Aggregate Data

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Grad IO

Aggregate Data

- Now we want to have both price endogeneity and flexible substitution in the same model.
- We are ultimately going with the random coefficients logit model, but we will start with the logit and nested logit.
- We will explore a technique that works with aggregate data.

Multinomial: Aggregation Property

Each individual's choice $y_{ij} \in \{0, 1\}$ and $\sum_{j \in \mathcal{J}} d_{ij} = 1$.
Choices follow a Multinomial distribution with $m = 1$:

$$(d_{i1}, \ldots, d_{iJ}, d_{i0}) \sim \text{Mult}(1, s_{i1}, \ldots, s_{iJ}, s_{i0})$$

If each individual faces the same $s_{ij} = s_j$ the the sum of Multinomials is itself Multinomial:

$$(q_1^*, \ldots, q_J^*, q_0^*) \sim \text{Mult}(M, s_1, \ldots, s_J, s_0)$$

where $q_j^* = \sum_{i=1}^{M} d_{ij}$ is a sufficient statistic.

Multinomial: Aggregation Property (Likelihood)

We can write the likelihood as $L\left((y_{i1},\dots,y_{iJ},y_{i0}) \mid \mathbf{x_i},\theta\right)$ where $\mathbf{x_i}$ is a J vector that includes all relevant product characteristics interacted with all relevant individual characteristics.

$$= \begin{pmatrix} M \\ q_{i1},\dots,q_{iJ},q_{i0} \end{pmatrix} \prod_{i=1}^{M} s_{i1}(\mathbf{x_i},\theta)^{d_{i1}} \cdots s_{iJ}(\mathbf{x_i},\theta)^{d_{iJ}} s_{i0}(\mathbf{x_i},\theta)^{d_{i0}}$$

$$\rightarrow \ell(\mathbf{x_i},\theta) = \sum_{i=1}^{M}\sum_{j\in\mathcal{J}} d_{ij} \log s_{ij}(\mathbf{x_i},\theta) + \log C(\mathbf{q})$$

If all individuals face the same $(\mathbf{x_i})$ and $\mathcal{J}$ they will have the same $s_{ij}(\mathbf{x_i},\theta)$ and we can aggregate outcomes into sufficient statistics.

$$\rightarrow \ell(\theta) = \sum_{j\in\mathcal{J}} q_j^* \log s_j(\theta)$$

Multinomial Logit: Estimation with Aggregate Data

Aggregation is probably the most important property of discrete choice:

- Instead of individual data, or a single group we might have multiple groups: if prices only change once per week, we can aggregate all of the week's sales into one "observation".
- Likewise if we only observe that an individual is within one of five income buckets – there is no loss from aggregating our data into these five buckets.
- All of this depends on the precise form of $s_{ij}(\mathbf{x_i}, \theta)$. When it doesn't change across observations: we can aggregate.
- Notice I didn't need anything to follow a logit/probit.

Aggregation with Unobserved Heterogeneity

$$s_{ij}(\mathbf{x_i}, \theta) \quad = \quad \int \frac{\exp[x_{ij}\beta_\iota]}{1 + \sum_k \exp[x_{ik}\beta_\iota]} f(\beta_\iota | \theta) \partial \beta_\iota = \sum_{\iota=1}^{S} w_\iota \frac{\exp[x_{ij}\beta_\iota]}{1 + \sum_k \exp[x_{ik}\beta_\iota]}$$

- Notice that while i subscripts "individuals" with different characteristics $\mathbf{x_i}$
- ι is the dummy index of integration/summation.
  - Even though we sometimes call these "simulated individuals"
  - Everyone with the same $\mathbf{x_i}$ still has the same $s_{ij}(\mathbf{x_i}, \theta)$
- Most papers will abuse notation and i will serve double duty!

Now suppose we have aggregate data: $(q_1, \dots, q_J, q_0)$ where $M = \sum_{j \in \mathcal{J}} q_j$.

- If M gets large enough then $(\frac{q_1}{M}, \dots, \frac{q_J}{M}, \frac{q_0}{M}) \rightarrow (\mathfrak{s}_1, \dots, \mathfrak{s}_J, \mathfrak{s}_0)$
  - Idea: Observe $(\mathfrak{s}_1(\mathbf{x_i}), \dots, \mathfrak{s}_J(\mathbf{x_i}), \mathfrak{s}_0(\mathbf{x_i}))$ without sampling variance.
  - Challenges: We probably don't really observe q_0 and hence M.
- Idea: Equate observed market shares to the conditional choice probabilities $(s_1(\mathbf{x_i}, \theta), \dots, s_J(\mathbf{x_i}, \theta), s_0(\mathbf{x_i}, \theta))$.
- Choose θ that minimizes distance: MLE? MSM? Least Squares? etc.

Inversion: IIA Logit

Add unobservable error for each $\mathfrak{s}_{jt}$ labeled ξ_{jt}.

$$u_{ijt} = x_{jt}\beta - \alpha p_{jt} + \xi_{jt} + \varepsilon_{ijt}, \quad s_{jt} = \frac{\exp[x_{jt}\beta - \alpha p_{jt} + \xi_{jt}]}{1 + \sum_k \exp[x_{kt}\beta - \alpha p_{kt} + \xi_{kt}]}$$

- The idea is that ξ_{jt} is observed to the firm when prices are set, but not to us the econometricians.
- Potentially correlated with price Corr$(\xi_{jt}, p_{jt}) \neq 0$
- But not characteristics $E[\xi_{jt} | x_{jt}] = 0$.
  - This allows for products j to better than some other product in a way that is not fully explained by differences in x_j and x_k.
  - Something about a BMW makes it better than a Peugeot but is not fully captured by characteristics that leads higher sales and/or higher prices.
  - Consumers agree on its value (vertical component).

Inversion: IIA Logit

Taking logs:

$$\ln s_{0t} = -\log\left(1 + \sum_k \exp[x_{kt}\beta + \xi_{kt}]\right)$$

$$\ln s_{jt} = [x_{jt}\beta - \alpha p_{jt} + \xi_{jt}] - \log\left(1 + \sum_k \exp[x_{kt}\beta + \xi_{kt}]\right)$$

$$\underbrace{\ln s_{jt} - \ln s_{0t}}_{Data!} = x_{jt}\beta - \alpha p_{jt} + \xi_{jt}$$

Exploit the fact that:

1. $\ln s_{jt} - \ln s_{0t} = \ln \mathfrak{s}_{jt} - \ln \mathfrak{s}_{0t}$ (with no sampling error)
2. We have one ξ_{jt} for every share s_{jt} (one to one mapping)

IV Logit Estimation (Berry 1994)

1. Transform the data: $\ln \mathfrak{s}_{jt} - \ln \mathfrak{s}_{0t}$.
2. IV Regression of: $\ln \mathfrak{s}_{jt} - \ln \mathfrak{s}_{0t}$ on $x_{jt}\beta - \alpha p_{jt} + \xi_{jt}$ with IV z_{jt}.

Was it magic?

- No. It was just a nonlinear change of variables from $s_{jt} \to \xi_{jt}$.
- Our (conidtional) moment condition is just that $E[\xi_{jt}|x_{jt}, z_{jt}] = 0$.
- We moved from the space of shares and MLE for the logit to the space of utilities and an IV model.
  - We are losing some efficiency – but now we are able to estimate under weaker conditions.
  - But we need aggregate data and shares without sampling variance.

Naive Approach

Did we need to do change of variables? Imagine we work with:

$$s_{jt} = \frac{\text{exp}[x_{jt}\beta - \alpha p_{jt}]}{1 + \sum_k \text{exp}[x_{kt}\beta - \alpha p_{kt}]}$$

$$\eta_{jt} \equiv (s_{jt}(\theta) - \mathfrak{s}_{jt})$$

- Each share depends on all prices $(p_{1t}, \dots, p_{Jt})$ and characteristics $\mathbf{x_t}$.
- Harder to come up with IV here.

Inversion: Nested Logit (Berry 1994 / Cardell 1991)

This takes a bit more algebra but not much

$$\underbrace{\ln s_{jt} - \ln s_{0t} - \rho \log(s_{j|gt})}_{\text{data!}} = x_{jt}\beta - \alpha p_{jt} + \xi_{jt}$$

$$\ln \mathfrak{s}_{jt} - \ln \mathfrak{s}_{0t} = x_{jt}\beta - \alpha p_{jt} + \rho \log(\mathfrak{s}_{j|gt}) + \xi_{jt}$$

- Same as logit plus an extra term $\log(s_{j|g})$ the within group share.
  - We now have a second endogenous regressor.
  - If you don't see it – realize we are regressing Y on a function of Y. This should always make you nervous.
- If you forget to instrument for ρ you will get $\rho \to 1$ because of attenuation bias.
- A common instrument for ρ is the number of products within the nest. Why?

Think about a generalized inverse for $\sigma_j(\mathbf{x}_t, \theta_2) = \mathfrak{s}_{jt}$ so that

$$\sigma_{jt}^{-1}(\mathcal{S}_{\cdot t}, \tilde{\theta}_2) = x_{jt}\beta - \alpha p_{jt} + \xi_{jt}$$

- After some transformation of data (shares $\mathcal{S}_{\cdot t}$) we get mean utilities δ_{jt}.
  - We assume $\delta_{jt} = h(x_{jt}, v_{jt}, \theta_1) - \alpha p_{jt} + \xi_{jt}$ follows some parametric form (often linear).
- Same IV-GMM approach after transformation
- Examples:
  - Plain Logit: $\sigma_j^{-1}(\mathcal{S}_{\cdot t}) = \ln \mathfrak{s}_{jt} - \ln \mathfrak{s}_{0t}$
  - Nested Logit: $\sigma_j^{-1}(\mathcal{S}_{\cdot t}, \rho) = \ln \mathfrak{s}_{jt} - \ln \mathfrak{s}_{0t} + \rho \ln \mathfrak{s}_{j|gt}$

We can't solve for δ_{jt} directly this time.

$$\sigma_j(\boldsymbol{\delta_t}, \tilde{\theta}_2) = \int \frac{\exp[\delta_{jt} + \mu_{ijt}]}{1 + \sum_k \exp[\delta_{kt} + \mu_{ikt}]} f(\boldsymbol{\mu_{it}} | \tilde{\theta}_2)$$

- This is a $J \times J$ system of equations for each t.
- It is diagonally dominant (with outside good).
- There is a unique vector $\boldsymbol{\delta_t}$ that solves it for each market t.
- If you can work out $\frac{\partial s_{jt}}{\partial \delta_{kt}}$ (easy) you can solve this using Newton's Method.

Contraction: BLP

BLP actually propose an easy solution to find $\boldsymbol{\delta}_{\mathbf{t}}$. Fix $\widetilde{\theta_2}$ and solve for $\boldsymbol{\delta}_{\mathbf{t}}$. Think about doing this one market at a time:

$$\boldsymbol{\delta}_{\mathbf{t}}^{(k)}(\tilde{\theta}_2) = \boldsymbol{\delta}_{\mathbf{t}}^{(k-1)}(\tilde{\theta}_2) + \left[\log(\mathfrak{s}_j) - \log(\mathbf{s}_j(\boldsymbol{\delta}_{\mathbf{t}}^{(k-1)}, \tilde{\theta}_2)\right]$$

- They prove (not easy) that this is a contraction mapping.
- If you keep iterating this equation enough $\|\boldsymbol{\delta}_{\mathbf{t}}^{(k)}(\theta) - \boldsymbol{\delta}_{\mathbf{t}}^{(k-1)}(\theta)\| < \epsilon_{tol}$ you can recover the δ's so that the observed shares and the predicted shares are identical.
- Practical tip: ϵ_{tol} needs to be as small as possible. ($\approx 10^{-13}$).
- Practical tip: Contraction isn't as easy as it looks: $\mathbf{s}_j(\boldsymbol{\delta}_{\mathbf{t}}^{(k-1)}, \tilde{\theta}_2)$ requires computing the numerical integral each time (either via quadrature or monte carlo).

BLP Pseudocode

From the outside, in:

- Outer loop: search over nonlinear parameters θ to minimize GMM objective:

$$\widehat{\theta_{BLP}} = \arg\min_{\theta_2} (Z'\hat{\xi}(\theta_2)) W (Z'\hat{\xi}(\theta_2))'$$

- Inner Loop:
    - Fix a guess of $\tilde{\theta}_2$.
    - Solve for $\boldsymbol{\delta_t}(\mathcal{S}_t, \tilde{\theta}_2)$ which satisfies $\sigma_{jt}(\boldsymbol{\delta_t}, \tilde{\theta}_2) = \mathfrak{s}_{jt}$.
        - Computing $s_{jt}(\boldsymbol{\delta_t}, \tilde{\theta}_2)$ requires numerical integration (quadrature or monte carlo).
    - We can do IV-GMM to recover $\hat{\alpha}(\tilde{\theta}_2), \hat{\beta}(\tilde{\theta}_2), \hat{\xi}(\tilde{\theta}_2)$.

$$\boldsymbol{\delta_t}(\mathcal{S}_t, \tilde{\theta}_2) = x_{jt}\beta - \alpha p_{jt} + \xi_{jt}$$

    - Use $\hat{\boldsymbol{\xi}}(\theta)$ to construct sample moment conditions $\frac{1}{N}\sum_{j,t} Z'_{jt}\xi_{jt}$
- When we have found $\hat{\theta}_{BLP}$ we can use this to update $W \rightarrow W(\hat{\theta}_{BLP})$ and do 2-stage GMM.

Coming Up

- Extensions and Variants
- Supply Side Restrictions
- Instruments
- Implementation Details