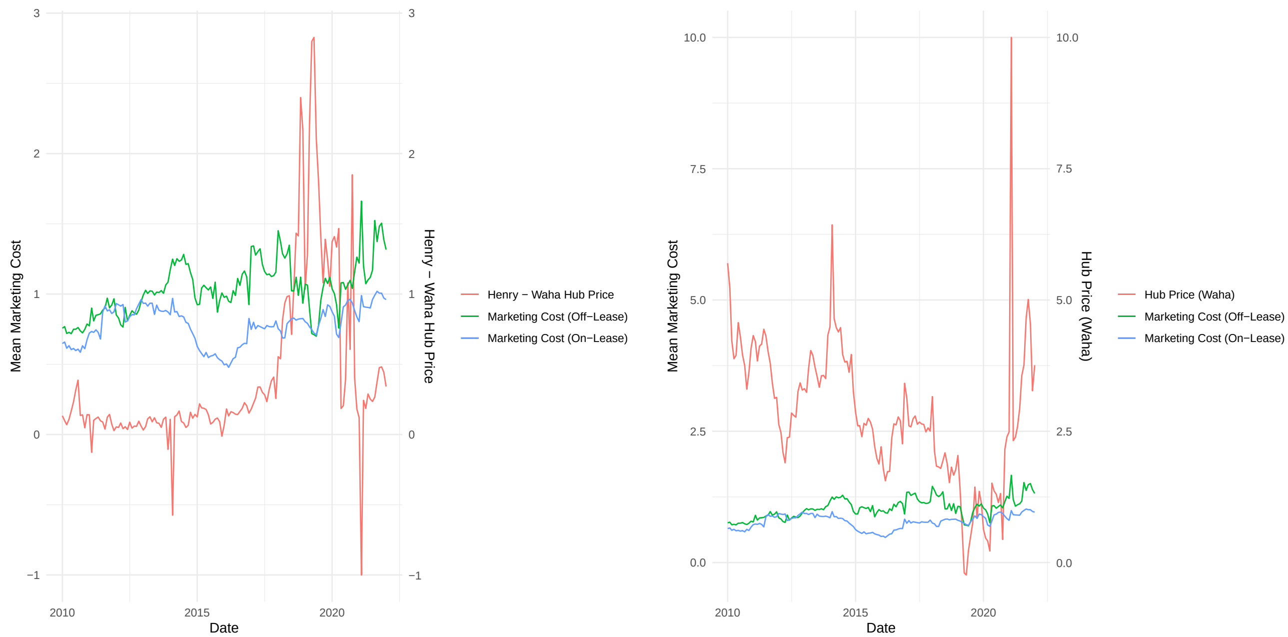
We have a more direct measure of some transport costs from tax data. Producers are able to deduct "marketing costs" (gas compression, processing, transport to buyer, etc.) from their taxable sales. From tax data we are also able to distinguish between gas that was sold on-lease vs. off-lease.

As expected, marketing costs are higher for off-lease transactions. Costs do not seem significantly related to the Henry-Waha price spread, suggesting that this variable does not capture long-distance transmission costs (Figure 3a). However, it does appear to co-move with Waha Hub prices, implying that marketing costs may capture some element of congestion in moving gas to the hub (Figure 3b).

Figure 3: Lease-level marketing costs

(a) Costs and Henry-Waha price gap

(b) Costs and Waha Price

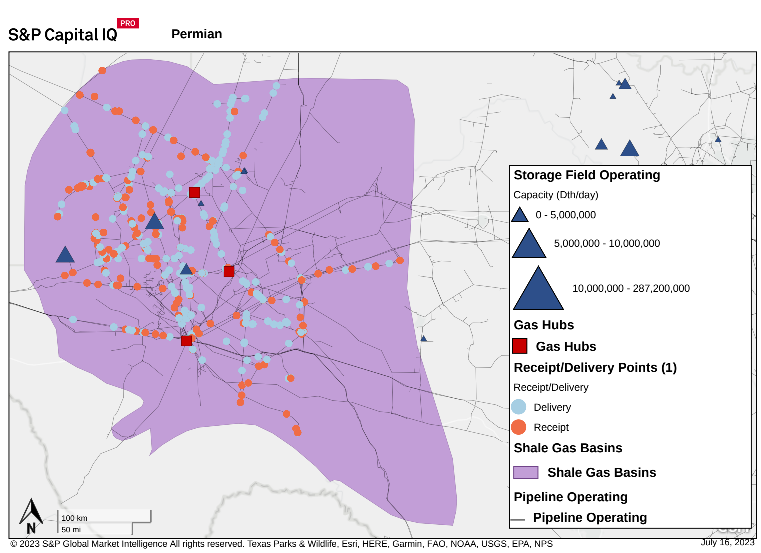


3.3 Utilization

The utilization rate most relevant to the Henry-Waha price gap is likely the rate for long-distance transmission pipelines. We do not have a good measure of this utilization, since reporting requirements for intrastate pipelines (e.g. Permian to Gulf Coast) are quite lax.

What we do have is utilization rates for various receipt/delivery points within the Permian Basin (Figure 4). Each point represents a place in the pipeline network where gas enters the system, is transferred to another pipeline, or exits the system. Points are grouped into categories including gathering, interconnect, processing, compressor, and delivery to a local distribution company.

Figure 4: Permian receipt and delivery points



A Appendix: Figures and Tables

Figure 5: Production by basin

(a) Gas production (b) Oil production

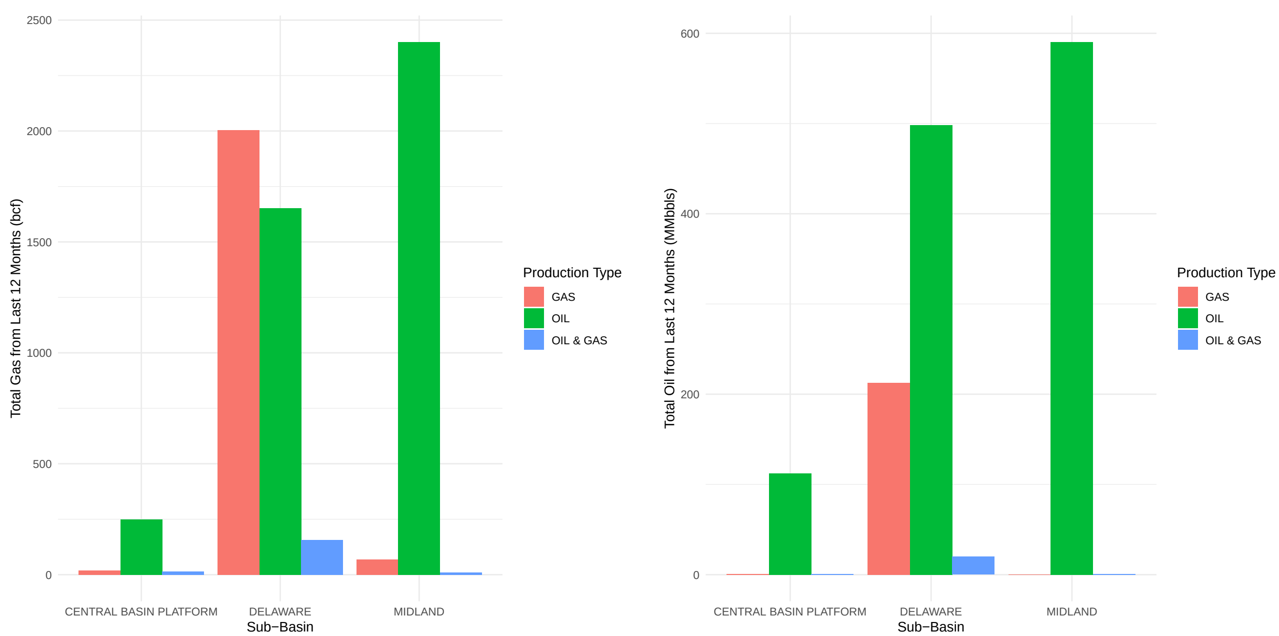


Table 1: Methane Emissions, Prices, and Production

	Dependent variable:			
	log(emissions)			
	All	Midland	Central	Delaware
	(1)	(2)	(3)	(4)
Waha Hub Price	0.040	0.005	0.006	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	-1.574^{*}	-0.496	3.584^{**}
	(1.205)	(0.809)	(0.754)	(1.390)
log(Gas Production)	-0.974	1.195	1.476	-3.263^{**}
	(1.018)	(0.757)	(0.905)	(1.278)
log(New Wells)	0.216	0.125	0.005	0.603^{**}
	(0.160)	(0.342)	(0.069)	(0.269)
log(Lagged New Wells)	0.035	0.312	-0.041	-0.242
	(0.162)	(0.348)	(0.070)	(0.271)
Constant	0.466	-13.280^{**}	-33.620^{***}	-19.696^{***}
	(5.075)	(5.483)	(7.467)	(4.619)
Observations	125	125	125	125
R^2	0.320	0.287	0.247	0.339
Adjusted R^2	0.279	0.244	0.202	0.299
Residual Std. Error (df = 117)	0.212	0.242	0.183	0.266
F Statistic (df = 7; 117)	7.859^{***}	6.713^{***}	5.483^{***}	8.560^{***}

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 2: 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.
$^{*}p < 0.1,^{**} p < 0.05,^{***} p < 0.01$

B Appendix: Bonus material

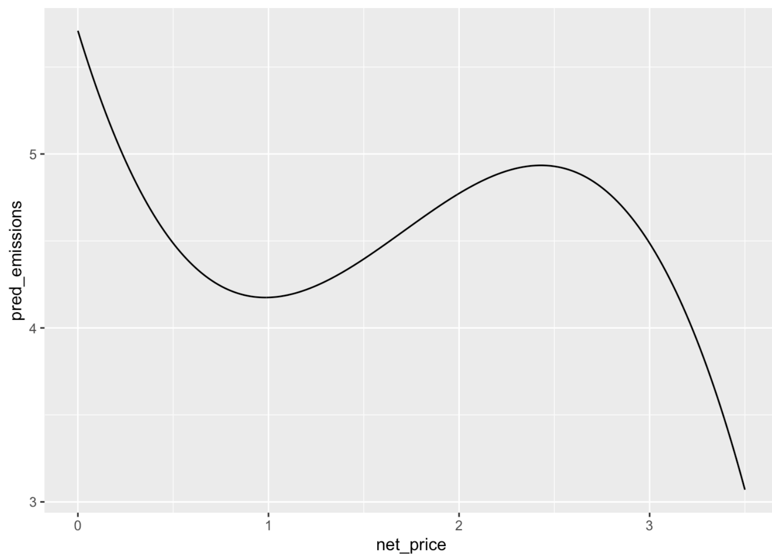
B.1 Attempt at MACC

We have attempted to estimate the MACC using variations on the following:

$$e_i = f(p_{i,sales} - c_{i,marketing}) + \beta X_i + \varepsilon$$

for sub-basin i, where f is a third-order polynomial and X_i is a vector of basin-specific characteristics (new wells, gas production, etc). Results have been noisy and inconsistent. See Figure 6 for example.

Figure 6: Attempt at estimating MACC



B.2 Production and prices

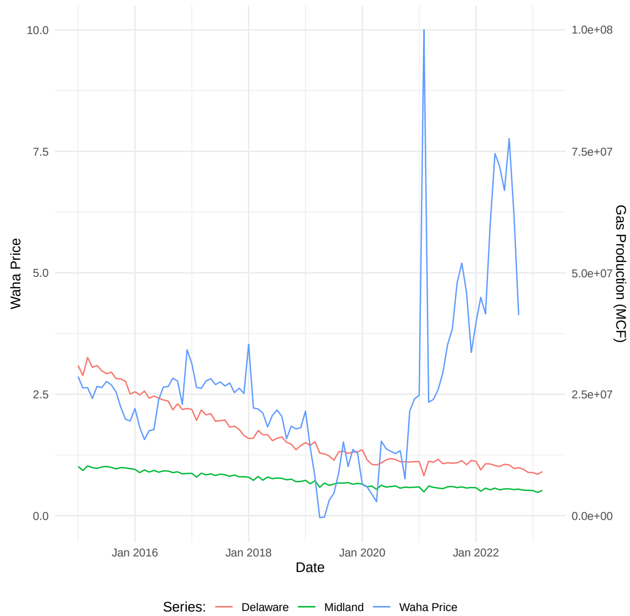
Inspired by Anderson, Kellogg, and Salant (2018), I explore how oil and gas production varies with prices. I define "intensive margin" to capture changes in production intensity at existing wells. I use "extensive margin" to refer to drilling activity to create new wells.

B.2.1 Intensive margin response

On the whole, it appears that production at existing wells (defined here to be wells with completion dates before 2015) does not change significantly in response to price fluctuations. There do appear to be some periods in which prices spike and gas production dips, but most (e.g. Jan 2021) occur during cold snaps in Texas, when demand for gas is high and production is disrupted by equipment freezes.

Figure 7: Gas production at existing wells

(a) Gas wells



(b) Oil wells

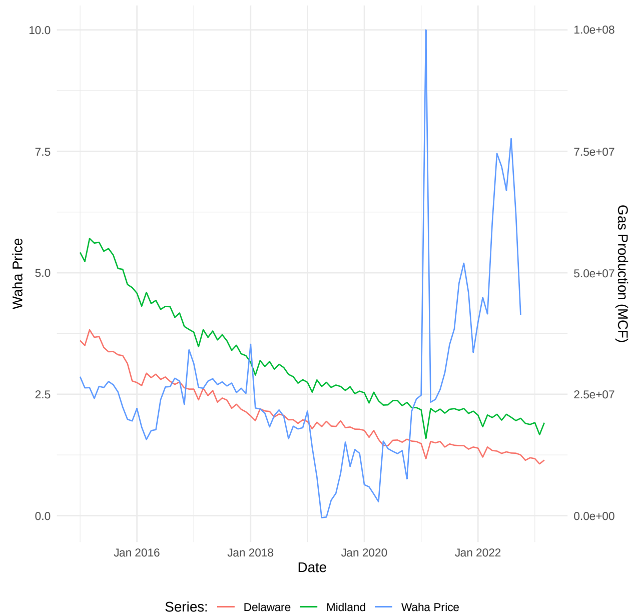
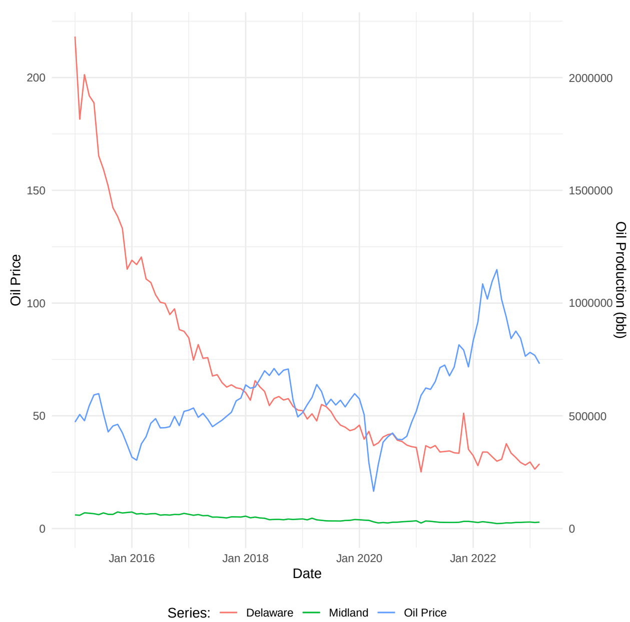
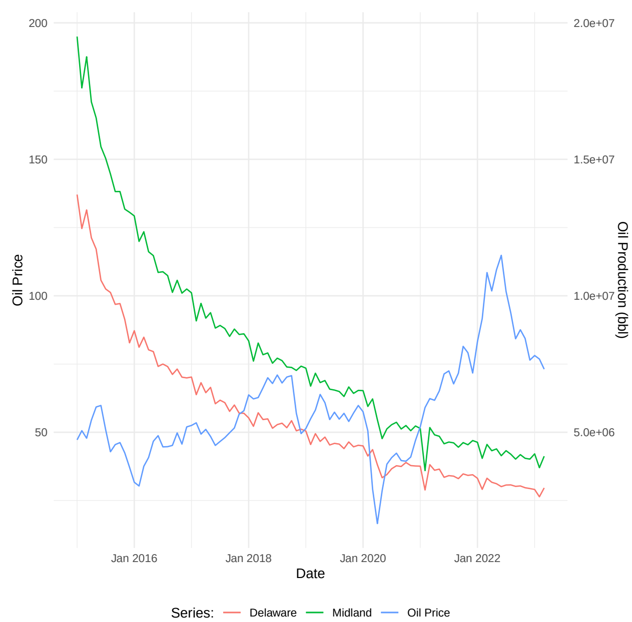


Figure 8: Oil production at existing wells

(a) Gas wells



(b) Oil wells



B.2.2 Extensive margin

Conversely, well drilling does appear to be strongly related to prices, particularly oil prices (Figure 3, panel b). This appears true in both the Delaware and the Midland basins, even though the Delaware Basin has more primarily gas production.

Figure 9: Well drilling and prices

(a) Gas prices

(b) Oil prices

Question: Can we use oil prices to instrument for congestion? If it is a valid instrument it has some advantages relative to a pipeline maintenance instrument:

- More natural intensive margin (difficult to compare size of impact on Permian gas across outages)
- Affects a measurable share of Permian production (pipeline outages may only affect some wells)
- Dataset does not cost $7,000