1 Upcoming

I will present in Labor/PF workshop on February 6.

2 Overview

Thanks for the draft edits! I've been working through them as we also work to refine the model. Here's what I see as our next steps:

- Refine model: We still need to figure out some model components (including the structure of random variables and the level of aggregation the model should represent) and how to map the model to data
- Additional empirics: emissions regressions in first differences, flaring/venting regressions for broader time range, more exploration of flaring permit applications data
- Estimate model
- Simulate counterfactuals

3 Big picture questions

This project:

- What are reasonable goals to aim for this semester regarding this project?
- What do you see as the value of going to the field and/or pursuing more connections with people in industry at this stage in the project?
- What kind of advice should I seek out to supplement your own for this project?
- We've had issues getting data on pipeline maintenance events. How essential is this data, and would it be worth promising to buy other data from the same provider in order to get the maintenance data?
  - Other data: $12,000 per year for a dataset including "over 10 years of historical scheduled, operational, available and design capacity", "pipeline summarised daily deliveries"
  - Our budget: about $38k total

Research in general:

- To what extent should I be developing other project ideas concurrently? How can I best balance pushing multiple projects forward?
- Do you have any advice for sharing responsibilities in a co-authorship relationship? How should this vary depending on project proximity to our primary fields?
- What is the role of workshop/seminar presentations in the research process? How much should I aim to present each semester?

4 Model questions

- Our current model gives us the following FOC characterizing optimal gas disposal:

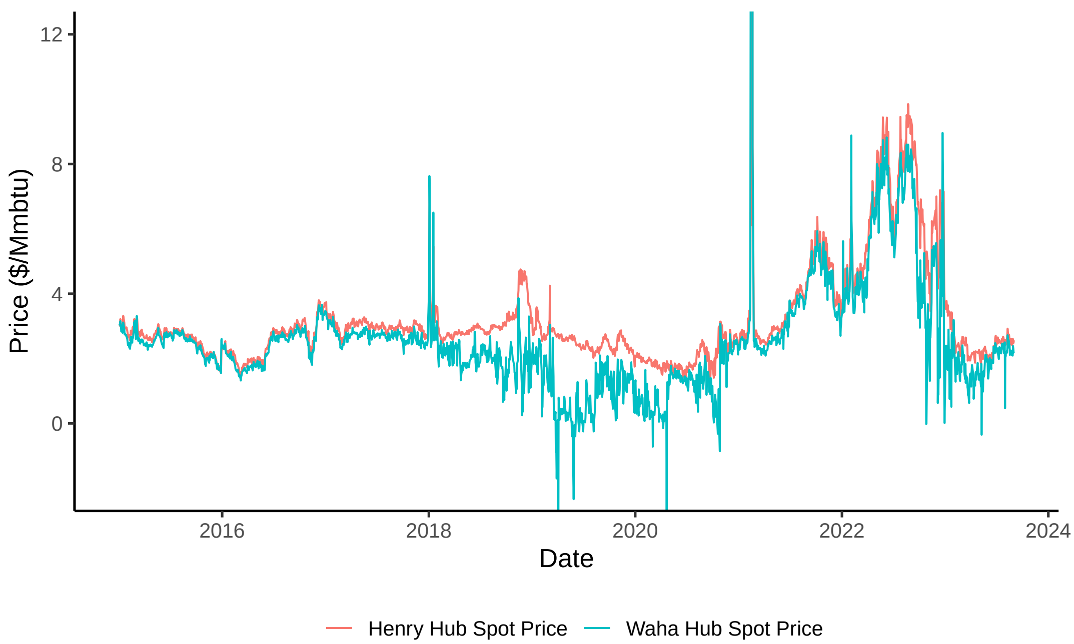
$$p^g - c_m(u) = c_a'(1 - e^*)$$

  But what does abatement cost function $c_a(1-e)$ map to in the real world? Now that we're thinking about intentional gas disposal rather than leak prevention, it makes less sense for the cost of abatement to be decreasing in emissions rate. But, we still want some sort of curve here so that gas disposal isn't all or nothing ($e = 1$ if $p^g < c_m$, $e = 0$ if $p^g > c_m$). We also see that, within a month, producers choose e strictly between 0 and 1, and that producers are heterogeneous in their choices of e. How should we model this?

- We want there to be some uncertainty about future production. But, as you point out, production is bounded below at 0 so it doesn't make sense for the error to have infinite support. What's the best way to structure this uncertainty? Should the uncertainty reflect that it is an aggregation of well- or field-level shocks?

- How should we model the evolution of utilization rates u? Currently, we do not observe u, only c_m as proxied by Henry-Waha basis. We could define uncertainty in terms of c_m rather than u, since we currently do not have data on u. But, looking at Figure 1, it seems that there are different regimes in terms of basis magnitude. Anecdotally, these regimes correspond to how close the system is to $u = 1$.

Figure 1: Spot market prices at Henry and Waha Hubs



5 Model

We present a dynamic model of a producer's investment and emissions decisions. Each period, the producer chooses the number of new wells to develop, a_t, and the share of produced gas to emit rather than sell, e_t. It chooses a_t and e_t to maximize current profits plus the discounted stream of expected future profits.

Let $\Omega_t = (q_t, w_t, p_t, u_t)$ be a producer's state space in period t, where q_t is the level of oil production from *existing* wells, w_t is the total number of wells the producer operates, $p_t = (p_t^o, p_t^g)$ are the oil and gas prices in the period, and u_t is the utilization rate of gas pipelines. The level of gas production in each period, $g_t = \alpha q_t$, follows deterministically from the level of oil production, according to the gas-to-oil ratio of the wells, α. We assume that each producer is small and so takes u_t and p_t as given.

In any given period, profits are equal to the following:

$$\pi_t(e_t, \Omega_t) = \underbrace{p_t^o q_t - c_o(q_t)}_{\text{oil profit}} + \underbrace{p_t^g\left[(1-e_t)g_t\right]}_{\text{gas revenue}} - \underbrace{c_g(e_t, g_t; u_t)}_{\text{gas capture/marketing costs}} - \underbrace{\tau\left(\mu e_t g_t + w_t \ell\right)}_{\text{emissions tax}} \tag{1}$$

Oil profits are the difference between oil revenues $p_t^o q_t$ and the marginal cost of oil extraction, $c_o(q_t)$. Gas revenues are the product of the gas price p_t^g and the amount of gas sold, which is equal to the sold share $1-e$ of total gas production $g_t = \alpha q_t$. Producers are subject to tax τ on each unit of emissions. Each producer emits a constant amount ℓ from each of its w_t wells, representing leakage and operational venting. Producers also dispose of share e_t of gas production g. A unit of disposed gas leads to μ units of methane emissions. Finally, the producer's choice of e determines how much it must pay in gas capture and marketing costs, which we decompose as follows:

$$c_g(e, \alpha q; u) = \underbrace{c_a(1-e)\cdot g}_{\text{abatement cost}} + \underbrace{c_m(u)\cdot(1-e)g}_{\text{marketing cost}}.$$

Abatement costs are a function of the disposal rate and must be paid for each unit of gas that is captured. Marketing costs capture the cost of moving gas to market, and depend on the utilization rate of gas pipelines, u. Marketing costs must be paid on each unit of sold gas, $(1-e)\alpha q$.

Firms choose how many wells to drill in each period, a_t, to maximize the stream of future-discounted expected profits. Wells drilled in period t begin producing in period $t+1$. Drilling costs c_t are a function of number of wells drilled and are allowed to vary by period. Production from a well decays exponentially at rate γ. The process of drilling a well results in emissions that are some multiple f of the well's typical per-period emissions ℓ. These emissions occur in the period that the well is drilled and are also subject to tax τ on methane emissions. In the period after a well is drilled, it begins producing r units of oil.

The value function for the producer is then given by

$$V(\Omega_t) = \max_{a_t, e_t} \pi(e_t, \Omega_t) - a_t[c_t + \tau f \ell] + \beta \mathbb{E}[V(\Omega_{t+1})|a_t, \Omega_t] \tag{2}$$

$$= \max_{a_t, e_t} \pi(e_t, \Omega_t) - a_t[c_t + \tau f \ell] + \beta \int V(\Omega_{t+1})\mathbb{P}(\Omega_{t+1}|a_t, \Omega_t) \tag{3}$$

subject to constraints:

$$\begin{aligned}
& q_t = \gamma q_{t-1} + r a_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \mathbb{N}(0, \sigma^2) && \text{Law of motion for production} \\
& w_t = w_{t-1} + a_{t-1} && \text{Law of motion for number of wells} \\
& a_t \geq 0 && \text{Zero lower bound for drilling} \\
& 0 \leq e_t \leq 1 && \text{Bounds for emissions rate}
\end{aligned}$$

Total producer emissions in period t are given by $\mu e_t g + \ell[w_t + f a_t]$ and the emissions rate is given by $(\mu e_t g + \ell w_t + f \ell a_t)/q_t$. Producers expectations are over future production q_t, commodity prices p_t, and utilization u_t.

5.1 Identification

In our data, we directly observe q_t, a_t, w_t, p_t, u_t, and α. If we assume that an individual producer's decisions don't affect c_t, we could pull c_t directly from the data on drilling rig costs (which we would need to purchase).

We can estimate γ (decline rate of production) and r (initial production from new wells) from a regression based on the law of motion for production. We can estimate these parameters as being constant across producers or estimate them separately for each producer or field.

We can estimate the parameters governing emissions from existing and new wells (ℓ and f) as follows: From total emissions, use reported flaring and venting totals to net out emissions from venting and flaring ($\mu e_t g_t$) at the sub-basin level. To figure out how remaining emissions depend on new vs. existing wells, run regression:

$$\text{net emissions}_t = \beta_1 w_t + \beta_2 a_t + \text{error}_t$$

where $\hat{\ell} = \beta_1$ and $\hat{f} = \beta_2/\beta_1$ and w_t and a_t (in a slight abuse of notation) are the aggregate number of operating wells and new wells in the sub-basin.

If we define p^g as the Henry Hub spot price and $c_m(\cdot)$ as the difference between Henry and Waha spot prices, then it is straightforward to estimate $c_a'(\cdot)$ in a static framework using the first order condition for emissions:

$$p^g - c_m(u) = c_a'(1 - e^*) + \epsilon.$$

Finally, we need to estimate the transition matrix $\mathbb{P}(\Omega_{t+1}|a_t, \Omega_t)$. We can assume commodity prices p_t follow a unit root process:[1]

$$p_t = p_{t-1} + \xi_t, \quad \xi_t \sim \mathbb{N}(0, \sigma_p^2).$$

[1]Alternatively, we could use futures prices.