# Stephen Ryan: "The Costs of Environmental Regulation in a Concentrated Industry"

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**Main question**: What are the sunk entry and adjustment costs for the cement industry? How does environmental regulation effect these costs as well as market structure?
**Basic idea**: Currently, costs of environmental regulation are computed as the engineering estimate of compliance. Ignores the dynamic effects on entry – larger costs may cause *exit*, leading to lower output and higher market concentration.

## 1 Overview of Cement Industry

- Cement used to make concrete and as fill material. Water and cement form a paste that is used as a binding agent.
- Difficult to store cement and it is heavy. Both reasons mean that it is expensive to transport. 83% of cement is shipped less than 200 miles, 99.8% less than 500 miles.
- Most markets are mostly local – with a few players
- Cement requires lots of limestone and heat. Need temperatures equal to one-third of those found on the surface of the sun. Kilns (the capital) are the third largest consumer of energy – so they are hugely impacted by environmental regulation.

- Clean Air Act Amendments of 1990 mandated monitoring, reporting and emissions requirements for cement industry.

  1. existing firms had to install monitoring equipment and draw up plans for compliance and certification (EPA $<$ \$5 million per establishment)
  2. greenfield plants have additional, rigorous certification and testing requirement (Industry sources, plus \$5-10 million). This change has large impact in the model.

# 2 Data

- US geological survey published regional data on number of plants, quantity shipped and prices of cement.
- As demand instruments, collects cost shifters: gas, coal and electricity prices, and skilled manufacturing wages.
- Plant level data from Portland Cement Association's Plant Information Survey (trade association). Detailed information on capacity, investment, etc.
- see table 2. note demand data is market-level, while production data is at plant-level.
- Kilns are typically run near capacity almost all the time, except for annual maintenance (e.g. one month of the year). See figure 1. Note the lumpy investment.
- See this production behavior across many industries (e.g. capital-intensive ones).
- Capacity, and investment in capacity seems to play a *major* role in industry.

# 3 Model

- Based on the data and industry knowledge, want to build a dynamic model.

- Big picture:
  - State variable is firm's capacity – vector of incumbents' capacity and potential entrant's capacity (?).
  - Firms receive state-dependent revenues, and choose entry, exit, and adjustments to capacity.
  - Firm strategies only depend on current state vector (i.e. Markov).
  - Equilibrium obtains when firms follow strategies that maximize the expected discounted present value of their revenue streams – Markov Perfect Nash Equilibrium (MPNE).
- Have $M$ markets with $N_m$ firms in each. state vector is $s_t$, where $s_{it}$ is the capacity of the $i$th firm. Of course, entrants have $s_i = 0$ and incumbents $s_{it} > 0$.
- Discount rate is fixed at $\beta = 0.9$
- Timing
  1. Potential entrants receive a draw from the distribution of entry values and make decisions. Incumbents make exit decisions
  2. Incumbents and new entrants make investment decisions
  3. Firms receive *private* productivity shocks (iid) and compete in quantities
  4. Exiting incumbents leave the market and receive scrap value, entrants pay entry fee
  5. end of period – state vector adjusts
- Note: since shocks are iid – firms do not update their expectations of future behavior after observing rivals' actions.

## 3.1 Product Market payoffs

- Firms compete in quantity in a homogenous good market. Firms face a constant elasticity of demand curve:

$$P(Q) = AQ^{1/\epsilon} \tag{1}$$

where $Q$ is aggregate quantity, and $\epsilon$ is the elasticity of demand.

- No dynamics!
- Production costs: constant marginal cost, increasing costs when close to capacity
- profit function

$$\begin{aligned}\pi_i = {} & Q_i \left(P(Q) - MC + SHOCK_i\right) \\ & - 1(UTILPCT_i > \nu)\left[CAPCOST \cdot (UTILPCT_i - \nu)^2\right]\end{aligned} \tag{2}$$

## 3.2 Entry, Exit and Investment Costs

- Costs to positive investment and negative investment can be different
- New entrants initially just pay entry fee and initial investment costs – next period get revenue

$$-SUNK_i - ADJPOS - INVPOS \cdot INV_i^e - INVPOS2 \cdot (INV_i^e)^2 \tag{3}$$

where $SUNK_i$ is drawn from a known distribution $G$

- Incumbents who stay

$$\begin{aligned}&\pi_i(s) - 1(INV_i > 0)\left(ADJPOS + INVPOS \cdot INV_i + INVPOS2 \cdot (INV_i)^2\right) \\ &\quad - 1(INV_i < 0)\left(ADJNEG + INVNEG \cdot INV_i + INVNEG2 \cdot (INV_i)^2\right)\end{aligned} \tag{4}$$

- Incumbents who leave

$$\pi_i(s) + SCRAP \tag{5}$$

### 3.3 Transitions between States

- $$\begin{aligned} \Pr(s_i \to s_i') =& 1(s_i > 0)\,(1 - \Pr(i \text{ exits}|s_i))\,\Pr(s_i'|s_i, INV_i) && (6)\\ &+ 1(s_i > 0)\Pr(i \text{ exits}|s_i)\Pr(j \text{ enters}|s_i, i \text{ exits})\Pr(s_i'|i \text{ exits}, j \text{ enters}, INV_j) && (7)\\ &+ 1(s_i = 0)\Pr(j \text{ enters}|s_i)\Pr(s_i'|j \text{ enters}, INV_j) && (8) \end{aligned}$$

- Multiply out individual probabilities to get state vector transition probabilities

$$\Pr(s \to s') = \prod_{i=1}^{N} \Pr(s_i' \to s_i) \tag{9}$$

- entry – function of state variables and distribution of sunk cost (common)

$$\Pr(entry|s_i) = \int \Theta(s_i, SUNK_i)dG(SUNK_i) \tag{10}$$

- exit – function of state variables (will be a probit)

$$\Pr(exit|s_i) = \Phi(s_i) \tag{11}$$

- exit and entry will be flexible specified, to capture the true, non-linear relationship between state variables (i.e. capacity) and exit/entry rules.

### 3.4 Equilibrium Concept

- Full set of dynamic Nash equilibrium is unbounded and complex - so need to simplify.
- Firms' strategies are anonymous, symmetric, and Markovian.
- Let $\sigma(s)$ denote firms' strategies. Value function

$$V_i(s|\sigma(s)) = u_i(\sigma(s)) + \beta \int V_i(s'|\sigma)dP(s'|\sigma(s), s) \tag{12}$$

- Nash equilibrium requires each firm's strategy profile to be optimal given the strategy profile of its competitors

$$V(s|\sigma_i, \sigma_{-i}) \geq V(s|\sigma_i', \sigma_{-i}) \tag{13}$$

This condition is central to recovering underlying structural parameters.

- Assume the equilibrium is unique
- Value function for potential entrant:

$$V_i^e(s, SUNK_i) = \max_{INV_i^e}\Big\{-SUNK_i - ADJPOS - INVPOS \cdot INV_i^e - \\ INVPOS2 \cdot (INV_i^e)^2 + \beta E[V(s')|s)\Big\} \tag{14}$$

- Note – there will be a value of $SUNK_i$ such that the potential entrant is exactly indifferent to entering or exiting.
- Value to incumbent to staying

$$V_i^{STAY} = \max_{INV_i} -1(INV_i > 0)((ADJPOS + INVPOS \cdot INV_i + INVPOS2 \cdot (INV_i)^2) \\ - 1(INV_i < 0)\left(ADJNEG + INVNEG \cdot INV_i + INVNEG2 \cdot (INV_i)^2\right) \\ + \beta E[V(s'|s)]$$

- Combining all the incumbent's options

$$V_i(s) = \int \pi_i(s_i)dS + (1 - \Phi(s_i))V_i^{STAY}(s) + \Phi(s_i)SCRAP_i \tag{15}$$

where we integrate over the private productivity shocks

# 4 Empirical Strategy

- Two part process (see Bajari, Benkard, Levin (BBL) (2006))

1. recover policy functions governing entry, exit and investment along with per period profit function
2. Take policy functions, impose MPNE, and recover structural parameters

- Careful decisions are made, using model above for guidance, on how to estimate policy functions in first stage.
- Also a whole section on identification, which is good to read.

## 4.1 First-stage

- Demand curve (static)

$$P(Q) = AQ^{1/\epsilon} \tag{16}$$

- So moment used to estimate price elasticity

$$m_1(\alpha) = \frac{1}{MT}\sum_{t=1}^{T}\sum_{i=1}^{M}\frac{1}{N_m}\sum_{j=1}^{N_m} Z'_{ijt}\left[\log MARKETQ_{ijt} - \alpha_0 - \alpha_1 \log PRICE_{ijt} + \alpha_2' REGION_i\right] \tag{17}$$

where $Z$ are instruments (cost shifters, e.g. gas and coal prices) and includes region dummies.

- Production parameters – minimizes first order conditions. There are 6 production parameters: CAPCOST, MC, and level at which capacity starts to bind ($\nu$), and late period dummy variables. Recall

$$\begin{aligned}\pi_i = Q_i\left(P(Q) - MC + SHOCK_i\right) \\ - 1(UTILPCT_i > \nu)\left[CAPCOST \cdot (UTILPCT_i - \nu)^2\right]\end{aligned}$$

and so moment condition is

$$m_2(\alpha) = \frac{1}{MT}\sum_{i=1}^{M}\sum_{t=1}^{T}\nabla_\alpha(Q_it - \tilde{Q}_{it}(\alpha)) \tag{18}$$

note that firm's production choice does *not* affect dynamics, only investment does. So it is a static maximization problem.

- Investment policies
  - These are more complicated, b/c of the dynamics and are central to the question of entry/exit.
  - Posits that an (S,s) rule is behind investment decisions (Attanasio (2000)).
  - Target level of capacity is a function of state variables

    $$TARGET_{it} = \alpha_4 s_1(CAP_{it}) + \alpha_5 s_2(SUMCAP_{-it}) + \alpha_6 SHOCK_{it} + u^d_{it} \quad (19)$$

    where CAP is own capacity and SUMCAP is all others' capacity (recall anonymous assumption). Know SHOCK b/c we can back it out of (static) production decision. $u$ is error term.
  - Bands are assumed to be symmetric with the same state variables as the target

    $$BAND_{it} = TARGET_{it} \pm \exp(\alpha_7 s_1(CAP_{it}) + \alpha_8 s_2(SUMCAP_{-it}) + \alpha_9 SHOCK_{it} + u^b_{it}) \quad (20)$$

    To estimate this investment model, minimizes moments formed from the score vector (first derivative) of the log likelihood function. Not sure why he does not just maximize the log likelihood
  - Entry and Exit – used probit models. Explanatory variables are
    1. constant
    2. sum of competitors' capacities
    3. dummies for after 1990 environmental act
    4. exit probit also has firm's capacity and productivity shock, SHOCK

## 4.2 Second stage

- this is the hard part – bringing all the components together

- trying to estimate, or recover

1. fixed costs of investment
2. variable costs of investment
3. the distribution of sunk entry costs
4. exit scrap

- Recall firm's optimal investment decision

$$\max_{\sigma_i} u_i(\sigma(s), s) + \beta \int V_i(s'|\sigma) dP(s'|\sigma(s), s) \tag{21}$$

where $u_i$ is equal to

$$u_i = \pi_i - 1(INV_i > 0)\left(ADJPOS + INVPOS \cdot INV_i + INVPOS2 \cdot (INV_i)^2\right) \tag{22}$$

$$- 1(INV_i < 0)\left(ADJNEG + INVNEG \cdot INV_i + INVNEG2 \cdot (INV_i)^2\right) \tag{23}$$

$$+ 1(i \text{ exits}) SCRAP_i \tag{24}$$

where we know $\pi_i$, capacity adjustment, and exit decision are known from the first stage.

- In the second stage, trying to determine the costs of capacity adjustment and scrap value.

- objective function – deviations from policy should NOT be profitable.

- Basic idea: want to find parameters that are consistent with the estimated policy functions being an equilibrium.

1. choose an initial vector of parameters, compute value function via simulation.
2. consider deviations in the policy functions – e.g. a random "noise" term in the exit probability, or in the investment choice equations.
3. This deviation is *only* for a specific firm — not all firms.
4. recompute the value function and compare. Is firm worse off by deviating?

- Example – have low exit prob with policy function. If choose SCRAP to be \$100 billion, will get profitable deviations where exit with a higher probability.

- Ryan's notation: decomposes the value function into vector of parameters, $\alpha$ and a vector of discounted payments and actions.

$$W(s_0; \sigma_i, \sigma_{-i}) = E_{\sigma_i, \sigma_{-i}|s_0} \sum_{t=0}^{\infty} \beta^t \zeta(s_{it}) \tag{25}$$

  where $\zeta$ is the vector of functions corresponding to the structural parameters

$$\zeta(s_i) = \{\pi_i, 1(INV_i > 0), 1(INV_i > 0)INV_i, 1(INV_i > 0)INV_i^2, \tag{26}$$

$$1(INV_i < 0), 1(INV_i < 0)INV_i, 1(INV_i < 0)INV_i^2, 1(i \text{ exits})\} \tag{27}$$

  where $\alpha$ will have a 1 as its first element.

- Markov perfect equilibrium implies that

$$W(s_0; \sigma_i, \sigma_{-i}) \cdot \alpha \geq W(s_0; \sigma_i', \sigma_{-i}) \cdot \alpha \tag{28}$$

- let $g(x, \alpha) \equiv [W(s_0; \sigma_i, \sigma_{-i}) - W(s_0; \sigma_i', \sigma_{-i})]\alpha$, then for set of $n_k$ inequalities, want to minimize the following

$$Q(\alpha) = \frac{1}{n_k} \sum_{i=1}^{n_k} 1(g(X_i, \alpha) > 0) g(X_i, \alpha)^2 \tag{29}$$

- The notation is odd and the objective function is a score function which has a history of being troublesome (from an empirical point of view).

- Uses Laplace-type estimator (see Chernozhukov and Hong (2003)) which jointly estimates the mean and variance of parameters, which seems slick.

- What about sunk costs? Back out from model:

$$V_i^e(s, SUNK_i) = \max_{INV_i^e} \{-SUNK_i - ADJPOS - INVPOS \cdot INV_i^e - INVPOS2(INV_i^e)^2 + \beta E[V(s'|s)]\} \tag{30}$$

- Recall there is a threshold level of SUNK, below which a firm enters. Simulate to get $V_i^e$.

$$\Pr(SUNK_i \leq E[V^e(s)]) = G(E[V^e(s)]; \mu_g, \sigma_g^2) \tag{31}$$

and so want to minimize

$$\min_{\mu_g, \sigma_g} \left\{ \frac{1}{NS} \sum_{i=1}^{NS} \big(\Pr(\text{entry}|s) - G(E[V^e(s)])\big)^2 \right) \tag{32}$$

## 4.3 Review

First stage

- entry probit
- exit probit
- demand model
- quantity decision
- (S,s) rule — investment decision

Above all estimated separately, with the theoretical model in mind (e.g. what are the state variables, etc)

Second stage

- SCRAP & costs to changing parameters (relied on all policy functions above, directly or indirectly)
- sunk costs

Objective function — relying on the MPNE concept. Want the estimated parameters, along with the policy functions estimated in first step, to result in an MPNE. In other words, given the second stage parameters, slight changes in the policy functions for a firm will lower value function.

## 5 Results

- elasticity of demand is -2.9.
- marginal cost and capacity constraints seem reasonable
- e.g. marginal cost didn't change with clean air act (there were dummies); little reason why it should
- Says implied prices, revenues, costs and profits are in line with the data but hard to tell what he is comparing it to. Margin is in line with industry data – markups of over 30%. Need to be high to cover high fixed costs!
- hard to tell if (S,s) rule is reasonable. Why doesn't he just show it?
- Exit — odd that CAP is not significant. But good that SUMCAP is.
- Entry – really just a constant, which does not seem right.
- Given the importance of entry and exit, I would have thought more work would be done here.
- Investment costs (table 8)
- sunk costs (table 9) increase with environmental regulation – in line with EPA estimates

## 6 Policy Experiment

Want to highlight change in industry behavior with the change in sunk costs w.r.t environmental regulation.

- See table 11
- Average market – with 4 potential entrants, high sunk costs can do the most damage

- Average market with 2 incumbents, high sunk costs should do little damage
- Sort of like a bounding exercise – see impact on producer and consumer surplus.
- throws in social planner — only has one firm enter!

How do they solve the MNPE? Problem with dealing with mixed strategies ... refer to Doraszelski and Satterthwaite (2005).