Application: Dynamic Response to Environmental Regulation in the Electricity Industry

ECON 392M: Econometrics III

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Cullen & Shscherbakov Mimeo'10- Background

This paper addresses the dynamic issues surrounding the startup and shutdown decisions of electric generators.

- Low startup cost generators will find profitable to shut down during periods of low demand (when prices are also low).
- High startup cost generators will either remain producing at a loss during periods of low demand or alternatively choose not to produce at all.
- Demand for electricity fluctuates daily and consumers do not respond immediately to conditions in the wholesale market (future: smart grid).

Emissions

This is a policy relevant application:

- Electricity accounts for 40% of annual US CO_2 emissions.
- Alternative sources of energy (wind, solar, geothermal) receive important subsidies $\Rightarrow$ the reduced size of residual demand for conventional electricity generation will require power plants to reduce or stop production during off-peak periods while maintaining output levels during peak demand periods.
- Cap and trade or carbon taxes will reduce demand for electricity, and thus the need of generation BUT renewable energy subsidization may increase demand for electricity by lowering input prices... How will the conventional electricity industry react to these regulatory changes?

Overview

Dynamic structural model of generator operation:

- Recovery of cost parameters allows us to simulate conterfactuals:
  - A carbon tax.
  - An increase in renewable energy production due to subsidies.
- Use very detailed data set from the Texas grid on generator output and energy prices.
- Results appear to indicate the the environmental policies currently considered are mostly ineffective in reducing emissions.

Power System

Basic elements:

- Demand for electricity is almost perfectly inelastic in the short run.
- Quantity of electricity demanded at a given price varies cyclically over the course of a day and through the year.
  - Peak demand may more than double off-peak demand within a day.
  - Demand in summer months generally exceeds that of winter.
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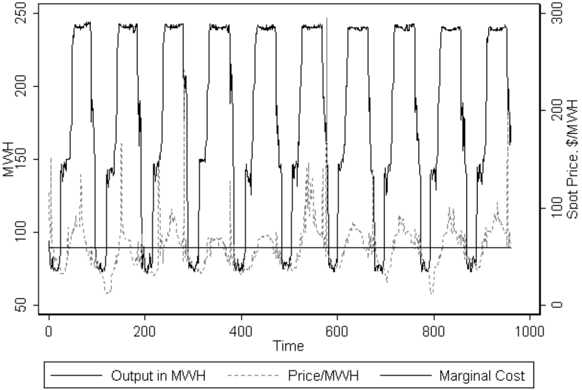
- Electricity cannot be stored in meaningful quantities $\Rightarrow$ production and consumption on a grid must be balanced at every moment.

Figure 1: Operating Decision Example



- One generator's output over a 10 day period in July of 2006.
- Marginal costs are constant.
- Even when the spot price falls below marginal cost, the firm does not shut down, but rather it reduces output to a minimum level.

Adjustment Costs

- The cost of operating a generator is determined by its technical design:
- Maximum output capability is fixed at the time of its construction.
- Adjustment costs are important (up to tens of thousands of dollars)
  - Startup – Costs of bringing the generator online after a period of zero production. They are important and furthermore increase the long run maintenance costs.
  - Ramping – Costs of increasing the output level. They also decrease output efficiency and increase operating costs. These costs increase with the severity of the adjustment.
- Adjustment costs make a generator's choice of output a dynamic problem $\Rightarrow$ Current benefits of increasing/decreasing current production relative to cost adjustments to market conditions in the future.

ERCOT

Electric Reliability Council of Texas:

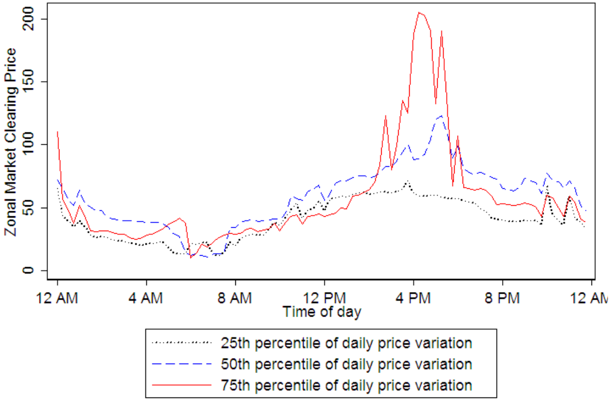
- Operates a quasi-deregulated market that serves most of Texas.
- Since the grid does not cross state lines it is under less federal oversight (none) than other grids in the US.
- Companies are vertically separated: There are no vertically integrated firms that control generation, transmission and retailing.

Generators

There are approximately 500 generators which supply electricity to the ERCOT grid:

- They are split in four geographically distinct congestion zones.
- They sell energy to buyers through bilateral contracts (95%) or through ERCOT's spot market (the Balancing Market).
- Generators need to submit a schedule of energy transactions a day ahead through a Qualified Scheduling Entity (QSE) – that is production and how power will be transmitted detailed by each hour of the day.
- QSEs also need to submit Balancing Market bidding functions for each hour of the day – willingness to deviate from the scheduled output as a function of the price in the Balancing Market.
- ERCOT equates demand and supply for each 15 minutes period via multi-unit uniform price auctions.

Figure 2: Representative Daily Price Variation by Percentile



- Spot prices are quite volatile, here the highest price is up to 20 times that of off-peak periods.

Congestion

Congestion arises at peak periods for a variety of reasons:

- Most of the time ERCOT operates as a single market.
- ERCOT allows for different prices in each four regions to minimize transmission congestion among them.
- Within zone congestion cannot be dealt with price differentials $\Rightarrow$ ERCOT deploys generators by offering them prices higher than the prevailing market price (which is covered by an output tax levied on all generators in the zone).

Demand

Demand does not respond directly to wholesale price signals:

- Residential and commercial users purchase electricity at fixed prices and thus they do not have any incentive to curtail demand during peak periods.
- Some large industrial consumers negotiate lower energy prices by agreeing to have their supply of electricity temporarily interrupted in emergency situations.

Data

Texas grid:

- 80 firms operate 180 power plants with 2-4 generators each.
- Maximum full capacity of 73,000 MW.
- Generation includes coal, nuclear, natural gas, water, and wind power plants.
- Data includes output of each generator every fifteen minute from April 2005 to April 2007 plus the market clearing prices for each zone for these same fifteen minute periods.
- For each generator-interval data also indicates whether it is shut down for maintenance of due to involuntary mechanical failure.
- Generator characteristics: maximum and minimum output capability, age, fuel type and location.

Data

From other data sources:

- Characteristics of power plants: average annual heat rate and emissions rates for SO_2, NO_x, and CO_2.
- Construction of marginal costs:
  - Fuel costs. Marginal cost of fuel $\Rightarrow$ Generator's heat rate times the average cost of delivered fuel.
  - Average permit prices from EPA permit auctions in 2006 (for SO_2, NO_x). Marginal cost of emissions $\Rightarrow$ Generator's emissions rate times the cost of pollution permits.
- The total marginal cost of electricity is the marginal cost of fuel plus the marginal cost of emissions.

Data

Data problems:

- Emissions and heat rate information are plant level characteristics.
- It is claimed that generators at the same plant are usually of the same vintage (not necessarily true).
- Heat rate information is averaged over the year but a significant portion of fuel consumption is used during frequent startups and thus overestimating marginal costs.
- Not all plants pay for permits. Many old generators were allocated those permits.
- The spot price represents the opportunity cost of production of a generator but actually only 5% of electricity is traded at this price.

Assumptions

Assumption 1: Firms are price takers.

- It allows the firm's decisions to be modeled as single agent dynamic problems.
- It renders ownership irrelevant.
- Is it realistic?
  - Any firm cannot own more than 20% of generation capacity in a single zone.
  - The spread use of bilateral contracts reduces the incentive to withhold production in order to increase the spot market price.

Assumptions

Assumption 2: The marginal cost of each generator is constant and known.

- Standard in the literature and appropriate depending on the technology used.
- However the heat rate of a generator is not constant over time: increasing efficiency over the output of a plant implies that marginal costs are increasing over some range of output.

Assumptions

Assumption 3: There are no transmission costs or local constraints.

- Plausible given the attempts that ERCOT makes to avoid transmission congestion.
- Intra-zonal congestion does pose problems because some generators respond differently to observable spot prices as they get overpaid.
- Still, the set of generators that operate to relieve congestion is known.

Assumptions

Assumption 4: Generators can costlessly adjust output within its operating range.

- It allows us abstracting from the choice of output level.
- Generators will produce at maximum capacity if price is above marginal cost and at minimum capacity otherwise.
- Generators with more flexible technology tend to follow this pattern.

Model

Each generator is assumed to be a single firm which:

- Each period it observes the price in the market and decides whether to operate or not.
- A firm operates at maximum capacity of the spot price exceeds marginal costs.
- Firms face constant marginal costs, fixed operating costs, plus the startup costs of the generator if it is bringing it back online.
- The state of the firm is given by whether it was operating or not in the previous period, which conditions whether it will face startup costs or not.
- Expected future spot prices: AR(1) Markov process $F(P_t|P_{t-1}, I_{t-1})$, where I_t is an indicator for each hour of the day (aggregate four 15 minutes periods to simplify).

Model

Optimal policy function:

- There is a cutoff rule P_t for every pair (I_t, s_t).
- The unobservable component of the state is allowed to be correlated.
- P_t needs to be discretized: 200 intervals.
- Since I_t has 24 possible values and s_t includes just two outcomes, this produces a state space size of 9,600.
- Use a parametric specification to approximate transition probabilities.