AEA Continuing Education “Class” on IO: Endogenous Market Structure

Steven Berry

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Empirical Models of Market Structure

"Market Structure" is not that well defined, but it consists of the factors that we hold fixed in a short-run model of oligopoly behavior, like BLP. Think of the

- number and nature of firms, including
- characteristics of products,
- geographic location,
- firm cost functions (capacity, etc.)

Endogenous Market Structure

We would like endogenous models of market structure, both to understand how markets and competition works, and to move in the direction of counterfactuals that allow market structure to change, not just prices and quantities.

For example, what is the effect of a merger on product quality, location, variety and on the number of rivals (entry/exit)?

Also: perhaps we need to adjust models of oligopoly demand and (marginal) cost to account for endogenous market structure?

Continuous vs Discrete Variables

Continuous variables (*e.g* observed quality) can be treated much the same as price in a BLP-ish framework. We can write down a first-order condition and we need more IVs.

Discrete variables are harder and they are the primary subject of my course material.

Classes of Models

Contrast models that are

1. purely cross-sectional, looking at different markets in "equilibrium" (we will do these first)
2. dynamic also looking at changes over time

Cross-sectional models are often called "entry models", even though they have no interesting time element. For older overviews see Berry and Reiss (2007) and Berry and Tamer (2007).

Cross Sectional "Entry" Models

"Revealed Profits"

The broad idea of entry models is the revealed preference of firms. Firms / products that "enter" a market (or market-location) are profitable, others are not.

Can a revealed-preference style analysis reveal the parameters of a profit function?

Variables of interest might include variables controlled by policy makers and/or endogenous variables such as the number of competitors.

Why Not Full Dynamics?

Fully dynamic models are "better" because they can capture features like sunk costs that lead to history-dependent market structure. Counterfactual analysis can account for a slow transition to new market structures and for the continuing evolution of industries.

If there is a counter-argument in favor of the pure cross-section, it is that identification and estimation of dynamic models is much harder, in practice sometimes requiring additional unrealistic assumptions. So there can be a trade-off.

The logic of pure-strategy static Nash equilibrium can be strong and it applies easily to a "revealed profit" strategy.

Some Older "Entry" Model Examples

- Bresnahan and Reiss (1991b) looked at symmetric entry, ex-post differentiation.
- Berry (1992) and Ciliberto and Tamer (2009) consider models where the differentiation is *ex ante*, prior to entry.
- Reiss and Spiller (1989) and Berry and Waldfogel (1999) estimated variable profits outside the entry model,
- Mazzeo (2002) considered discrete product segments ("quality") and ex-post differentiation (ordered models), needs strong assumptions on order to get unique equil.
- Seim (2006) uses private info
- Jia (2008) adds network effects in geographic entry
- Manski (many papers) – use incomplete models, bounds
- Ishii (2008) uses Pakes et al. (2015) to estimate similar ordered models plus bounds estimation.

Today

Emphasize

- Broad Questions
- Identification
- Some (select) details of implementation
- Some applied examples along the way
- Finish with a series of empirical papers on airlines

Next: a set of classic papers by Bresnahan and Reiss

Intro to Bresnahan and Reiss

Bresnahan and Reiss (1991b), Bresnahan and Reiss (1988) & Bresnahan and Reiss (1991a) look at retail and professional firms in small isolated markets.

This is a valuable introduction to:

- The idea of revealed profits
- (very) Simple game theory leading directly to estimation
- Interesting (but hard!) question about competition

The Nature of Competition

B & R want to answer really big question:

> *what is the "nature of competition," as measured by "how fast do profits decline in the number of firms" (because price is falling?).*

A hard thing to do with only a few observables, not including price.

Bresnahan and Reiss Data

Their only data are

- the number of firms in the market, N_t ("market structure")
- the size of the market (population), M_t, and
- market-level profit shifters (e.g., average income, x_t).
- but not prices!

One could get this data from the Census + city business directories ("Yellow Pages").

Note: there is a lot of market share data out in the wild.

Today's approach to B & R

1. Review their method, findings
2. Do a more modern analysis of identification, with broader lessons.

B&R Model

slightly simplified

Profits in market t are

$$\pi(N_t) = M_t v(N_t, x_t, \theta_v) - F_t$$

with M_t being market size, N_t, the number of firms, x_t are market characteristics and. The function v is variable profit (strictly declining in N_t). F_t is fixed costs, the same for all firms in the market. θ_v is a vector of unknown parameters & there may be additional parameters of the distribution of F_t.

Information and Observation

Complete information for the firms. Is this good in a cross-section? Nash's original argument said that eventually players would settle into a best-response to each other's actions, maybe this is a not-bad metaphor for a stable cross-section?

We observe $(M_t, N_t, x_t,)$, for a cross-section of markets within an industry, but not F_t or θ. F_t is the source of "randomness" in the model.

Variable Profits in the Model

Variable Profits:

$$V(N_t, x_t, \theta_v) = M_t v(N_t, x_t, \theta_v)$$

The model must involve identical (symmetric) firms. The proportionality of variable profits in M_t is typically justified via constant mc (e.g. look at the Cournot first-order condition with constant mc.) Note also: no unobservable in v, F_t is the only unobservable (additive in the profit function).

The Economic Question in B & R

How fast does $v(N, x)$ decline in N? For example, what is the value of $\frac{v(2,x)}{v(1,x)}$?

Think of benchmark models:

1. Fixed Prices: $\frac{v(2,x)}{v(1,x)} = 1/2$.
2. Cournot Competition: $\frac{v(2,x)}{v(1,x)} \in (0, 1/2)$
3. Homogeneous Goods Bertrand: $\frac{v(2,x)}{v(1,x)} = 0$

Can think of similar ratios for other N.

The Entry Game

- Large (infinite?) number of identical potential entrants
- In "stage 1" each decides to enter, or not
- In "stage 2" the entrants earn symmetric variable profits and pay fixed cost, other firms earn zero
- No unique equilibrium in the "identity" of the entrants,
- Unique in the number of entrants

Equilibrium

In equilibrium, each entrant must earn profits:

$$M_t v(N_t, x_t, \theta_v) - FC_t \geq 0$$

while an additional entrant would not:

$$M_t v(N_t + 1, x_t, \theta_v) - FC_t < 0$$

If v is strictly declining in N_t, these define a unique pure strategy complete info Nash equilibrium N_t^*.

Idea of estimation: "revealed profitability" using the equilibrium condition.

Estimation by Ordered Prob

Given a distributional assumption on FC, the Nash Equilibrium condition

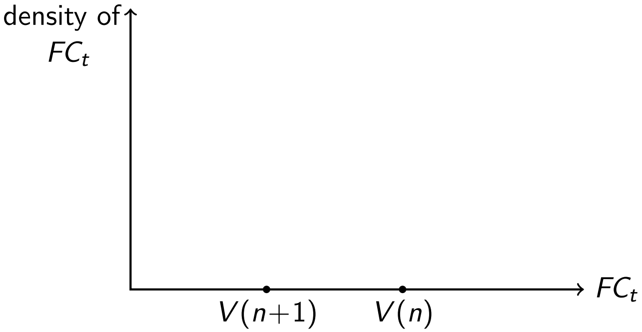
$$M_t v(N_t, x_t, \theta_v) > FC_t > M_t v(N_t + 1, x_t, \theta_v).$$

generates an ordered "probit". If $FC \sim \Phi(\cdot, \theta_F)$ then the likelihood of N firms is

$$\Phi(M_t v(N_t, x_t, \theta_v), \theta_F) - \Phi(M_t v(N_t + 1, x_t, \theta_v), \theta_F).$$

and one can estimate (θ_v, θ_F) by MLE.

Probability that $N_t = n$



$$M_t v(N_t, x_t, \theta_v) > FC_t > M_t v(N_t + 1, x_t, \theta_v).$$

Bresnahan and Reiss, Ordered Entry

Variable profits, $V(N, M, X) = Mv(N, x)$ naturally decline in N. With an i.i.d. F, we have

$$\begin{aligned}
\Pr(N_t = 0|x_t) &= 1 - \Phi(V(1, M_t, x_t, \theta_v), \theta_F) \\
\Pr(N_t = 1|x_t) &= \Phi(V(1, M_t, x_t, \theta_v), \theta_F) - \Phi(V(2, M_t, x_t, \theta_v), \theta_F) \\
\Pr(N_t = 2|x_t) &= \Phi(V(2, M_t, x_t, \theta_v), \theta_F) - \Phi(v(2, M_t, x_t, \theta_v), \theta_F) \\
&\dots
\end{aligned}$$

B & R estimate by fully parametric MLE. If $\Phi(\cdot)$ is the normal CDF, then this is an "ordered probit," a standard command in STATA.

B& R Intuition

B & R's intuition about identification makes use of how N changes in market size.

Suppressing x, market size necessary for N firms:

$$M_N^* v(N) = F$$

$$M_N^* = F/v(N)$$

- Fixed Prices: $M_N^* = \frac{F}{\bar{v}} N$, linear in N
- Cournot: $M_N^* = \frac{F}{v(N)} N$ rises faster than rate N (since $v(N)$ declines in N),
- Bertand: $M_2^* = \infty$

B & R Results

The table gives the estimated ratios of per-firm thresholds ($S_N = \frac{M_N^*}{N}$). B & R interpret the ratios greater than one as evidence of prices declining in N. Under this interpretation, the prices seem to decline a lot when moving from one to two doctors, tire dealers or dentists. However, further increases in N do not seem to increase competition much. Consistent with old jokes, plumbers' prices never fall.

Per Firm Entry Thresholds from
Bresnahan and Reiss, 1991 Table 5

Profession	S_2/S_1	S_3/S_2	S_4/S_3	S_5/S_4
Doctors	1.98	1.10	1.00	0.95
Dentists	1.78	0.79	0.97	0.94
Plumbers	1.06	1.00	1.02	0.96
Tire Dealers	1.81	1.28	1.04	1.03

Nearly exact 1.00s seem very suggestive of the benchmark case of fixed prices. Is this plausible?

Issues with B&R

- Trying to learn an awful lot from almost no data! Formal identification? More data?
- How important is the idea that variable profits are proportional to M? This can be motivated by many models with constant mc, but that is somewhat special.
- What about differentiation: this could lead to Per-firm thresholds equal to or greater than 1. If the second firm is in a different market (neighborhood?) from firm 1, then they don't compete but this isn't the effect of duopoly.
- Greater firm heterogeneity?

Identification of B & R

The parametric approach seems straightforward, but are the distributional assumptions driving the result? There is not much data! To discuss, let's go back to earlier results on discrete choice models, then we will return to B & R.

Review: The Monopoly Entry problem

Following on Berry and Tamer (2007), we consider identification of the B & R model using the results of Matzkin (1992) and others, beginning with the potential monopoly entry (binary threshold crossing) example.

In the monopoly problem, profits of an entering firm are:

$$\pi(z_t, F_t) = V(z_t) - F_t,$$

where V is the deterministic variable monopoly profit, $z_t = (M_t, x_t)$ and F_t is the random fixed cost, with iid distribution $\Phi(F)$.

Identification in the "Monopoly" problem

In a cross-section of markets, entry occurs when $V(z_t) > F_t$. For the purposes of identification, we assume that we observe the entry probabilities

$$p(z_t) = \Phi(V_t(1, z_t))$$

1. If we somehow know $V(1, z_t)$, then this last equation reveals Φ at each $V(1, z_t)$ that we see across the support of z_t.
2. If we somehow know Φ, then we learn variable profits as $V_t(1, z_t) = \Phi^{-1}(p(z_t))$.

So, we can learn variable profits from the CDF of F and vice versa. But: can we ever learn them both without knowning one of them first?

Identification up to Monotonic Transformation

What if we know neither $\Phi(F)$ nor $V(z)$?

An immediate problem is that any monotonic transformation of both V and F results in the same entry probabilities. That is, for a strictly monotonic $H(\cdot)$

$$V(z_t) > F_t \iff H(V(z_t)) > H(F_t)$$

So we could assume $F_t \sim \Phi$ and infer $V(z_t)$ or assume $F_t \sim \Phi(H^{-1}(F_t)) = \tilde{\Phi}(F_t)$ and infer variable profits of $\tilde{V}(z_t) = H(V_t(z_t))$ via

$$\tilde{\Phi}(\tilde{V}_t(z_t)) = \Phi\left(H^{-1}(H(V_t(z_t)))\right) = \Phi(V_t(z_t)) = p(z_t).$$

That is, for any monotonic transformation $H(V_t(z_t))$, we can find a distribution $\tilde{\Phi}$ that fits the data exactly. So, $V(z_t)$ is identified only up to a monotonic transformation.

Non-Robustness to Monotonic Transformations

How bad is the problem? For many issues, not bad at all. Assume F is i.i.d. Then $p(z_t) = \Phi(V(z_t))$ is one possible monotonic transformation of V, and it reveals

- $\partial p/\partial z$
- The sign of the effect of an z on V
- Relative effects of different z's on V.

$$\begin{aligned}\frac{\partial p/\partial z_{1t}}{\partial p/\partial z_{2t}} &= \frac{(\partial \Phi/\partial V)(\partial V/\partial z_{1t})}{(\partial \Phi/\partial V)(\partial V/\partial z_{1t})} \\ &= \frac{\partial V/\partial z_{1t}}{\partial V/\partial z_{2t}}\end{aligned}$$

This is the kind of problem in, e.g. Berry '92. (What is the sign and relative magnitude of "airport presence" in entry and profits, as compared to other z_t?)

Back to the B&R question

B & R care about ratios like $\frac{V(N=2,z)}{V(N=1,z)}$.

But these ratios are not robust to monotonic transformations.

In fact, there is a monotonic transformation that (for one fixed z) sets the ratio to anything between 0 and 1.

Therefore, in the absence of further restrictions, the B&R data provides no interesting restriction on the B&R "parameter"

Qualitative Shape Restrictions

But what if we want to know the full shape of V? Matzkin '92 suggests qualitative shape restrictions, preferably derived from theory, together with an i.i.d. assumption on F.

E.g. assume constant marginal costs, then for many models variable profit is proportional to population, $V(z_t) = M_t v(x_t)$, with $z_t = (M_t, x_t)$.

Sketch of Matzkin's proof: for some $\bar{x}$ normalize units so that $v(\bar{x}) = 1$. Then $p(M, \bar{x}) = \Phi(M)$, which reveals the distribution of F as M varies. Full support on M gives $\Phi(\cdot)$, and from this we get the other values of $v(x_t), x_t \neq \bar{x}$, as

$$p(M_t, x_t) = \Phi(M_t v(x_t))$$

$$v(x_t) = \Phi^{-1}\left(p(M_t, x_t)\right) / M_t$$

Done!

(Matzkin considers broader class of V's that are h.d.1 in some subset of z.)

Identification of the B & R Model via a Shape Restriction

B & R "see" $p(N, M_t, x_t)$. We can write their model as series of threshold-crossing models:

$$1 - p(0, M_t, x_t) = \Pr(N \geq 1 | z_t) = \Phi(M_t v(1, x_t))$$

...

$$1 - \sum_{n=o}^{K-1} p(n, M_t, x_t) = \Pr(N_t \geq K | z_t) = \Phi(M_t v(K, x_t))$$

As in Matzkin, the normalization $v(1, \bar{x}) = 1$ identifies $\Phi(\cdot)$. Then for each (N_t, x_t) and any M,

$$v(N, x_t) = \Phi^{-1}\left(1 - \sum_{n=o}^{N-1} p(n, M, x_t)\right) / M$$

Identification Lessons from the B & R Model

Without qualitative shape restrictions, the object of interest (the "nature of competition") cannot be identified, but with one natural (though restrictive) shape assumption, the nature of competition is fully identified.

Here, the binary threshold crossing literature is enough, but it will not enough be in more complicated models.

Some Extensions

1. Firm Heterogeneity
   - Ex Post differentiation: firms identical before entry
   - Ex Ante differentiation: existing firms decide in which markets to operate.
   - Learn about variable profits from data on p and q

Variety with Discrete Types

Mazzeo on motel entry

Mazzeo (2002) is interested in empirical evidence as to whether firms want to differentiate from rivals. He models discrete product types. Does competition in your own product type harm profits more than competition from related types? This gives an incentive to differentiate. How empirically large is the effect?

Mazzeo considers a model with a large number of potential entrants who differentiate on entry. Fixed costs are equal within market/type.

Mazzeo's model

Profits for any firm choosing quality level $k = (1, \ldots, K)$ in market t are assumed to be

$$\pi_{kt} = x_t \beta_k + g_k(\bar{N}, \theta_k) + \epsilon_{mt}.$$

where $\bar{N} = N_1, \ldots, N_K$ is the vector of the number of firms of each type. The parameters (specific to each quality) are β_k on the market level variables and θ_k, which parameterizes the effect of own-type and other-type competition.

Mazzeo: Non-uniqueness of equlibrium?

Consider two locations. Might have equilibria at both $(2,1)$ and $(1,2)$, for example. Hard to rule out. Existence of Equilibrium?

Assumptions on the order of entry help. Example 1: potential entrants make a decision one at a time. Example 2: first choose whether to entry and then quality (or vice versa).

These assumptions often lead to *ex post* regret which is maybe odd in a purely static model of market structure. Are you stuck forever with your regret? Complete Info Nash has some appeal in a static model of cross sectional market structure: since there is no *ex post* regret, the situation might persist for awhile.

Multiple Equilibrium and MLE

Absent some equilibrium selection rule (imposed or estimated), multiple equilibria are a problem for MLE analysis. It is hard to define the probability of the data when the same combination of unobservables and observables lead to different outcomes with unknown probability.

In discrete choice models generally, we often associate the conditional probability of the observed outcome with the probability that the unobservables fall into the region that generates that outcome. But this requires an "if and only if" (necessary and sufficient) relationship between the observables and the outcome, conditional on exogenous data. This is lacking when there are multiple equilibria.

Mazzeo Results

Parameter		Two-Substage Version		Stackelberg Version	
		Estimate	Standard Error	Estimate	Standard Error
Effect on low-type payoffs					
Constant	C_L	1.6254	.9450	1.5420	.9192
Low competitor #1	θ_{LL1}	−1.7744	.9229	−1.6954	.8931
Low competitor #2	θ_{LL2}	−.6497	.0927	−.6460	.0922
High competitor #1 (0 lows)	θ_{L0H1}	−.8552	.9449	−.7975	.9258
Additional high competitors (0 lows)	θ_{L0HA}	−.1247	.0982	−.1023	.0857
Number of high competitors (1 low)	θ_{L1H}	−.0122	.1407	−.0154	.0444
Number of high competitors (2 lows)	θ_{L2H}	−.0000	.0000	−1.12E-6	.0001
PLACEPOP	β_{L-P}	.2711	.0550	.2688	.0554
TRAFFIC	β_{L-T}	−.0616	.1070	−.0621	.1069
SPACING	β_{L-S}	.3724	.1271	.3700	.1271
WEST	β_{L-W}	.5281	.1515	.5246	.1511

Seim

Seim (2006) considers retail location. Again, what is the trade-off between more profitable locations vs. more competition?

Methodologically, she introduces asymmetric information into an econometric models of potential entrants' location decisions. This definitely helps with existence of equilibrium and might help with uniqueness (not clear.) Specifically, Seim models a set of K potential entrants deciding in which one, if any, of K locations they will locate. In Seim's application, the potential entrants are video rental stores and the locations are Census tracts within a town.

Entry and Information

Seim (2006) models pure i.i.d. private shocks to each firm's profits. The firms know nothing about the "unobserved" portion of a rival's profit and they are entirely surprised by the location of their rival.

Magnolfi and Roncoroni (2019) introduce more flexible information structures, in particular Bayes Correlated Equilibrium.

The Problem of Multiple Equilibria

Multiple equilibria are likely to be very common once we have a rich “entry space.” To help with this, Mazzeo and Seim suggest moving away from static pure info Nash (either a “order of moves” or “imperfect info”).

One problem with these ideas is that they introduce ex post regret which seems odd in a model of “one and for all” entry. Why don’t firms know where their rivals are located? What is the “order of entry” in a static equilibrium? These ideas might make more sense in a real dynamic framework.

Adding information on p and q

We have seen that it is heroic to learn about both variable profits and fixed costs from just "entry" data.

What if we could learn about variable profits from data on prices, quantities, characteristics, etc.? It is natural to learn about variable profits from variable decisions (p, q) and fixed costs from operate / not.

This might also offer practical help with the multiple equilibria problem. On the other hand, it creates a selection problem: what are the ξ's of the firms that don't enter?

Broad Idea of Bounds on Fixed Costs

What if you know variable profits from a BLP-like or Cournot-like exercise? (having somehow solved the selection issue)

Then Nash equilibrium, and other equilibrium concepts, give direct bounds on fixed costs:

If "in"

$$V(N_t, x_t, \xi_t, \omega, \theta) > F_t$$

If "out"

$$V_i(N_t + 1, x_t, \xi_t, \omega, \theta) < F_t$$

"N" could be a vector of outcomes (locations in product space), in which case this won't necessarily define a unique equilibrium; we still get bounds on FC.

Radio Example: Background

- There is a long history of arguing that radio is a good example of “business stealing” and excess entry.
- Recall that in radio, the “consumers” are advertisers and the “product” is the attention of listeners. “If you are not paying for a product, then you are the product.”
- Note that there is a positive externality of the unpriced programming provided to listeners; hard to measure but could offset excess entry with respect to “market participants.”
- Berry and Waldfogel (1999) assume only scalar N matters, get unique equilibrium, find a large degree of excess entry.

Variety and Multiple Equilibria

- Can easily introduce variety into the post-entry variable profits model (e.g. BLP, nested logit, etc.), although measure of variety is now endogenous.
- BUT: as in Mazzeo, often lose unique equilibrium

Estimation with Multiple Equilibria

- Berry, Eizenberg, and Waldfogel (2016) model radio variety via *ex post* differentiation into different discrete horizontal and vertical "locations"
- they estimate variable profits using an assumption of within-location symmetry that helps solve the selection problem
- they then use a simple extension of the "semi-parametric" Bresnahan and Reiss bounds, avoid estimating the distribution of F altogether.
- Harder part is extending to *unobserved* vertical quality (see the paper)

Observed Data and Variable Profits

No Variable Cost (but add endogenous fixed cost of "quality" later).

In market t, format k, We observe:

- ad price p_t,
- format share s_{kt},
- stations numbers N_{kt},
- market demographics x_t,
- population M_t.

At observed vector N_{kt}, observed variable profits are

$$V_{kt} = p_t(s_t)M_t s_{kt}$$

At market outcome, variable profit V_{kt} is just observed revenue, R_{kt}.

Counter-Factual Variable Profits

To create bounds on fixed cost, also need variable profits at $N_{kt} + 1$.

To get this counter-factual, need to

1. Estimate model of listening demand $s_{kt}(x_t, N_{kt}, N_{-k,t}, \theta_d, \xi_{kt})$,
2. Estimate model of Advertising Price $p_t(x_t, s_t, \omega_t, \theta)$.

Listening Model: Horizontal case

- Discrete-choice model: listen to one of the “inside” stations, or choose outside option (not listening to commercial radio)
- Nested-logit, 11 nests (ten format categories + “not listening”)
- Listener i's utility from listening to station j, which belongs to format category g, in market t, is given by:

$$u_{ijgt} = \underbrace{x_{gt}\beta + \xi_{gt}}_{\delta_{gt}} + \nu_{igt}(\sigma) + (1-\sigma)\epsilon_{ijgt}$$

- x includes: market average income, share college educated, share Black & Hispanic, regional dummies, format dummies, interactions (“country$\times$ South”); ξ_{gt} taste shock

Estimation of Horizontal Differentiation Model

- For a station in format g, market t (follow Berry 1994):

$$ln(s_{jt}) - ln(s_{0t}) = x_{gt}\beta + \sigma ln(s_{j/g,t}) + \xi_{gt}$$

1. One observation for each format-market pair; Within-format symmetry imposed: $s_{jt} = S_{gt}/N_{gt}$, $s_{j/g,t} = 1/N_{gt}$
2. The above adjusted to allow for home vs. nonhome stations (so really two observations for each format-market pair)
3. Estimation using 2SLS accounting for the endogeneity of $s_{j/g,t}$ with instruments (i) market population (ii) number of out-metro stations (taken to be exogenous) (iii) number of out-metro stations in same format
4. Selection challenge for "Urban," "Spanish," "Religious" solved by looking at large markets where such stations exist with prob=1.

Table 4: The listening equation - base case (horizontal differentiation)

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Region Dummies	northeast	0.122***	**Interactions**	hispXspan	0.352***
		(0.042)			(0.036)
	midwest	0.0974**		blackXurban	0.506***
		(0.041)			(0.050)
	south	-0.0506		southXreligious	0.809***
		(0.041)			(0.095)
Demographics	black	-0.0681***		southXcountry	0.316***
		(0.014)			(0.072)
	hisp	-0.0233**	**Corr. Parm.**	σ	0.519***
		(0.0097)			(0.063)
	income	-0.00258	**In-metro dummy**		0.639***
		(0.017)			(0.082)
	college	-0.0630**	**Constant**		-5.325***
		(0.027)			(0.15)
Format Dummies	*included*				
Observations	1919				
R-squared	0.72				

Demand from Advertisers

We treat stations as "producing" listeners and then selling them to advertisers. For now, a very simple inverse ad-demand function.

The demand from advertisers for listeners in market t is modeled by a downward-sloping, constant-elasticity specification:

$$ln(p_t) = x_t\alpha - \eta ln(s_t) + \omega_t$$

Popl. and out-metro stations are instruments for endogenous share. Might be able to have this vary by format / demographic, but data is pretty bad for this. Same IVs as in listening demand.

Bounds on F

We know that

$$R_{kt} > F_{kt}$$

This provides an upper bound for F, making only the assumption that R and F are constant within segment.

Lower Bound on F: in equilibrium,

$$V_k(N_{kt}+1, y_t, x_t, \theta_0) < F_{kt}.$$

We get bounds in each market without making *any* assumption on the distribution of fixed costs.

Table 8: Actual and Optimal Numbers of Stations per Format

Format	Observed	Optimal (lower)	Optimal (upper)	Optimal ("mid interval')
Mainstream	3.35	1.29	1.60	1.38
CHR	1.06	0.85	0.86	0.85
Country	2.10	0.99	1.10	1.05
Rock	2.33	1.01	1.21	1.09
Oldies	1.02	0.85	0.88	0.88
Religious	1.66	0.75	0.90	0.81
Urban	1.50	0.68	0.77	0.73
Spanish	1.34	0.54	0.67	0.60
News/Talk	3.08	1.22	1.56	1.35
Other	2.12	1.01	1.19	1.07
Total In-metro	**19.58**	**9.20**	**10.75**	**9.79**

Welfare Loss from Excess Entry

A welfare loss comes from having too many stations generating excess fixed costs as compared to the benefit. BUT! This is for market participants only and there is a large unpriced external benefit to listeners.

Ex Ante Heterogeneity

Next: Ex Ante Heterogeneity

Think of chain stores, like Walmart, and where they locate. The identity of the firm is fixed, but it's locations are not.

For Walmart, see Jia (2008) and Holmes (2011). Another retail entry paper is Magnolfi and Roncoroni (2016).

See also Bresnahan and Reiss (1991a), Berry (1992) and later work by Tamer.

For a simple example, consider two firms with symmetric post-entry profits given by

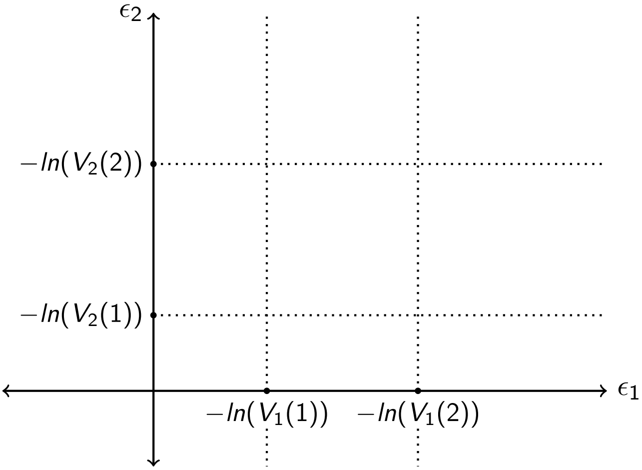
$$\ln(\pi_{jt}) = \ln\left(V(N_t, x_t)\right) + \epsilon_{jt},$$

with $\epsilon \sim \Phi(\cdot)$. The entry threshold defining an equilibrium best response is

$$\epsilon_{jt} > -\ln(V(N_t, x_t))$$

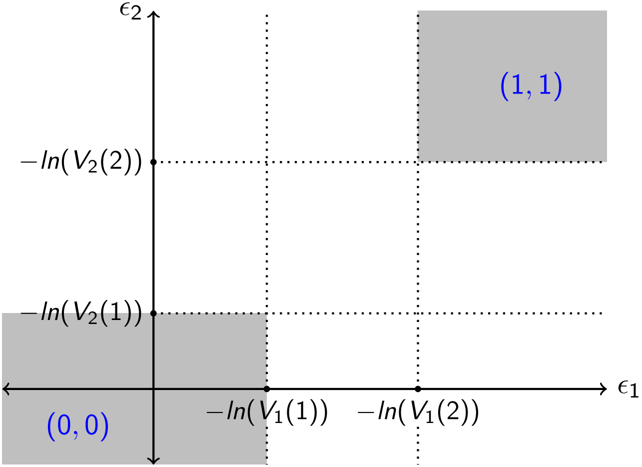
There are multiple equilibria in the identities of firms, depending on the number of potential entrants, J. Here $J = 2$.

Two Firm Entry Thresholds



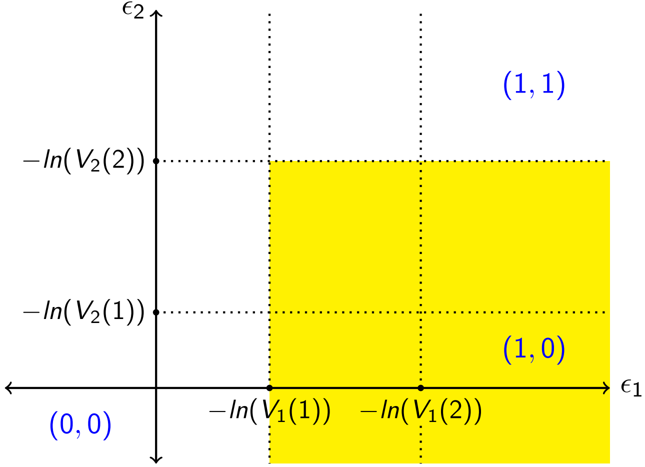
Two Firm Entry Game

These are the necessary and sufficient regions for no firms and for duopoly.



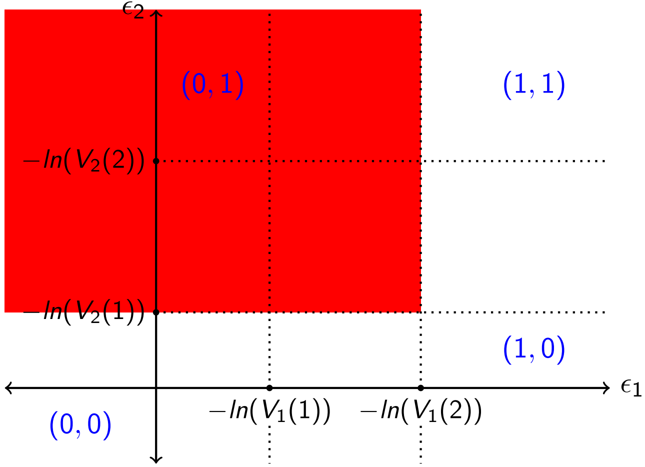
Two Firm Entry Game

This region is necessary for firm 1 to enter and firm 2 not. Firm 1 is profitable as a monopolist, 2 is not profitable as a duopolist.



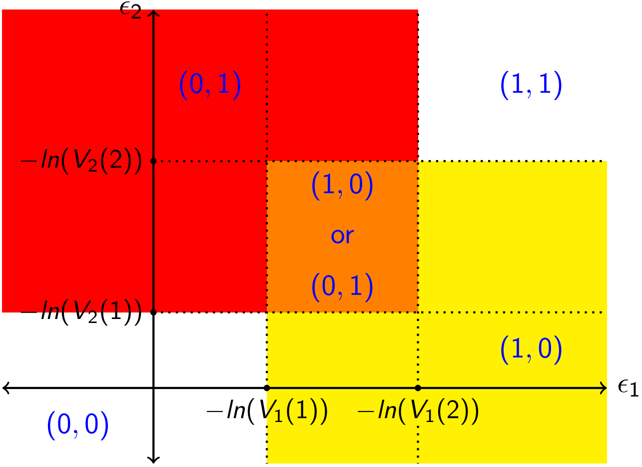
Two Firm Entry Game

This region is necessary for firm 2 to enter and firm 1 not. Firm 2 is profitable as a monopolist, 1 is not profitable as a duopolist.



Two Firm Entry Game

Region of multiple equilibrium: both profitable as monopolist, neither as duopolist.



How to Deal with Multiple Equilibria

With $J = 2$, Tamer (2003) later suggests estimating the probability of each equilibria. With large J, very large number of regions with multiple equilibria, have a too many parameters problem with this suggestion.

How to estimate? Berry (1992) suggests:

- Nonlinear GMM using just the number of firms, not identities. Can generalize the $J = 2$ result that this is unique.
- Add an assumption on the order of entry (most profitable first)? For *this case*, an order of entry assumption picks out one of the complete info simultaneous move N.E.

Estimation

The likelihood is hard to calculate because (with large J) the region of the ϵ space that leads to an N-firm equilibrium is hard to describe. This sort of complexity, which occurs often in game-theoretic situations differs from the computation problem of having to compute a high-dimensional multiple integral.

Estimation via Nonlinear Regression (GMM)

Think of a non-linear parametric regression (NLLS) like framework:

$$N_t^* = E\left[N_t^* | w_t, \theta\right] + \nu_t$$

with $w_t = (x_t, z_{1t}, \ldots, z_{Jt})$. Clearly,

$$E\left[\nu_t | w_t, \theta^0\right] = 0.$$

But, $E\left[N_t^* | w_i, \theta\right]$ is also hard to compute.

Simulation Methods

Berry (1992) suggests simulation methods to solve the problem. Begin by taking S draws on the underlying vector of random variables in the profit functions of the firms. For each guess of θ, construct the equilibrium number of firm,

$$\hat{N}(u_s, w_i, \theta),$$

via the constructive method of the equilibrium proof.

For simulation methods see also Pakes and Pollard (1989) and McFadden (1989). Note the importance of *holding fixed* the simulation draws u_s while changing the parameter θ, otherwise the objective function will bounce around due to changes in simulation draws (bad!). Here, the underlying u_s are standard normal and are transformed by the parameter ρ into ϵ's.

Formal Identification of the Two Firm *Ex Ante* Model

Tamer (2003) considers $J = 2$.

First, show identification for the simple linear model with a single x (conditioning on all others)

- if rival doesn't enter, profits are

$$x_{jt}\beta - F_{jt},$$

  normalize $\beta = 1$, so profits are $x_{jt} - F_{jt}$.

- if rival enters, profits are

$$x_{jt} - \Delta_j - F_{jt}$$

Object of interest is the "competition effect" Δ_j.

The linearity in x is particularly convincing if x_t is actually variable profits as identified from (p, q) data.

Tamer: Identification from Uniqueness of $N = 0$ & $N = 2$

"Usual" trick:

$$Prob(N_t = 0 \,|x) = Prob\,(F_{1t} < x_{1t} \text{ and } F_{2t} < x_{2t})$$
$$= \Phi_\epsilon\,(x_{1t}, x_{2t})$$

With full support on x, we uncover the distribution of (F_1, F_2).

Now, only two scalars, Δ_1 and Δ_2 to uncover from

$$Prob(N = 2\,|x) = Pr_\epsilon\,(\epsilon_{1t} > x_{1t} - \Delta_1 \text{ and } \epsilon_{2t} > x_{2t} - \Delta_2)\,, \forall x$$

Note that this uses the uniqueness of equilibrium when necessary conditions for $N = 2$ are satisfied.

Heterogeneous Variable Profits

BUT: in models with heterogeneous variable profits, there is often not a unique equilibrium in N (for $N > 0$). In addition, without full support for x we cannot easily identify the full distribution of F by using $Pr(N = 0|x)$

In these cases, we may not have point identification of the model. However, we may still have set identification.

Estimation from Inequalities from Revealed Profits

Intro to Set Identification

In a series of papers, Manski argued in favor of "incomplete" models for which there is no likelihood function and where the constraints of the model are often expressed as inequalities. See Manski (2003), Manski (2000) and Manski and Tamer (2002). Often, not always, these models are set identified?

Questions include

- How to compute the identified set (which could be a point)
- How to be sure you have found the smallest identified set (sharp bounds)
- How to do inference? Confidence regions?

Incomplete Entry Models

It seems that there ought to be some information in the fact that the firm's choice is more profitable than its other choices, without necessarily imposing all the conditions of equilibrium. But if we don't already know variable profits, or if we want to know the parameters of the distribution of FC, early estimating approaches were usually parametric MLE and this doesn't work with multiple equilibria.

Basic Idea: the necessary conditions for any simultaneous-move Nash equilibrium give a set of well-defined inequality constraints on

set of parameters that satisfy the inequalities. (Often, some of these inequalities can be shown to also hold with equality and other restrictions on equilibria may also be available.)

Idea of Estimation

Estimator: find set of parameters that satisfies a sample analog of necessary condition inequalities (which come from the model).

Confidence regions: See many recent econometrics papers, including Chernozhukov et al. (2007), Andrews and Soares (2010) and Andrews and Shi (2013)

General Entry Model

Consider a profit function for firm j in market i of

$$\pi_{j,t}(Y_{j,t}, Y_{-j,t}, \varepsilon_{j,t}, X_{j,t}, \theta_0) = \bar{\pi}_{j,t}(Y_{j,t}, Y_{-j,t}, X_{j,t}, \theta_0) + Y_{j,t}\varepsilon_{j,t},$$

where $Y_{j,t}$ is firm j's strategy, $Y_{-j,t}$ is the vector of firm j's opponents' strategies, $X_{j,t}$ is a vector of profit shifters (some of which are specific to the firm), $\theta_0 \in R^p$ are parameters, and $\varepsilon_{j,t}$ is an unobserved profit shifter. The number of firms is J and the number of markets is n. For market i, the observed strategy vector is $Y_t = (Y_{j,t}, ..., Y_{j,t})'$ ($\in R^{d_Y}$), and the observed profit shifters X_t ($\in R^{d_X}$)

Strategies

In different models, a strategy $Y_{j,t}$ might be a continuous variable (a level of investment), an indicator function (an "entry" variable), an integer-valued variable (the number of store locations), or a vector of multiple strategies. In the case of a continuous $Y_{j,t}$, first-order conditions often allow for estimation even in the case of multiple equilibria. The discrete case, however, is harder.

Equilibria

Complete information Nash Equilibrium generates Y_t. Data are X_t and Y_t. The researcher does not observe the ε_t's, but does know the parametric form of $\bar{\pi}_{j,t}$ and does know that ε_t is i.i.d. across i and independent of the X_t's. Further, we assume that the distribution of ε_t is known up to a set of unknown parameters (that are included in the parameter vector θ_0).

Necessary Conditions

In any pure strategy equilibrium in market i, it must be the case that the action $Y_{j,t}$ taken by each firm j, is at least as good as any other possible action Y', given the actions of the other firms:

$$\bar{\pi}_{j,t}(Y_{j,t}, Y_{-j,t}, X_{j,t}, \theta_0) + Y_{j,t}\varepsilon_{j,t} \geq$$

$$\bar{\pi}_{j,t}(Y', Y_{-j,t}, X_{j,t}, \theta_0) + Y'\varepsilon_{j,t},$$

$$\forall Y', \forall j.$$

In the absence of multiple equilibria, this condition is necessary and sufficient for $Y_{j,t}$ to be the pure-strategy Nash equilibrium. However, if multiple equilibria are possible, this condition is only necessary—the same (X_t, ε_t) might lead to another outcome.

An Inequality on the Unobservables

Note that the best-reply condition on the last slide can be expressed as a restriction on the unobservables:

$$(Y' - Y_{j,t})\varepsilon_{j,t} \leq \bar{\pi}_{j,t}(Y_{j,t}, Y_{-j,t}, X_{j,t}, \theta_0) - \bar{\pi}_{j,t}(Y', Y_{-j,t}, X_{j,t}, \theta_0), \forall Y', \forall j.$$

The probability of this necessary condition is an orthant probability that is relatively to compute.

The Unobservables Consistent with a Necessary Condition

Let $\Omega(Y_t, X_t, \theta_0)$ be the region of the ε_t's that satisfy (85):

$$\Omega(Y_t, X_t, \theta_0) =$$

$$\Big\{\varepsilon_t : (Y' - Y_{j,t})\varepsilon_{j,t} \leq \bar{\pi}_{j,t}(Y_{j,t}, Y_{-j,t}, X_{j,t}, \theta_0)$$

$$- \ \bar{\pi}_{j,t}(Y', Y_{-j,t}, X_{j,t}, \theta_0), \forall Y', \forall j\Big\}.$$

The Prob of a Nec Condition – cont.

Given θ_0 and X_t, the probability that the necessary conditions for Y_t hold is the probability (with respect to the distribution of ε_t) of $\Omega(Y_t, X_t, \theta_0)$. Because necessary and sufficient is a subset of necessary, the probability of necessary conditions for an event is greater than or equal to the probability of the event itself.

The Probability of a Necessary Condition

It is relatively easy, however, to calculate the probability given θ that the necessary conditions in (86) hold. Let $\mathcal{Y}$ and $\mathcal{X}$ denote the supports of Y_t and X_t, respectively. By assumption, $\mathcal{Y}$ is a finite set. For any $(y, x) \in \mathcal{Y} \times \mathcal{X}$, this probability is defined to be

$$P(y \mid x, \theta) = Pr(\varepsilon_t \in \Omega(y, x, \theta)).$$

Inequalities in the Model and Data

At the true $\theta = \theta_0$, the probabilities of the necessary conditions must be at least as large as the true probabilities of the events $y \in \mathcal{Y}$, denoted $P_0(y \mid x)$:

$$P(y \mid x, \theta_0) \geq P_0(y \mid x), \ \forall (y, x) \in \mathcal{Y} \times \mathcal{X}.$$

Again, the inequality follows from the fact that the outcome y implies the necessary conditions for y but the necessary condition need not imply the outcome y.

Set Identification

The inequalities are satisfied for the true θ and possibly for other values of the parameters. If only one θ satisfies the inequalities, then the model is point identified. If the necessary conditions are derived from an incorrect model, then perhaps no θ satisfies the inequalities.

In the absence of a proof, it is often difficult to rule out the case of set-identification, where more than one θ satisfies the inequalities. Note that point identification is certainly possible given multiple equilibria, but moving from equality to inequality constraints increases our concern with a lack of point identification.

The Identified Set

The asymptotically identified set of parameters, Θ_0, is the set of parameters such that the inequality restrictions hold.

Θ_0 could be (i) the null set, (ii) a single point, (iii) a strict subset of the parameter space consisting of more than one point, or (iv) the entire parameter space. Correspondingly, we would say the model is (i) rejected, (ii) point identified, (iii) set identified, or (iv) completely uninformative.

Less Restrictive Necessary Conditions

Fan and Yang (2020b) note that checking all the necessary conditions for Nash Equilibrium can be hard when there are many possible products/choices.

They suggests a weaker set of conditions, which is to check to see that firms avoid dominated strategies.

This work very well in a study of the US craft beer market. They study mergers and find that mergers lead larger producers to drop products, but smaller producers add products. The net effect is positive in some large markets, but negative in the smaller markets (exacerbating the effects of price increases).

Fan and Yang (2020a) also discuss a case with insufficient product variety (in mobile phones).

An Alternate Approach: Pakes, Porter, Ho and Ishii

Critical discussion in Pakes, Porter, Ho, and Ishii (2015) is about the nature of the error, ν. One component is uncorrelated with the decision, ν_{jt}^{1}. This is not known to the firm at the time of the decision – could it be measurement error, approximation error, error from the realization of mixed strategies in $d_{-j,t}$?

Second component is a classic "structural" error that is known to the firm at the time of the decision. This is ν_{jt}^{2}.

All kinds of ideas open up when we only have ν_1; outside of ordered entry models it is hard to deal with both ν^1 and ν^2.

Airline Entry as an Empirical Example

- Berry (1992): cross-sectional entry to get “revealed profit” idea of the importance of airline hubs
- Ciliberto and Tamer (2009): add airline heterogeneity, use inequalities to study firm heterogeneity
- Ciliberto, Murry, and Tamer (2018): add data on post-entry outcomes to study effects of mergers on entry/exit
- Li, Mazur, Park, Roberts, Sweeting, and Zhang (2018): an alternative approach to the selection problem of post-merger repositioning,

Berry 1992

Question is the effect of airline hubs on profits, answer is attempted using only cross-sectional "entry" data. Later papers add richer heterogeneity and data on p and q.

Latent profit function is

$$\ln\left(\pi(N_t, x_t, z_{it}, u_t)\right) = x_t\beta + z_{it}\gamma - \delta \ln(N_t) + \sqrt{1-\rho^2}u_{it} + \rho u_{ot}$$

The hub dummy and "airport presence" are elements of the firm-specific shifters, z_{it}.

Ciliberto Tamer 2009

Extend Berry 1992 to include heterogenous competition effects, by type of competitor. Lose uniqueness (even of equilibrium N) and so have to use bounds methods on necessary and sufficient conditions for "entry".

Results from Ciliberto Tamer

Entry into airline city-pairs

Confidence Intervals for Selected Parms

	Model	
Profit Shifter	Berry (1992)	Heterogenous Effects
Market Size	[0.97,2.2]	[0.53,1.2]
Hub Measure	[3.1,5.1]	[11.3,14.3]
Competition	[-14,-11]	
Competition AA		[-11,-8.8]
Competition WN		[-13,-11]
Competition LCC		[-20,-15]

Ciliberto, Murry and Tamer

Ciliberto, Murry, and Tamer (2018): airline competition via Entry plus post-entry Demand & Price

- Broad idea goes back to Reiss and Spiller (1989), but much progress made possible by recent methods.
- There are strong methodological reasons to combine entry and post-entry competition

Endogenous Market Structure in the Demand and Pricing Model

Primary emphasis here is on correlated shocks, leading to bias in estimation.

Example: if the marginal entrant is an (unobservably) high quality firm, on entry the price may go down a bit, but demand will go up a lot. Makes demand look unrealistically elastic.

(Note that firms are not, however, choosing their demand quality, ξ, which is a different kind of endogeneity.)

Endogeneity and Selection

How to deal with the endogeneity of market structure when estimating demand and supply?

- With timing assumptions (don't observe D shocks at time of entry, etc.), can get no endogeneity problem.
- Or, if all shocks are revealed post-entry (say shock is that the discrete market-location level, as in Berry et al. (2016), then get an endogeneity problem, but not a selection problem.

Selection with Firm Specific shocks

The selection problem here is nothing like the "traditional" one-equation selection model. The "selection region" involves all the unobservables and it is some very complicated area that depends on the full equilibrium map. Many have tried . . . few have returned.

Solution here: brute force. Simulate all possible equilibria for many unobservables and thereby simulate the selection region (I think). Would be even harder with non-logit demand, as might have multiple pricing equilibria as well.

Merger Application

- More inelastic demand: merger looks worse
- Entry possibilities: merger often looks better.
- Offsetting effect: entry by merged firm may lead to exit by other competitors

There is an implicit "synergy" parameter, set to make the merger look as good as possible. Might "fit" this parameter using pre-post merger dummies as instruments.

Also: interesting contrast to Lazarev et al. (2018) who have a dynamic model of entry with i.i.d. private shocks.

“Repositioning and Market Power After Airline Mergers”

2018, by Li, Mazur, Park, Roberts and Sweeting

Another crack at post-entry positioning in airline entry games. Here, drop focus on multiple equilibria, keep a strong focus on the selection of active firms and how this affects anti-trust discussions of “post-merger entry.”

Li, Mazur, Park, Roberts and Sweeting

Similar to CMT, but with less computational burden (only takes a long time) because of

- an order of entry assumption (in the main specs) to avoid multiple equilibria.
- use of the Ackerberg importance sampling / simulation method
- focus on connecting / nonstop

Identification and Instrumental Variables

The "characteristics of own and rival products (both D and mc) are now endogenously selected. It would be nice to see more discussion of this.

Solution here involves stepping back to characteristics of the network, which define potential competition, but they need some strong exclusion restrictions.

Conclusions of the Paper

The finding for antitrust is important. In this case, selection is key: firms are systematically less profitable on the routes they don't serve and if you don't account for that, you will predict a lot of post-merger entry that will not actually occur.

A lot of the selection is on observables, but not all. Models of pure incomplete information (Bodoh-Creed, et al) will miss this (although parameters will also change.)

References I

Andrews, D. W. and X. Shi (2013): "Inference based on conditional moment inequalities," *Econometrica*, 81, 609–666.

Andrews, D. W. and G. Soares (2010): "Inference for Parameters Defined by Moment Inequalities Using Generalized Moment Selection," *Econometrica*, 78, 119–157.

Berry, S., A. Eizenberg, and J. Waldfogel (2016): "Horizontal and Vertical Product Variety in Radio Markets," *RAND Journal of Economics*, 47, 463–497.

Berry, S. and E. Tamer (2007): "Identification in Models of Oligopoly Entry," in *Advances in Economics and Econometrics: Theory and Applications, Ninth World Congress*, ed. by W. N. R. Blundell and T. Persson, Cambridge University Press, vol. 2.

Berry, S. and J. Waldfogel (1999): "Free Entry and Social Inefficiency in Radio Broadcasting," *RAND Journal*, 70, 397–420.

References II

Berry, S. T. (1992): "Estimation of a Model of Entry in the Airline Industry," *Econometrica*, 60, 889–917.

Berry, S. T. and P. Reiss (2007): "Empirical Models of Entry and Market Structure," in *Handbook of Industrial Organization, vol. 3*, ed. by M. Armstrong and R. Porter, North Holland, chap. 29.

Bresnahan, T. and P. Reiss (1988): "Do Entry Conditions Vary Across Markets," *Brookings Papers in Economic Activities: Microeconomic Annual*, 1, 833–882.

——— (1991a): "Empirical Models of Discrete Games," *Journal of Econometrics*, 48, 57–82.

——— (1991b): "Entry and Competition in Concentrated Markets," *Journal of Political Economy*, 99, 977–1009.

Chernozhukov, V., H. Hong, and E. Tamer (2007): "Estimation and Confidence Regions for Parameter Sets in Econometric Models1," *Econometrica*, 75, 1243–1284.

References III

Ciliberto, F., C. Murry, and E. Tamer (2018): "Market Structure and Competition in Airline Markets," working paper, University of Virginia.

Ciliberto, F. and E. Tamer (2009): "Market Structure and Multiple Equilibria in Airline Markets," *Econometrica*, 77, 1791–1828.

Fan, Y. and C. Yang (2020a): "Competition, Product Proliferation, and Welfare: A Study of the US Smartphone Market," *American Economic Journal: Microeconomics*, 12, 99–134.

——— (2020b): "Merger, Product Variety and Firm Entry: the Retail Craft Beer Market in California," Working paper, University of Michigan.

Holmes, T. J. (2011): "The Diffusion of Wal-Mart and Economies of Density," *Econometrica*, 79, 253–302.

References IV

Ishii, J. (2008): "Compatibility, Competition, and Investment in Network Industries: ATM Networks in the Banking Industry," Tech. rep., Stanford.

Jia, P. (2008): "What Happens When Wal-Mart Comes to Town: An Empirical Analysis of the Discount Retailing Industry," *Econometrica*, 76, 1263—-1316.

Lazarev, J., L. Benkard, and A. Bodoh-Creed (2018): "Simulating the Dynamic Effects of Horizontal Mergers: U.S. Airlines," Working paper, NYU.

Li, S. Y., J. Mazur, Y. Park, J. W. Roberts, A. Sweeting, and J. Zhang (2018): "Endogenous and Selective Service Choices After Airline Mergers," Working Paper 24214, NBER.

Magnolfi, L. and C. Roncoroni (2016): "Political Connections and Market Structure," working paper, University of Wisconsin.

References V

——— (2019): "Estimation of Discrete Games with Weak Assumptions on Information," Tech. rep., Univ of Wisconsin.

Manski, C. F. (2000): "Identification Problems and Decisions under Ambiguity: Empirical Analysis of Treatment Response and Normative Analysis of Treatment Choice," *Journal-of-Econometrics*, 95, 415–42.

——— (2003): *Partial Identification of Probability Distributions*, New York: Springer.

Manski, C. F. and E. Tamer (2002): "Inference on Regressions with Interval Data on a Regressor or Outcome," *Econometrica*, 70, 519–546.

Matzkin, R. L. (1992): "Nonparametric and Distribution-Free Estimation of the Binary Choice and Threshold Crossing Models," *Econometrica*, 60.

References VI

Mazzeo, J. M. (2002): "Product Choice and Oligopoly Market Structure," *RAND Journal of Economics*, 33, 221–242.

McFadden, D. (1989): "Method of Simulated Moments for Estimation of Discrete Response Models without Numerical Integration," *Econometrica*, 57, 995–1026.

Pakes, A. and D. Pollard (1989): "Simulation and the Asymptotics of Optimization Estimators," *Econometrica*, 54, 1027–1057.

Pakes, A., J. Porter, K. Ho, and J. Ishii (2015): "Moment Inequalities and Their Application," *Econometrica*, 83, 315–334.

Reiss, P. and P. Spiller (1989): "Competition and Entry in Small Airline Markets," *Journal of Law and Economics*, 32, 179–202.

Seim, K. (2006): "An Empirical Model of Firm Entry with Endogenous Product-Type Choices," *The RAND Journal of Economics*, 37, pp. 619–640.

References VII

Tamer, E. (2003): "Incomplete Simultaneous Discrete Response Model with Multiple Equilibria," *The Review of Economic Studies*, 70, pp. 147–165.