Retail Demand Estimation using Public Spatial Data

An Equilibrium Configuration Approach

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Motivation

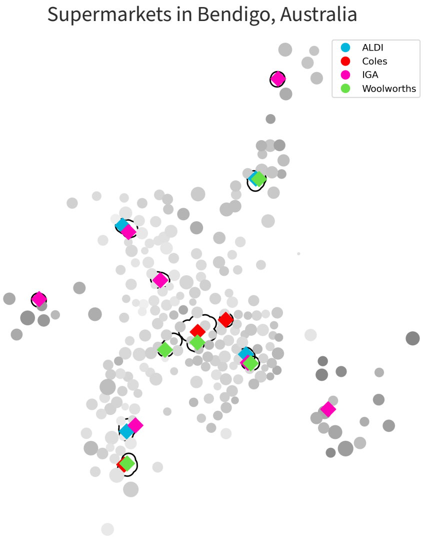
Retail Chain Mergers

Retail Chain Competition:

- Multi-product retailers
- Chain level differentiation
  - Vertical
  - Horizontal
- Geographic differentiation
  - Customer proximity
  - Local retail agglomeration

Retail Merger Counterfactuals:

- Price effects
  - Unilateral effects
  - Distribution efficiencies
- Store divestitures, rebrandings & closures



Literature

Retail Demand Estimation - Data Requirements

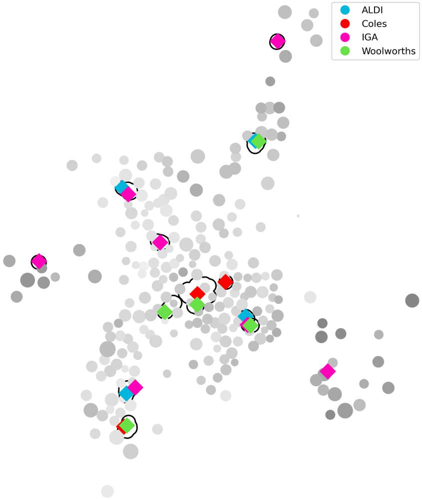
Proprietary Data:

- Store quantities/revenues
  - Davis (2006 RJE)
  - Manuszak (2010 IJIO)
  - Ho & Ishii (2011 IJIO)
  - Houde (2012 AER)
  - Seim & Waldfogel (2013 AER)
  - Aguirregabiria & Vicentini (2016 JIE)
  - Ellickson, Grieco & Khvastunov (2020 RJE)
- Store prices
  - Thomadsen (2005 RJE; 2007 MS)
- Household store choices
  - Smith (2004 RES)

Public Data:

- Store locations ✓
  - Endogenous store-level prices ✓
    - This paper
  - Exogenous/market-level prices ✗
    - Chernew, Gowrisankaran & Fendrick (2002 JHE)
    - Gowrisankaran & Krainer (2011 RJE)

Supermarkets in Bendigo, Australia



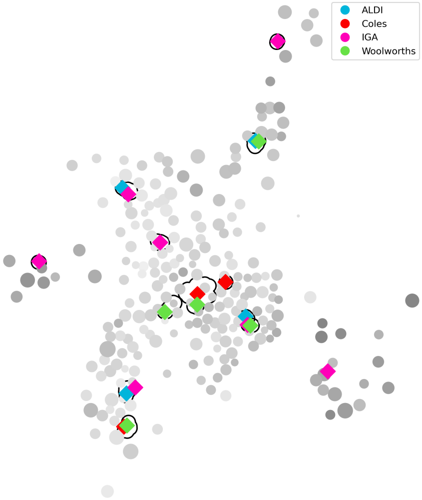
Model

Data Requirements & Notation

Data Requirements

- Markets: $m \in \mathcal{M}$
  - Location set: $\mathcal{L}_m$
- Retail shopping precincts: $r \in \mathcal{R}$
  - Location set: $\mathcal{L}_r$
  - Agglomeration: a_r
- Households types: $h \in \mathcal{H}$
  - Location: l_h
  - Income: i_h
  - Count: n_h
  - Size: z_h (# Residents)
- Stores: $s \in \mathcal{S}$
  - Location: l_s
  - Brand: b_s (Chain-Format)
  - Owner: o_s
- Wholesale distribution centres: $w \in \mathcal{W}$
  - Location: l_w
  - Brand(s) supplied: $\mathcal{B}_w$

Supermarkets in Bendigo, Australia



Model

Price Equilibrium

Household Store Choice

- Brand differentiation
  - Horizontal: ρ
  - Vertical: β_b
- Location differentiation
  - Distance: δ
  - Agglomeration: α
- Price disutility
  - f(income): η_0, η_i
- Demand
  - f(household size): ζ

$$u_{hs} = \underbrace{\alpha a_r + \beta_b + \delta d_{hs} + \eta_h p_s}_{\overline{u}_{hs}} + \underbrace{\epsilon_{hb} + (1-\rho)\epsilon_{hs}}_{\nu_{hs}}$$

$$\eta_h = \eta_0 + \eta_i i_h \text{ and } \mathrm{Corr}[\nu_{hs}, \nu_{hs'}] = \rho \text{ for } s, s' \in \mathcal{S}_b$$

$$q_s = \sum_h n_h \underbrace{{z_h}^{\zeta}}_{q_h} \cdot \underbrace{\frac{\exp(\frac{\overline{u}_{hs}}{1-\rho})}{\Sigma_{bh}}}_{\Pr[s|b,h]} \cdot \underbrace{\frac{{\Sigma_{bh}}^{1-\rho}}{1 + \sum_b {\Sigma_{bh}}^{1-\rho}}}_{\Pr[b|h]} \text{ with } \Sigma_{bh} = \sum_{s \in \mathcal{S}_b} \exp(\frac{\overline{u}_{hs}}{1-\rho})$$

Owner Profits

- Fixed costs
  - f(brand): F_b
- Marginal costs
  - f(brand, distance): μ_b, μ_w

$$\pi_o = \sum_{s \in \mathcal{S}_o} \pi_s \text{ with } \pi_s = (p_s - c_s)q_s - f_s \text{ and } c_s = \mu_b + \mu_w d_{sw}$$

$$, \Pr[f_s < x] = F_b(x)$$

Price Equilibrium

- Nash-Bertrand

$$\boldsymbol{p}_o^* = \arg\max_{\boldsymbol{p}_o} \pi_o(\boldsymbol{p}_o, \boldsymbol{p}_{-o}) \quad \forall o \in \mathcal{O}$$

Model

Spatial Equilibrium

Spatial Equilibrium

Sutton (1997 RJE; 1998; 2000; 2007): *Equilibrium configuration*

- Mutual best response in store networks
  - Testable marginal profit inequalities:

    $$\Delta\pi_s := \pi_o[s \in \mathcal{S}|\mathcal{S}_{-s}] - \pi_o[s \notin \mathcal{S}|\mathcal{S}_{-s}]$$

    - Observed stores: marginally profitable

      $$\Delta\pi_s \geq 0 \quad \forall s \in \mathcal{S},$$

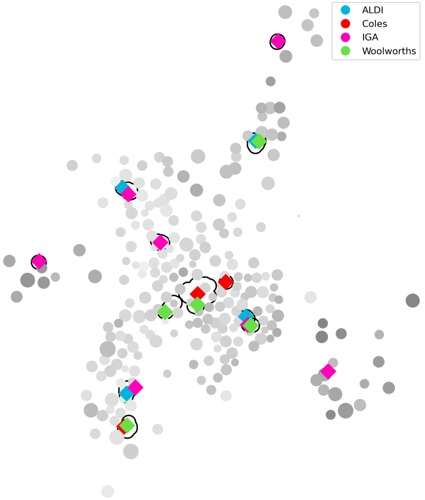
    - Unobserved stores: marginally unprofitable

      $$\Delta\pi_{s'} \leq 0 \quad \forall s' \notin \mathcal{S}$$

- Agnostic to order of entry, equilibrium selection
  - Robust to first mover advantages, multiple equilibria
- Long run (cf static) interpretation
  - Ciliberto & Tamer (2009 E)
  - Ellickson, Houghton & Timmins (2013 RJE)
  - Pakes, Porter, Ho & Ishii (2015 E)

    $\vdots$

Supermarkets in Bendigo, Australia



Conditional Store Existence Probabilities:

- Store-level observables: $\boldsymbol{\mathcal{X}}_s = (b_s, l_s, o_s, \mathcal{S}_{-s}, \mathcal{H}, \mathcal{R}, \mathcal{W})$
- Conditional independence assumption: $F_b(\cdot|\boldsymbol{\mathcal{X}}_s) = F_b(\cdot)$
- Conditional store existence probabilities: $\underbrace{\Pr[s \in \mathcal{S}|\boldsymbol{\mathcal{X}}_s]}_{\text{Observed}} = \Pr[\Delta\pi_v(\boldsymbol{\mathcal{X}}_s) - f_s \geq 0] = F_b\big(\Delta\pi_v(\boldsymbol{\mathcal{X}}_s)\big)$

Fixed & Variable Profit Decomposition:

Matzkin (1992 E; 1994), Berry & Tamer (2006)

- $F_b(\cdot)$, $\Delta\pi_v(\boldsymbol{\mathcal{X}}_s)$ recoverable:
  - Shape restriction: $\Delta\pi_v(\boldsymbol{\mathcal{X}}_s) \propto$ household counts
  - Special regressor: $\Delta\pi_v(\boldsymbol{\mathcal{X}}_s)$ continuous, monotone decreasing in full support d_{sw}

Variable Profit Parameters:

- $\Delta\pi_v(\boldsymbol{\mathcal{X}}_s; \boldsymbol{\theta}_v)$ identifies variable profit parameters: $\boldsymbol{\theta}_v = (\alpha, \delta, \eta_0, \eta_i, \rho, \sigma, \zeta, \mu_w, \boldsymbol{\mu}', \boldsymbol{\beta}')$
  - High dimensional system of nonlinear equations
    - $|\boldsymbol{\theta}_v| = 8 + 2|\mathcal{B}|$ parameters
    - $|\mathcal{S}| + |\mathcal{B}||\mathcal{R}| + 1$ store states
    - $|\mathcal{S}_m|$ first order conditions per store state
  - Numerical verification
    - Latent equilibrium prices

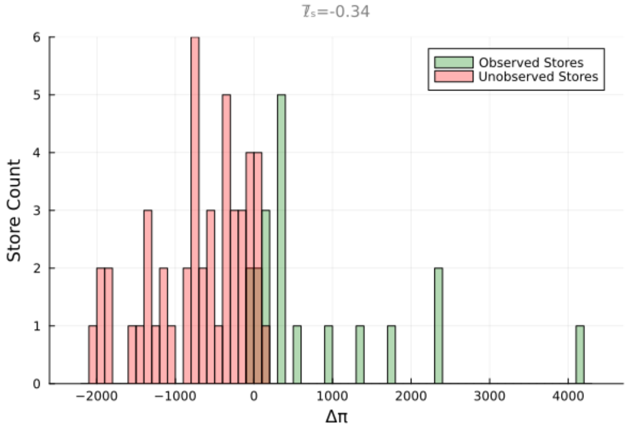
Estimator:
Maximise weighted log-likelihood of conditional store existence & non-existence probabilities

$$\ell(\boldsymbol{\theta}) := |\mathcal{S}|^{-1} \sum_{s \in \mathcal{S}} \log \Big[\underbrace{F_b(\Delta\pi_v(\boldsymbol{\mathcal{X}}_s; \boldsymbol{\theta}))}_{\Pr[s \in \mathcal{S}]} \Big] + |\mathcal{B} \times \mathcal{R}|^{-1} \sum_{s' \in \mathcal{B} \times \mathcal{R}} \log \Big[\underbrace{1 - F_b(\Delta\pi_v(\boldsymbol{\mathcal{X}}_{s'}; \boldsymbol{\theta}))}_{\Pr[s' \notin \mathcal{S}]} \Big]$$

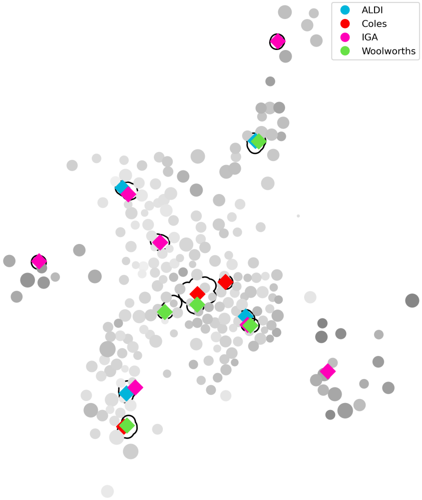
- Outcome-based sampling
  - $|\mathcal{S}|$ observed stores
  - $|\mathcal{B}| \times |\mathcal{R}|$ unobserved stores
    - Extra store of each brand at each retail precinct
- Parametric fixed cost distribution
  - $F_b : f_b \sim N(\phi_b, \sigma)$
    - Brand-specific means: ϕ_b
    - Common unobservables: $N(0, \sigma)$

Results

Subsample - Bendigo, Australia - Profit Differences



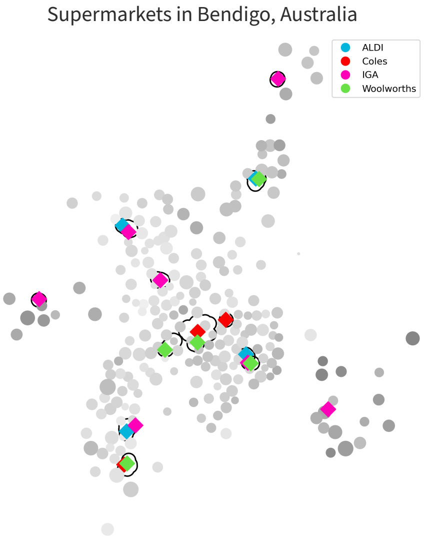
Supermarkets in Bendigo, Australia



Results

Subsample - Bendigo, Australia - Observed Stores

Store	$\hat{p}_s$	$\hat{q}_s$	$\hat{\pi}_s$	$\widehat{\Delta\pi_s}$
ALDI EagleHawk	2.06	1269	28	24
ALDI Kangaroo Flat	2.05	1401	111	110
ALDI Epsom	2.26	1349	360	357
ALDI Strathdale	1.96	1439	0	-2
Coles Kangaroo Flat	1.99	1146	-11	-12
Coles McIvor Rd	2.37	1273	563	127
Coles Bendigo	2.07	2080	890	382
IGA EagleHawk	3.30	2608	1426	365
IGA Kangaroo Flat	3.05	2225	345	310
IGA Huntly	4.64	870	182	182
IGA Maiden Gully	5.87	1023	1852	1762
IGA Strathfieldsaye	5.44	1847	4326	4188
IGA Stonemans Village	2.89	3788	1532	1376
IGA Long Gully	3.67	3060	3204	2360
Woolworths Lansell Plaza	3.92	1371	71	57
Woolworths Golden Square	4.89	1851	2461	933
Woolworths Kennington	3.76	2413	974	338
Woolworths Epsom	4.52	2154	2345	2340
Woolworths Bendigo	4.36	2207	2074	503

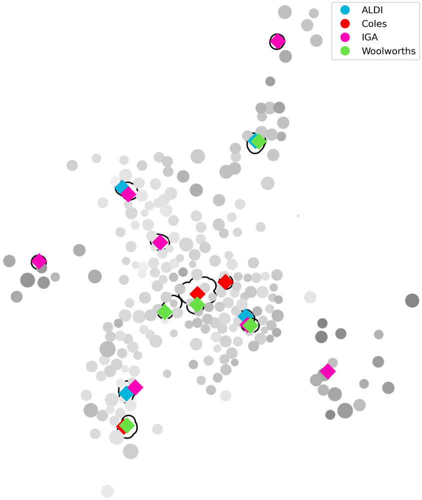


Results

Subsample - Bendigo, Australia - Unobserved Stores

Retail Precinct r	Observed Brands $\mathcal{B}_r$	Profitable Entrants $b : \widehat{\Delta\pi_{br}} > 0$	Profit $\widehat{\Delta\pi_{br}}$
Golden Square	Woolworths	ALDI	164
Bendigo	Woolworths Coles	ALDI	77
Long Gully	IGA	ALDI Coles Woolworths	74 70 1

Supermarkets in Bendigo, Australia



Results

Subsample - Bendigo, Australia - Parameter Estimates

Demand

- Household Size: $\hat{\zeta} \approx 0.54 \implies q_h \propto z_h^{0.5}$

Preferences

- Agglomeration: $\hat{\alpha} \approx 0.19 \implies \hat{\alpha} a_s \in [0, 1]$
- Distance: $\hat{\delta} \approx -3.05$ (per Km) $\implies \hat{\delta} d_{hs} \in [-60, 0]$
- Differentiation: $\hat{\rho} \approx 0.67 \implies \mathrm{Corr}[\nu_{hs}, \nu_{hs'} | s, s' \in \mathcal{S}_b] = 0.67$
- Price Disutility: $\hat{\eta}_h \approx -9.9 + 1.1 i_h \implies \hat{\eta}_h p_s \in [-50, -5]$

Brand Vertical Differentiation & Cost Structure

Brand	$\hat{\phi}_b$	$\hat{\mu}_b$	$\hat{\beta}_b$
Woolworths	1648	2.67	12.49
IGA	2196	1.91	11.54
Coles	908	1.21	8.53
ALDI	873	1.35	8.54

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