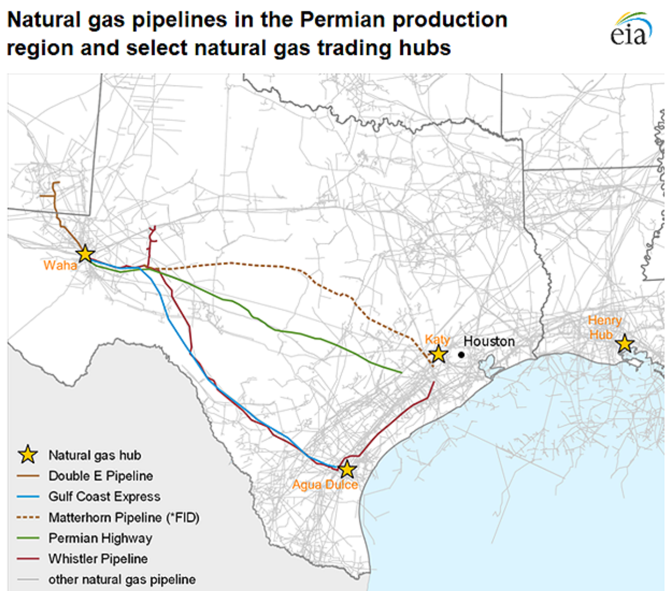
# 1 Introduction

Methane is both a commodity (as the primary component of natural gas) and a potent greenhouse gas. In this project, we examine the 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.

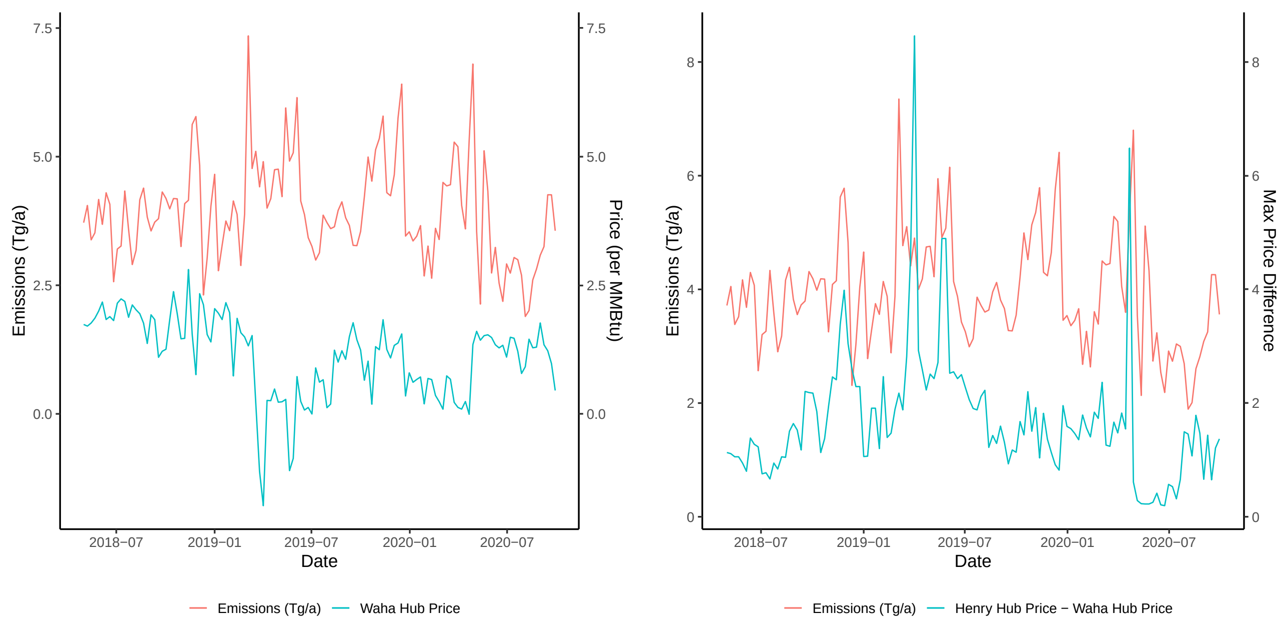



Natural gas can only be transported long-distance via pipeline, and pipelines have fixed capacities. As a result, prices at different hubs can diverge. The price gap differential with Henry Hub is a proxy for capacity constraints. We plot weekly methane emissions estimates against prices at Waha, and against the Henry-Waha price differential.

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. These relationships appear only in the sub-basins of the Permian in which gas is produced mostly as a byproduct of oil. We infer that congestion leads producers to flare rather than sell their gas, resulting in higher emissions. See appendix for these results.

## 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)

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

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

We can 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 will need to instrument for utilization using unexpected pipeline outages (or changes in the oil price- see section 5.3). Together, these estimates will allow us to do a rough calculation of the social cost of insufficient capacity.

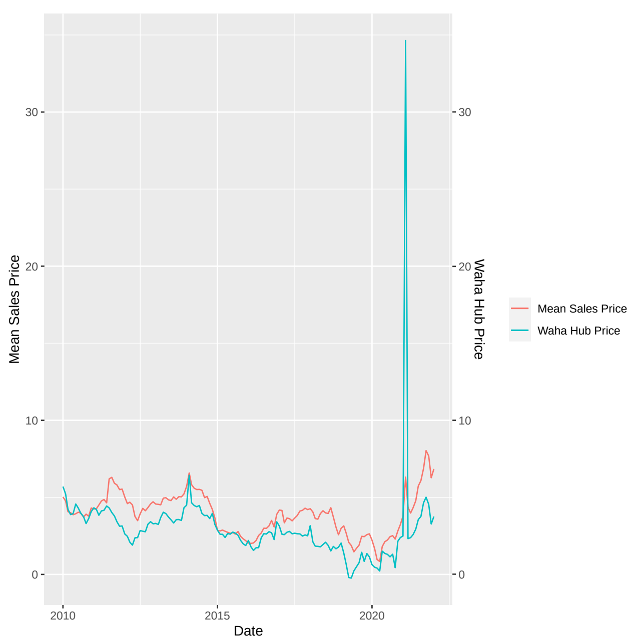
# 3 Sub-basin data

We have fine-grained geographic data on production and capacity. On the production side, we have lease-month level data from Enverus on revenues, derived from Texas tax records then linked with lease ID. Variables include volume of gas sold, value of gas, and marketing costs (gas compression, processing, transport to buyer). We can link each lease ID to a latitude/longitude pair and production history.

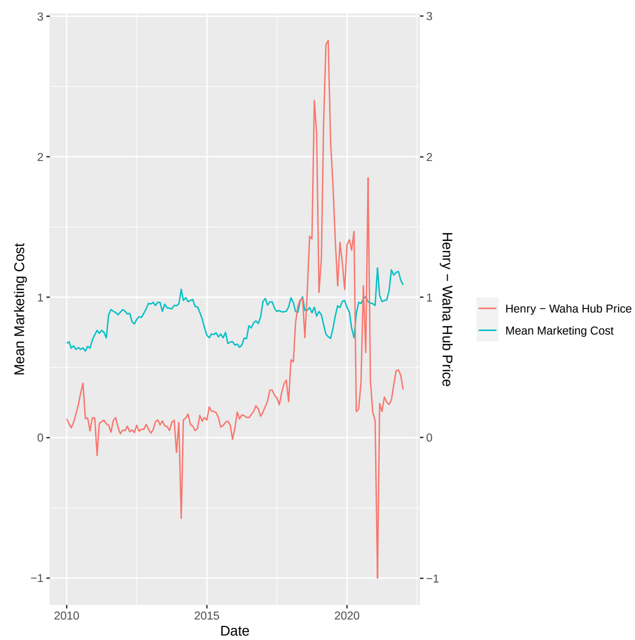
Across leases, the mean of unit sales values appears to closely track the Waha Hub price (2), though it is unclear why these values exceed hub prices at most points. Marketing costs, however, do not seem significantly related to the Henry-Waha price spread, suggesting that these costs do not correspond to transmission costs.

Figure 2: Lease-level sales prices and marketing costs

(a) Sales prices

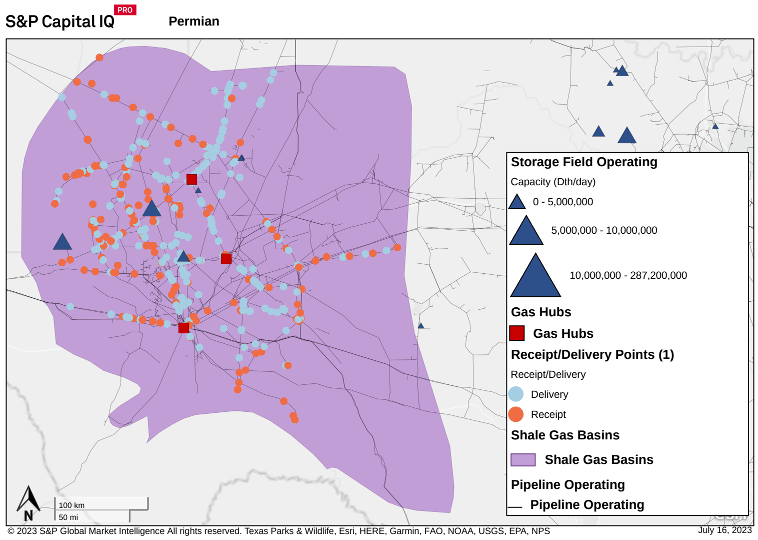



(b) Marketing costs




We also have capacity and utilization at the level of receipt and delivery points (Figure 3). Each point represents a place in the pipeline network where gas enters the system, is transferred to another pipeline, or is delivered to an end user.

Figure 3: Permian receipt and delivery points




# 4 Questions

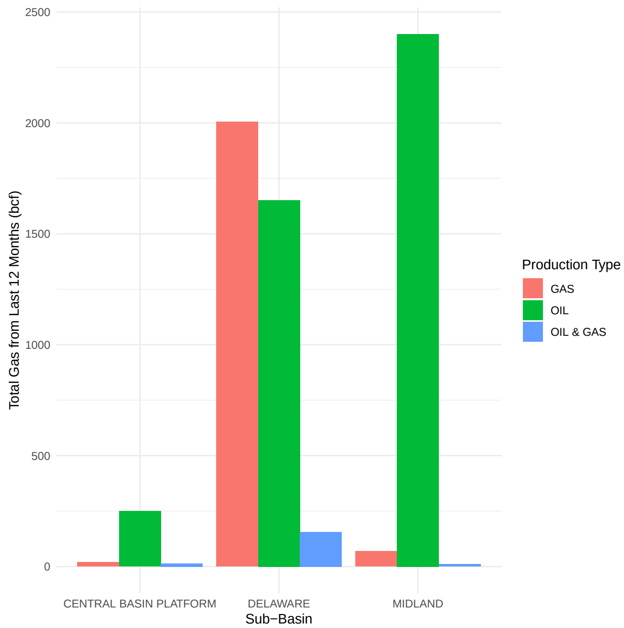
- Ideas for leveraging spatial data?
- Convinced by the MACC?

# 5 Appendix

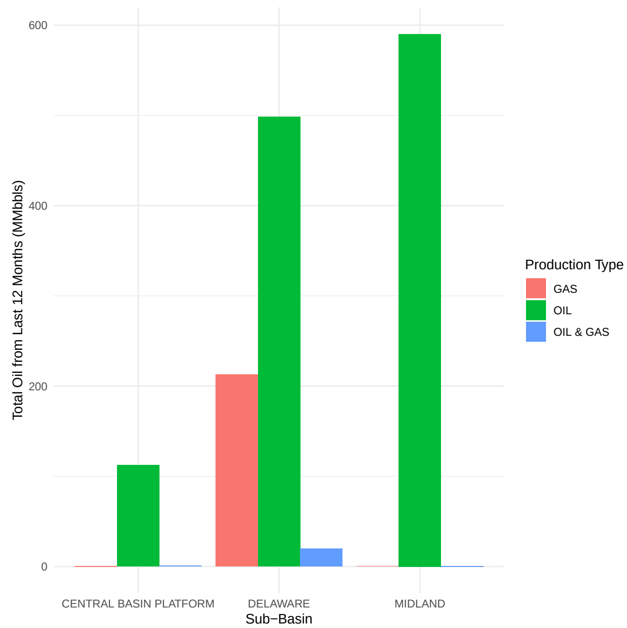
## 5.1 Figures

Figure 4: Production by basin

(a) Gas production




(b) Oil production



### 5.2 Tables

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

## 5.3 Production and prices

Below, I include figures summarizing oil and gas production and how it 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.

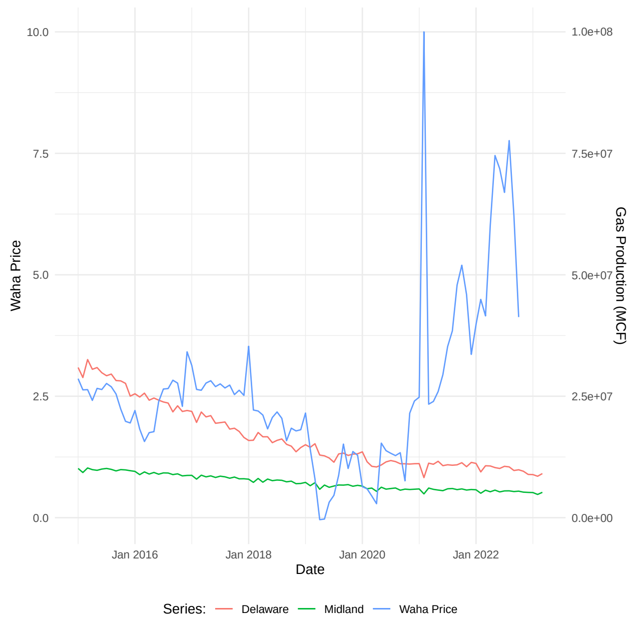
### 5.3.1 Intensive margin response

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 many of these (e.g. Jan 2021) occur during cold snaps in Texas, when demand for gas is high and production is disrupted by equipment freezing.

Figure 5: Gas production at existing wells

(a) Gas wells




(b) Oil wells

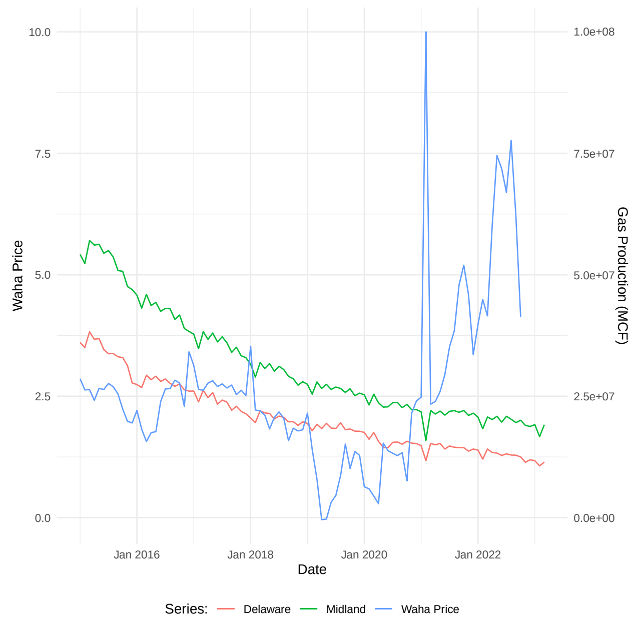
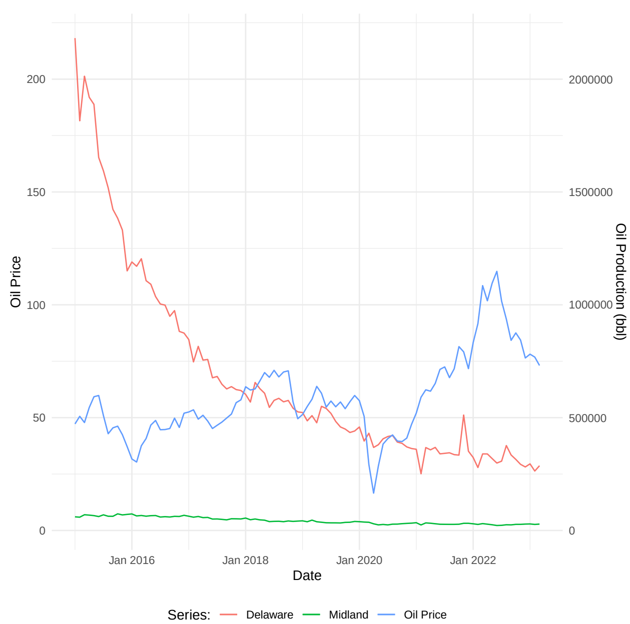
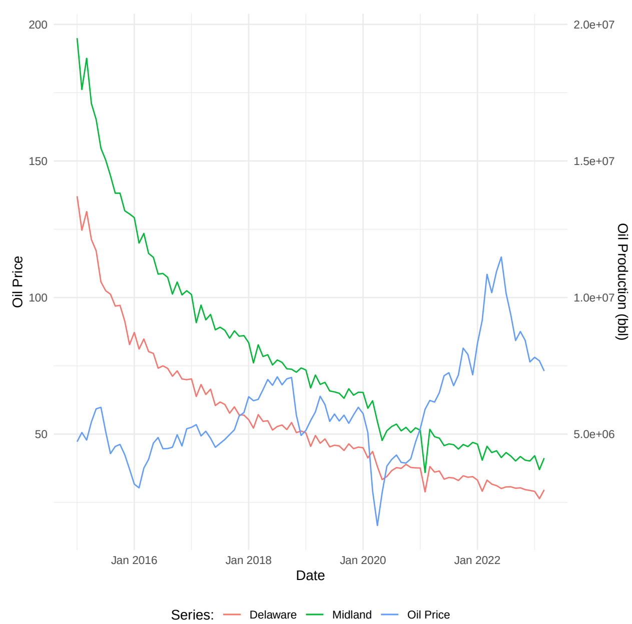



Figure 6: Oil production at existing wells

(a) Gas wells




(b) Oil wells

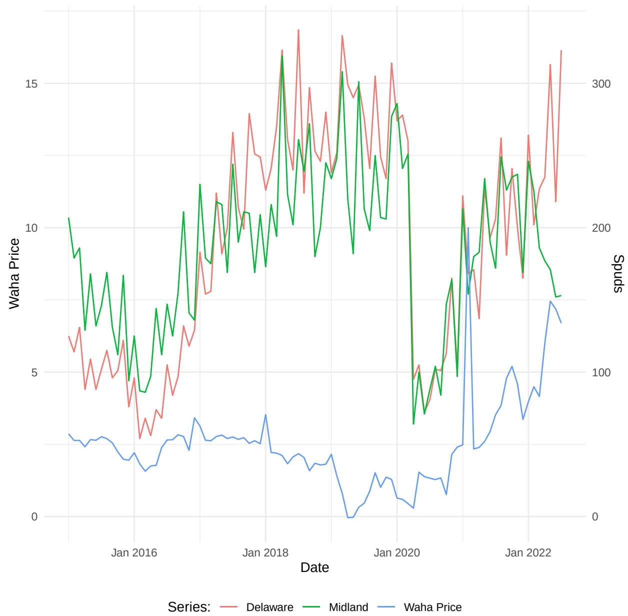



### 5.3.2 Extensive margin

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 7: Well drilling and prices

(a) Gas prices




(b) Oil prices