Estimation of Dynamic Games

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Notation

- Agents/players: $i \in \{1, 2, ...N\}$
- Time: $t = 1, 2, ...$
- Actions: $a_{it} \in A = \{0, 1, 2, ...J\}$
- Payoffs: $\pi_{it}(a_t, x_t, \epsilon_{it})$
  where: a_t = vector of actions at time t; x_t = vector of observable states; ϵ_{it} = states observed only to the firm;
- States: $s_t = (x_t, \epsilon_t)$
- Transition $P(s_{t+1}|s_t, a_t)$

Assumptions

- Additive Separability (AS)

$$\pi_{it}(a_t, x_t, \epsilon_{it}) = \pi_i(a_t, x_t) + \epsilon_{it}$$

- Conditional Independence (CI)

$$P(x_{t+1}, \epsilon_{t+1} | a_t, x_t, \epsilon_t) = p_\epsilon(\epsilon_{t+1}) f(x_{t+1} | a_t, x_t)$$

- Independent Values

$$p_\epsilon(\epsilon_t) = \prod_i^N g(\epsilon_{it})$$

- Markov Strategies

$$\sigma_i(x, \epsilon_i) : X \times R^{J+1} \rightarrow A$$

Note: strategies (i) are not indexed by time (ii) depend only on payoff relevant information

Conditional Choice Probabilities

- A strategy σ generates conditional choice probabilities:

$$P_i^{\sigma}(a_i|x) = Pr[\sigma_i(x,\epsilon_i) = a_i|x] = \int 1(\sigma_i(x,\epsilon_i) = a_i) dG(\epsilon)$$

- $P_i^{\sigma}(a_i|x)$ is i's expected behavior (if following strategy σ)
- Expected profits (i.e., integrating ϵ) from action a_i when others use σ:

$$\Pi_i^{\sigma}(a_i, x_t) = \sum_{a_{-i}} \left(\prod_{j \neq i} P_j^{\sigma}(a_j|x) \right) \pi_i(a_{-i}, a_i, x_t)$$

The objective function

- The value function

$$V_i(S|\sigma_i, \sigma_{-i}) = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \pi_i(a_t, s_t)$$

Best Response

Assume that others play σ. What is the optimal behavior?

$$\tilde{V}_i^\sigma(x,\epsilon) =$$

$$max_{a_i \in A}\left\{\pi_i^\sigma(a_i, x_t) + \epsilon_i(a_i) + \beta \sum_{x' \in X} \int \tilde{V}_i^\sigma(x', \epsilon`) dG(\epsilon) f_i^\sigma(x'|x,a)\right\}$$

where $f_i^\sigma(x'|x,a)$ is the transition generated by a_i and σ^{-i}.

As in the single agent case, integrate wrt to ϵ:

$$V_i^\sigma(x) = \int max_{a_i \in A}\left\{\pi_i^\sigma(a_i, x_t) + \epsilon_i(a_i) + \beta \sum_{x' \in X} V_i^\sigma(x') f_i^\sigma(x'|x,a)\right\} dG(\epsilon)$$

which is a contraction. So for a given σ there is a unique $V_i^\sigma(x)$ that solves the single agent problem.
Can follow methods from single agent like HM or HMSS or AM.

Markov Perfect Equilibrium (MPE)

The equilibrium strategy satisfies:

$$\sigma^*(x,\epsilon) = argmax_{a_i \in A} \left\{ \pi_i^{\sigma^*}(a_i, x_t) + \epsilon_i(a_i) + \beta \sum_{x' \in X} V_i^{\sigma^*}(x') f_i^{\sigma^*}(x'|x,a) \right\}$$

Thus

$$P_i^{\sigma^*}(a_i|x) \equiv \int 1(\sigma_i^*(x,\epsilon_i) = a_i) dG(\epsilon)$$

is a fixed point of

$$\Lambda_i(a_i|x, P_{-i}) =$$

$$\int 1 \left(a_i = argmax_{j \in A} \left\{ \pi_i^{\sigma^*}(j,x) + \epsilon_i(j) + \beta \sum_{x' \in X} V_i^{\sigma^*}(x') f_i^{\sigma^*}(x'|x,j) \right\} \right) dG(\epsilon$$

Markov Perfect Equilibrium (MPE)

$$\Lambda_i(a_i|x, P_{-i}) =$$

$$\int 1\left(a_i = argmax_{j\in A}\left\{\pi_i^{\sigma^*}(j,x) + \epsilon_i(j) + \beta\sum_{x'\in X} V_i^{\sigma^*}(x') f_i^{\sigma^*}(x'|x,j)\right\}\right) dG(\epsilon$$

1. Λ is a BR in probabilities
2. Λ is continuous in a compact set, so the MPE exists
3. Equil probabilities solve fixed point of V and BR
4. Estimation in principle would require solving both FP (+parameter search)

An alternative

$$V_i^{p^*}(x) = \sum_{a_i \in A} p_i^*(a_i|x) \left[\pi_i^{p^*}(a_i, x) + e_i^{p^*}(a_i) + \beta \sum_{x' \in X} V_i^{p^*}(x') f_i^{p^*}(x'|x) \right]$$

- Reorganize and invert to recover $V_i^{p^*}(x)$ as weighted average of expected payoffs. Call this inversion $\Gamma_i(x, P)$
- $\Gamma_i(x, P)$ provides the value of the firm if everyone behaves today and in the future according to (any arbitrary) P
- We get an equilibrium if, P is a FP of:

$$\Psi_i(a_i|x, P) =$$

$$\int 1 \left(a_i = argmax_{j \in A} \left\{ \pi_i^{p^*}(j, x) + \epsilon_i(j) + \beta \sum_{x' \in X} \Gamma_i(x', P) f_i^{p^*}(x'|x, j) \right\} \right) dG($$

An comparison of BR

- Ψ is a best response but unlike Λ it takes i's future as given.
- Using Ψ avoids having to compute the inner FP.

$$\Psi_i(a_i|x,P) =$$

$$\int 1\left(a_i = argmax_{j\in A}\left\{\pi_i^{p^*}(j,x)+\epsilon_i(j)+\beta\sum_{x'\in X}\Gamma_i(x',P)f_i^{p^*}(x'|x,j)\right\}\right) dG($$

$$\Lambda_i(a_i|x,P_{-i}) =$$

$$\int 1\left(a_i = argmax_{j\in A}\left\{\pi_i^{\sigma^*}(j,x)+\epsilon_i(j)+\beta\sum_{x'\in X}V_i^{\sigma^*}(x')f_i^{\sigma^*}(x'|x,j)\right\}\right) dG(\epsilon$$

Estimation

- A variety of methods that mimic what we saw in single agent problems.
- Two step procedure:
  - Estimate the policy functions from the data
  - Base estimation on BR to this policy
- Data: typically observations across markets
- Assume all data come from the same equilibrium; can allow for multiple equilibria but need to assume only one observed in the data
- I will mostly focus on Bajari, Benkard and Levin (BBL)

First step: estimate the policy function

- Estimate
  - Policy function
    $$\sigma_i : S \to A_i$$
  - State transition function
    $$P : S \times A \to \Delta(S)$$
  - Often "static" parts of the period return.
    - production functions
    - investment policies
    - entry/exit
    - demand
- Common to all the methods used for estimation (not just BBL)
- Different ways of doing this

Step two: estimate the parameters

- Find the set of parameters that rationalize the data;
- Conditional on the first stage estimates find the set of parameters that satisfy the equilibrium requirements.
- BBL use inequalities implied by the equilibrium
- A MPE is given by a Markov profile, σ, such that for all i, s, σ_i'

$$V_i(S|\sigma_i, \sigma_{-i}) \geq V_i(S|\sigma_i', \sigma_{-i})$$

- For all i, σ_i' and initial state s_0 it must be that

$$\mathbb{E}_{\sigma_i, \sigma-i|s_0} \sum_{t=0}^{\infty} \beta^t \pi(a_t, s_t) \geq \mathbb{E}_{\sigma_i{}^{`}, \sigma-i|s_0} \sum_{t=0}^{\infty} \beta^t \pi(a_t, s_t)$$

How do we compute the above?

1. Starting at x_0 draw shocks ϵ_{i0}
2. Calculate $a_{i0} = \sigma_i(x_0, \epsilon_{it})$ for each i, and compute the profits $\pi_i(a_0, x_0, \epsilon_0; \theta)$
3. Draw new state using the estimated transition probabilities (given the action and state)
4. Repeat 1-3 for T periods
5. Sum up over the discounted profits and average over paths to get $\hat{v}(s, \sigma; \theta)$

This can be done for any strategy, but will be done for the estimates from Step 1

Linearity

- The simulation can be simplified if we assume linearity

$$\pi_i(a, s); \theta) = \phi_i(a, s) \cdot \theta$$

- Define $W(s_0; \sigma_i, \sigma_{-i}) \equiv \mathbb{E}_{\sigma_i, \sigma_{-i}} \left[\sum_{t=0}^{\infty} \beta^t \phi_i(a_t, s_t) \middle| s_0 = s \right]$
- We can now write the value function as

$$V_i(s|\sigma_i, \theta) = W_i(s|\sigma) \cdot \theta$$

- The system of inequalities can now be written as

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

for all i, σ_i', s_0

The identified set

- Let Θ_0 be the set of parameters that satisfy the above inequalities
- Two cases:
  - Θ_0 is a singleton (model is identified)
  - Θ_0 is a set (model is not/set identified)

The identified case

- Let x index the (n) inequalities
- Define

$$g(x,\theta) = \left[\hat{W}_i(s|\sigma) - \hat{W}_i(s|\sigma')\right] \cdot \theta$$

- Minimize

$$Q_n(\theta) = \frac{1}{n}\sum_i 1\{g(x_i,\theta) < 0)g(x_i,\theta)^2$$

- Constructed using the first step estimator
- Simulation can be done prior to estimation

The set identified case

- Set identification via minimum distance

$$\hat{Q}_n(\theta) = \{\theta : Q_n(\theta) \leq min_\theta Q_n(\theta) + \mu_n\}$$

where μ_n is a "slack" parameter such that $\mu_n \to 0$

Ryan (EMA, 2012)

Q: What are the welfare costs of the 1990 Clean Air Act on the Portland Cement Industry?

- Portland cement: binding material in concrete
- Generates by-products and therefore targeted by the EPA
- General approach:
  - Model of entry/exit, production + investment
  - Estimate parameters following BBL
  - Simulate equilibrium with different cost structure

Background

- Industry
  - limestone + (intense) heat generate cement
  - $10B industry, but because of heat large energy needs
  - Product not storable
  - Costly to ship
- 1990 Clean Air Act
  - required permits to pollute
  - new plants required additional environmental certification (adds $5-$10 M to new plant construction); changes entry cost

Data

- 1980-1990
- P + Q at market level (regional markets) from US Geological Survey (USGS)
- Market is roughly a circle with 100 mile radius
- For IVs collects electricity prices, coal prices, natural gas and wgaes

Model

- series of markets
- $s_t = (s_{1t}, ...S_{\bar{N}t})$ where $\bar{N}$ is max number of firms, and s_{it} is the capacity of firm i
- Timing in each period
  1. I draws scrap value and decides if to exit
  2. E draws investment + entry cost; I draw costs of investment; Simultaneously decide entry + investment for $t+1$
  3. I set P+ Q (Cournot competition)

Model

- Demand (homogeneous good)

$$lnQ_m = \alpha_{0m} + \alpha_1 lnP_m$$

- Cost

$$C_i(q_i) = \delta_0 + \delta_1 q_i + \delta_2 1(q_i > vs_i)(q_i - vs_i)^2$$

- Change capacity through costly investment x_i. The adjustment cost

$$\Gamma(x_i) = 1(x_i > 0)(\gamma_{i1} + \gamma_2 x_i + \gamma_3 x_i^2) + 1(x_i < 0)(\gamma_{i4} + \gamma_5 x_i + \gamma_6 x_i^2)$$

- The FC of adjustment (γ_i) will be drawn from F_γ and G_γ

Model

- Fixed cost depends on action
  - $\phi_i(a_i) = -\kappa_i$ if new entrant (entry cost) $\kappa_i \sim F_k$ IPV
  - $\phi_i(a_i) = \phi$ if firm exits (scrap value) $\phi \sim F_\phi$ IPV
- Putting this ll together, the current period profits are

$$\pi(s, a) = \bar{\pi}(s) - \Gamma(x_i) + \phi(a_i)$$

- Transitions: states change through entry and exit, and firms making capacity choice (investment + disinvestment)

Equilibrium

Focuses on strategies that are symmetric and Markov

$$\sigma_i(s, \epsilon_i) \rightarrow a_i$$

The Incumbent's Bellman equation

$$V_i(s; \sigma(s), \theta, \epsilon_i) = \bar{\pi}(s; \theta) + \max\{\phi_i, E_{\epsilon_i}\{$$
$$\max_{x_i^* \geq 0}[-\gamma_{i1} - \gamma_2 x_i - \gamma_3 x_i^2 + \beta \int E_{\epsilon_i} V_i(s'; \sigma(s'), \theta, \epsilon_i) dP(s_i + x^*, s_{-i}; s, \sigma(s))],$$
$$\max_{x_i^* < 0}[-\gamma_{i4} - \gamma_5 x_i - \gamma_6 x_i^2 + \beta \int E_{\epsilon_i} V_i(s'; \sigma(s'), \theta, \epsilon_i) dP(s_i + x^*, s_{-i}; s, \sigma(s))]\}\}$$

Equilibrium

The Potential Entrants' Bellman equation

$$V_i(s; \sigma(s), \theta, \epsilon_i) = \max\{0. E_{\epsilon_i}\{$$

$$\max_{x_i^* \geq 0}[-\gamma_{i1} - \gamma_2 x_i - \gamma_3 x_i^2 + \beta \int E_{\epsilon_i} V_i(s'; \sigma(s'), \theta, \epsilon_i) dP(s_i + x^*, s_{-i}; s, \sigma(s))], \}$$

Equilibrium

In MPE $\forall s_i, \epsilon_i, \hat{\sigma}_i(s)$

$$V_i(s; \sigma_i^*(s), \sigma_{-i}(s), \theta, \epsilon_i) \geq V_i(s; \tilde{\sigma}_i(s), \sigma_{-i}(s), \theta, \epsilon_i)$$

Also holds integrating over the ϵ's

Estimation

- Two-step method following BBL
- 2 key assumptions:
    1. Same equilibrium is played in all markets
    2. Firms assume that the regulatory environment is permanent

Step 1

- (static) Demand: log-log (constant elasticity) curve, using market level data and IV regression (wages as IV)
- (static) Cost
  - set fixed costs, $\delta_0 = 0$
  - Solve for Cournot equilibrium and min distance between actual an predicted quantities
- Investment policy: (S, s) model (see paper for details)
- Entry/Exit: Probit

Step 2

The expected payoff function

$$E_{\epsilon_i}\pi(s,\sigma(s);\theta) = \bar{\pi}(s)\cdot 1 - p_{\text{invest}}(s)(\tilde{\gamma}_{i1} + \gamma_2 x_i - \gamma_3 x_i^2)$$
$$p_{\text{divest}}(s)(\tilde{\gamma}_{i4} + \gamma_5 x_i - \gamma_6 x_i^2) + p_{\text{exit}}(s)\tilde{\phi}_i$$

where ˜ denotes the conditional expectation that accounts for selection.
Can be written as

$$[\tilde{\pi}_i(s_{it}) \quad \xi(s_{it})] \cdot [1 \quad \theta]'$$

As before we can linearize the value function

Step 2

Let

$$W_i(s_{it};\sigma(s)) = E_{\sigma(s)} \sum_{t'=0}^{\infty} \beta^t \left[\tilde{\pi}_i(s_{it}) \quad \xi(s_{it})\right]$$

The equilibrium strategy should satisfy

$$W_i(s_{it};\sigma_i^*,\sigma_{-i}) \cdot [1 \quad \theta]` \geq W_i(s_{it};\tilde{\sigma}_i,\sigma_{-i}) \cdot [1 \quad \theta]`$$

pick θ so that this holds for random variations of policies

Step 2

Define

$$g(\tilde{\sigma}_i;\theta) = [W_i(s_{it};\tilde{\sigma}_i,\sigma_{-i}) - W_i(s_{it};\sigma_i^*,\sigma_{-i})] \cdot [1 \quad \theta]\,`$$

draws $n_k = 1,250$ alternative policies by adding (normally distributed) noise to the policies estimated in step 1.
The estimator

$$\min_\theta \frac{1}{n_k} \sum_{j=1}^{n_k} 1(g(\tilde{\sigma}_i;\theta) > 0) g(\tilde{\sigma}_i;\theta)^2$$

TABLE III

CEMENT DEMAND ESTIMATES[a]

	I	II	III	IV	V	VI
Price	−3.21	−1.99	−2.96	−0.294	−2.26	−0.146
	(0.361)	(0.285)	(0.378)	(0.176)	(0.393)	(0.127)
Intercept	21.3	10.30	20.38	−3.41	11.6	−6.43
	(1.52)	(1.51)	(1.56)	(1.09)	(2.04)	(0.741)
Log population		0.368		0.840	0.213	0.789
		(0.0347)		(0.036)	(0.074)	(0.033)
Log permits					0.218	0.332
					(0.072)	(0.035)
Market fixed effects	No	No	Yes	Yes	No	Yes

[a]Dependent variable is logged quantity. Instruments were gas prices, coal prices, electricity prices, and skilled labor wage rates. There are a total of 517 observations.

TABLE IV

PRODUCTION FUNCTION RESULTS[a]

Production Function Estimates

Parameter	Coefficient	Standard Error
Marginal cost (δ_1)	31.58	1.91
Capacity cost (δ_2)	1.239	0.455
Capacity cost threshold ($\tilde{\nu}$)	1.916	0.010
Marginal cost post-1990 shifter	2.41	3.33
Capacity cost post-1990 shifter	−0.0299	0.22
Capacity cost threshold post-1990 shifter	0.0917	0.0801

Prices, Revenues, and Profits

Variable	Value	Standard Deviation
Price	57.81	16.83
Revenues	39,040	19,523
Costs	22,525	11,051
Profit	16,515	12,244
Margin	39.29 percent	18.21 percent

[a]The binding threshold at which the capacity costs become important is restricted to [0, 1] by estimating a logit probability: $\nu = \exp(\tilde{\nu})/(1.0 + \exp(\tilde{\nu}))$. At the estimated value of 1.916, this implies that capacity costs start to bind at an approximately 87 percent utilization rate.

TABLE V

PRODUCTIVITY ESTIMATES[a]

Specification	I	II	III	IV	V
Capacity	0.8617	0.8600	0.860	0.860	0.860
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Rivals' capacity	−0.007	−0.005	−0.002	−0.003	0.0003
	(0.001)	(0.001)	(0.001)	(0.001)	(0.0006)
Firm entered * capacity		0.0009	0.0002	0.0112	0.0103
		(0.0027)	(0.0027)	(0.0064)	(0.007)
Firm exited * capacity		−0.0154	−0.0128	−0.0173	−0.0135
		(0.0035)	(0.0036)	(0.0078)	(0.008)
Time trend			0.671	0.681	
			(0.130)	(0.131)	
Entry dummy				−11.66	−11.49
				(6.141)	(6.678)
Exit dummy				3.041	0.492
				(4.810)	(5.107)
Market fixed effects	Yes	Yes	Yes	Yes	No
Market-time fixed effects	No	No	No	No	Yes
R^2	0.9925	0.9925	0.9926	0.9926	0.9933

[a]Number of observations = 2233.

TABLE VI

INVESTMENT POLICY FUNCTION RESULTS: ADJUSTMENT BAND SIZE[a]

Specification	I	II	III	IV
Sum competitors' capacity b-spline 1	6.31	7.18	3.29	5.74
	(0.973)	(5.42)	(0.827)	(1.14)
Sum competitors' capacity b-spline 2	6.51	7.16	2.04	4.53
	(0.930)	(5.43)	(0.953)	(1.37)
Sum competitors' capacity b-spline 3	5.66	6.41	3.57	4.89
	(0.910)	(5.40)	(0.888)	(1.28)
Sum competitors' capacity b-spline 4	6.98	7.85	2.05	4.05
	(0.960)	(5.46)	(0.978)	(1.36)
Sum competitors' capacity b-spline 5	5.77	6.72	2.91	5.40
	(0.939)	(5.33)	(0.994)	(1.47)
Sum competitors' capacity b-spline 6	7.3	8.15	2.11	4.23
	(0.944)	(5.67)	(1.15)	(1.50)
Own capacity b-spline 1	−3.79	−3.97	0.374	−2.71
	(0.923)	(0.925)	(0.880)	(1.22)
Own capacity b-spline 2	−3.3	−3.37	0.720	−0.754
	(0.893)	(0.894)	(0.902)	(1.22)
Own capacity b-spline 3	−2.3	−2.51	1.06	−0.325
	(0.967)	(0.969)	(1.04)	(1.28)
Own capacity b-spline 4	−1.72	−1.76	1.87	−0.149
	(0.943)	(0.952)	(1.27)	(1.60)
Own capacity b-spline 5	−2.63	−2.66	2.05	3.32
	(1.35)	(1.35)	(2.25)	(2.02)
Population b-spline 1		−5.11		
		(6.78)		
Population b-spline 2		0.886		
		(5.16)		
Population b-spline 3		−1.39		
		(5.52)		
Population b-spline 4		−0.008		
		(5.06)		
Population b-spline 5		−1.60		
		(6.69)		
Capacity is per capita	No	No	Yes	Yes
Region fixed effects	No	No	No	Yes
Adjusted R^2	0.8952	0.8955	0.8816	0.8946
Band σ^2	1.40	1.40	1.56	1.41

[a]Dependent variable is the natural log of the change in capacity. Number of capacity changes = 774. Parameters estimated using ordinary least squares (OLS). Capacity is measured in thousands of tons per year. Population is denominated in tens of millions.

TABLE VII
INVESTMENT POLICY FUNCTION RESULTS: INVESTMENT TARGET[a]

	I	II	III	IV
Sum competitors' capacity b-spline 1	7.74	5.80	7.26	7.094
	(0.124)	(0.714)	(0.927)	(0.282)
Sum competitors' capacity b-spline 2	7.70	5.67	7.06	6.96
	(0.123)	(0.715)	(0.929)	(0.326)
Sum competitors' capacity b-spline 3	7.76	5.80	7.17	7.50
	(0.120)	(0.711)	(0.936)	(0.303)
Sum competitors' capacity b-spline 4	7.64	5.65	6.60	6.50
	(0.127)	(0.719)	(0.964)	(0.334)
Sum competitors' capacity b-spline 5	7.88	5.96	6.82	7.31
	(0.124)	(0.701)	(0.987)	(0.340)
Sum competitors' capacity b-spline 6	7.59	5.52	6.36	6.71
	(0.124)	(0.746)	(0.992)	(0.391)
Own capacity b-spline 1	−2.24	−2.24	−2.15	−0.912
	(0.121)	(0.121)	(0.124)	(0.301)
Own capacity b-spline 2	−1.36	−1.36	−1.31	−0.136
	(0.118)	(0.118)	(0.124)	(0.308)
Own capacity b-spline 3	−0.752	−0.753	−0.702	−0.762
	(0.128)	(0.128)	(0.130)	(0.354)
Own capacity b-spline 4	−0.182	−0.186	−0.120	1.27
	(0.124)	(0.125)	(0.134)	(0.432)
Own capacity b-spline 5	0.074	0.0096	0.063	−0.831
	(0.179)	(0.178)	(0.181)	(0.767)
Population b-spline 1		1.43	0.482	
		(0.892)	(2.30)	
Population b-spline 2		2.08	0.483	
		(0.679)	(0.876)	
Population b-spline 3		1.95	0.656	
		(0.727)	(1.04)	
Population b-spline 4		1.98	0.015	
		(0.666)	(0.802)	
Population b-spline 5		2.37	−0.566	
		(0.881)	(1.21)	
Capacity is per capita	No	No	No	Yes
Region fixed effects	No	No	Yes	No
Adjusted R^2	0.9994	0.9994	0.9995	0.9958
Estimated σ^2	0.0244	0.0242	0.0235	0.184

[a]Dependent variable is log of capacity level after adjustment. Number of capacity changes = 774. Parameters estimated using OLS. Capacity is measured in thousands of tons per year. Population is denominated in tens of millions.

TABLE VIII

ENTRY AND EXIT POLICY RESULTS[a]

Specification	I	II	III	IV
Exit Policy				
Own capacity	−0.0015661	−0.0015795		
	(0.000268)	(0.0002712)		
Competitors' capacity	0.0000456	0.0000379		
	(0.0000173)	(0.0000249)		
Population		0.0590591		
		(0.1371835)		
After 1990	−0.5952687	−0.606719	−0.6328867	−0.4623664
	(0.1616594)	(0.1639955)	(0.157673)	(0.1910193)
Own capacity per capita			−0.0005645	−0.0010199
			(0.0001255)	(0.0002164)
Competitors' capacity per capita			0.0000744	0.0002379
			(0.00000286)	(0.0001023)
Constant	−1.000619	−1.019208	−1.664808	−1.529715
	(0.1712286)	(0.176476)	(0.1475588)	(0.3526938)
Region fixed effects	No	No	No	Yes
Log-likelihood	−227.21	−227.12	−238.54	−217.38
Entry Policy				
Competitors' capacity	0.0000448	−0.0003727		
	(0.0000365)	(0.0002351)		
After 1990	−0.6089773	−0.8781589	−0.602279	−1.003239
	(0.2639545)	(0.3229502)	(0.2651052)	(0.337589)
Constant	−1.714599	−0.454613	−1.665322	−0.3434765
	(0.2152315)	(0.7086509)	(0.2642566)	(0.6624767)
Competitors' capacity per capita			0.000026	−0.0003633
			(0.000038)	(0.0001766)
Region fixed effects	No	Yes	No	Yes
Log-likelihood	−70.01	−56.47	−70.491	−55.53
Prob > χ^2	0.0177	0.4516	0.0287	0.3328

[a]Sample size for exit policy function = 2233; sample size for entry policy function = 414. Capacity is measured in thousands of tons of cement per year. Population is normalized to be measured in tens of millions. Per-capita capacity is measured as thousands of tons per year per tens of millions in population.

TABLE IX

DYNAMIC PARAMETERS[a]

	Before 1990		After 1990		Difference	
	Mean	SE	Mean	SE	Mean	SE
Parameter						
Investment cost	230	85	238	51	−8	19
Investment cost squared	0	0	0	0	0	0
Divestment cost	−123	34	−282	56	−155	35
Divestment cost squared	3932	1166	5282	1130	1294	591
Investment Fixed Costs						
Mean (μ_γ^+)	621	345	1253	722	653	477
Standard deviation (σ_γ^+)	113	72	234	145	120	97
Divestment Fixed Costs						
Mean (μ_γ^-)	297,609	84,155	307,385	62,351	12,665	34,694
Standard deviation (σ_γ^-)	144,303	41,360	142,547	29,036	109	17,494
Scrap Values						
Mean (μ_ϕ)	−62,554	33,773	−53,344	28,093	9833	21,788
Standard deviation (σ_ϕ)	75,603	26,773	69,778	27,186	−6054	11,702
Entry Costs						
Mean (μ_κ)	182,585	36,888	223,326	45,910	43,654	21,243
Standard deviation (σ_κ)	101,867	22,845	97,395	14,102	−6401	12,916

[a]Means of the parameters are reported for the pre-1990 period and the post-1990 period. Units are in thousands of dollars per ton for capital costs; the distributions are denominated in thousands of dollars. Standard errors were calculated via subsampling.

TABLE X

COUNTERFACTUAL POLICY EXPERIMENTS[a]

	Low Entry Costs (Pre-1990)		High Entry Costs (Post-1990)		Difference	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
De Novo Market						
Total producer profit ($ in NPV[b])	43,936.11	(7796.98)	33,356.87	(7767.22)	−11,182.04	(7885.20)
Profit firm 1 ($ in NPV)	45,126.30	(10,304.87)	34,321.61	(9520.93)	−11,965.22	(11,684.96)
Total net consumer surplus ($ in NPV)	1,928,985.09	(62,750.34)	1,848,872.52	(75,729.17)	−66,337.44	(58,404.32)
Total welfare ($ in NPV)	2,116,810.12	(74,265.74)	1,992,937.65	(96,634.83)	−119,771.39	(49,423.06)
Periods with no firms (periods)	1.29	(0.08)	1.32	(0.09)	0.04	(0.08)
Periods with one firm (periods)	1.51	(0.37)	2.60	(0.86)	1.05	(0.78)
Periods with two firms (periods)	8.17	(4.68)	21.43	(9.92)	12.26	(9.99)
Periods with three firms (periods)	54.71	(20.22)	91.35	(21.27)	33.38	(18.85)
Periods with four firms (periods)	135.91	(24.64)	84.03	(32.67)	−46.73	(25.04)
Average size of active firm (tons)	980.71	(76.18)	1054.65	(85.17)	73.42	(74.01)
Average market capacity (tons)	3467.85	(188.21)	3352.23	(208.94)	−112.75	(107.84)
Average market quantity (tons)	3094.23	(161.57)	2987.61	(177.58)	−105.69	(89.41)
Average market price	66.66	(1.90)	68.12	(2.11)	1.47	(1.14)
Mature Market						
Total producer profit ($ in NPV)	223,292.75	(4831.95)	231,568.23	(5830.42)	9551.01	(5465.77)
Profit firm 1 ($ in NPV)	549,179.30	(14,138.37)	579,742.32	(20,446.75)	32,968.00	(19,161.33)
Total net consumer surplus ($ in NPV)	2,281,584.08	(52,663.88)	2,208,573.20	(62,906.14)	−62,974.37	(32,662.05)
Total welfare ($ in NPV)	3,178,504.60	(60,267.34)	3,141,916.43	(62,618.02)	−30,099.56	(18,078.21)
Periods with no firms (periods)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Periods with one firm (periods)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Periods with two firms (periods)	8.63	(3.57)	23.20	(10.05)	14.13	(10.00)
Periods with three firms (periods)	61.32	(16.83)	98.37	(21.49)	35.73	(20.16)
Periods with four firms (periods)	131.52	(20.10)	78.38	(31.99)	−50.00	(27.39)
Average size of active firm (tons)	989.33	(44.45)	1059.31	(63.41)	73.48	(54.64)
Average market capacity (tons)	3502.49	(171.20)	3371.03	(191.87)	−117.56	(73.19)
Average market quantity (tons)	3123.42	(150.66)	3001.98	(165.51)	−108.16	(69.48)
Average market price	66.82	(1.64)	68.36	(1.91)	1.44	(0.85)

(*Continues*)

TABLE X—*Continued*

[a]Industry distributions were simulated along 25,000 paths of length 200 each. All values are present values denominated in thousands of dollars. The new market initially has no firms and four potential entrants. The incumbent market starts with one 750,000 TPY incumbent and one 1.5M TPY incumbent and two potential entrants. Counts of active firms may not sum to 200 due to rounding off. Means and standard deviations were calculated by subsampling.

[b]Where NPV denotes Net Present Value.