Estimating a Model of Strategic Network Choice: The Convenience-Store Industry in Okinawa

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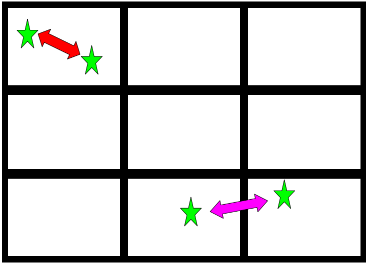
Motivation: Why Model Location Choice of Chains?

- We often observe store-location choices of multi-store firms.
  - Convenience stores (Family Mart, LAWSON), discount retailers (Wal-Mart, Target), groceries (Whole Foods, Trader Joe's)
- Two features: (1) internalizing a trade-off due to clustering own stores and (2) taking a rival chain's store locations into account

- What are the underlying primitives that generate the observed store networks? Can we explain these networks as the outcomes of games?
- Can we predict new store networks after a merger (or deregulation)?
  - *"The proposed settlement doesn't resolve the competitive problem that would lead to these higher prices." (FTC, Staples-Office Depot merger, 1997)*

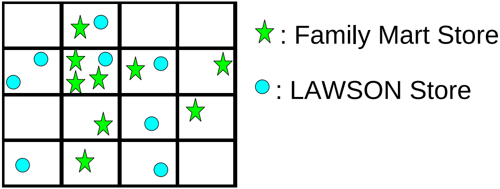
- This paper develops a new framework to estimate a game in which two chains choose store networks.

A Trade-off Due to Clustering Own Stores



- There is a trade-off between
  1. Own Business-Stealing Effect: revenue reduction due to presence of own chain stores and
  2. Cost Savings due to presence of own chain stores.
- A trade-off can be within a market (red) or across markets (pink).

Underlying Difficulties in Chain-Entry Game



Family Mart

0	1	0	0
0	3	1	1
0	1	0	1
0	1	0	0

LAWSON

0	1	0	0
2	1	1	0
0	0	1	0
1	0	1	0

- $N_{FM} = (0,1,0,0,0,3,1,1,0,1,0,1,0,1,0,0)$
- Issues: Huge number of
  1. possible store networks: $5^{16} = 1.5 * 10^{11}$
  2. possible outcomes of the game: $(5^{16})^2 = 2.3 * 10^{22}$

My Approach

- This paper proposes a general framework for estimating a chain-entry model.
- New features: a chain is allowed to
  1. decide where and how densely to open stores and
  2. internalize a trade-off due to clustering own stores.
- Methodological improvements
  1. Provide algorithms to reduce burden of solving for a Nash Equilibrium.
  2. Integrate chain-entry model with post-entry outcome, correcting for selection for entrants by simulations
- Apply to convenience stores in Okinawa to evaluate hypothetical merger and deregulation
- Empirical findings
  1. Trade-off due to clustering stores is important consideration for a chain.
  2. Merger: Acquirer increases in number of stores in city centers but decreases in suburbs.
  3. Deregulation: significantly impacts store networks.

Empirical Entry Models

- Traditional unit of analysis is the single-store firm.
  - Bresnahan and Reiss (1990, 1991), Berry (1992), Mazzeo (2002a), Seim (2006)
  - Markets are independent both in demand and costs
- Analysis on multi-store firms
  - Jia (2008): equilibrium store-network choice model
  - Ellickson, Houghton, and Timmins (2008), Holmes (2008)
- Integration of post-entry outcomes into entry model
  - Reiss and Spiller (1989), Berry and Waldfogel (1999), Mazzeo (2002b), Ellickson and Misra (2008)

Model Outline

- Two players $i \in \{FamilyMart, LAWSON\}$
- Complete information, simultaneous move
- Markets denoted $m = 1, ..., M$
- Strategy profile: $N_i = [N_{i,1}, ..N_{i,m}, .., N_{i,M}]'$
- Each player maximizes total profits:

$$\Pi_i(N_i, N_j) = \sum_{m=1}^{M} \pi_{i,m}(N_i, N_j)$$

- Nash equilibrium: a pair of store networks that are best responses
- $N_{i,m} \in \{0, 1, .., K\}$

Profit Function and Revenue Equation

- $$\underbrace{\pi_{i,m}(N_i, N_j)}_{\text{Profits, market level}} = \underbrace{r_{i,m}(N_i, N_j)}_{\text{Revenue}} - \underbrace{c_{i,m}(N_i)}_{\text{Costs}}, \text{ where}$$

$$r_{i,m}(N_i, N_j) = N_{i,m} * [\underbrace{-\delta_{own,within}\log(\max(N_{i,m}, 1)) - \delta_{own,adj}\sum_{l\neq m}\frac{D_{i,l}}{Z_{m,l}}}_{\text{business-stealing effect, own chain stores}}$$

$$\underbrace{-\delta_{rival,within}\log(N_{j,m}+1) - \delta_{rival,adj}\sum_{l\neq m}\frac{D_{j,l}}{Z_{m,l}}}_{\text{business-stealing effect, rival chain stores}}$$

$$\underbrace{-\delta_{local,within}\log(N_{local,m}+1) - \delta_{local,adj}\sum_{l\neq m}\frac{D_{local,l}}{Z_{m,l}}}_{\text{business-stealing effect, local stores}}$$

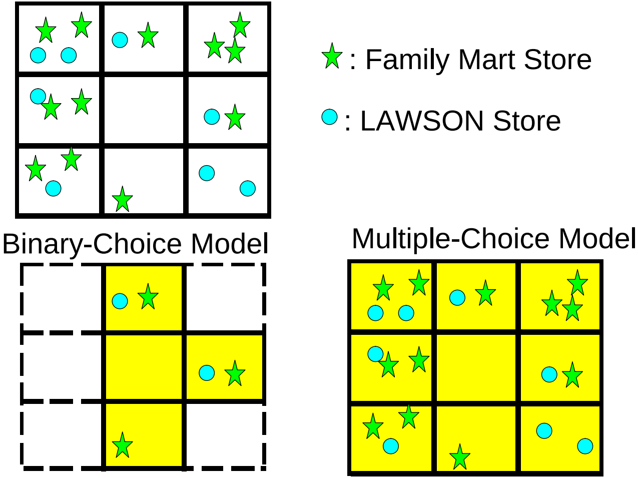
$$+ \underbrace{X_m\beta}_{\text{demographics}} + \underbrace{\mu_{LAWSON} * 1(i \text{ is LAWSON})}_{\text{brand fixed effect, LAWSON}} + \underbrace{\lambda_1(\sqrt{1-\rho_1^2}\epsilon^r_m + \rho_1\eta^r_{i,m})}_{\text{revenue shocks}}].$$

Cost Equation

$$
\begin{aligned}
c_{i,m}(N_i) \quad = \quad & N_{i,m} * [\underbrace{-\alpha_{saving,within} \log(\max(N_{i,m},1))}_{\text{cost savings from stores within a market}} \\
& \underbrace{-\alpha_{saving,adj} \sum_{l \neq m} \frac{D_{i,l}}{Z_{m,l}}}_{\text{cost savings from stores in adjacent markets}} \\
& + \underbrace{\mu_{dist} * Distance_{i,m}}_{\text{costs due to distance to distribution center}} + \underbrace{\gamma * 1(\text{market } m \text{ is zoned})}_{\text{fixed costs due to regulation}} \\
& + \underbrace{\mu_{cost}}_{\text{fixed costs of opening a store}} + \underbrace{\lambda_2(\sqrt{1-\rho_2^2}\epsilon_m^c + \rho_2 \eta_{i,m}^c)}_{\text{cost shocks}}]
\end{aligned}
$$

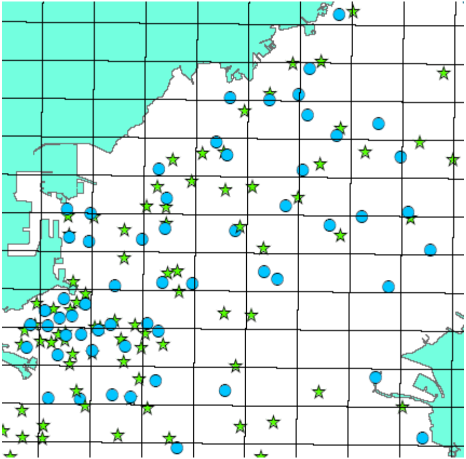
Motivation for Mult-Store Model

Multiple-choice model (1) has better coverage, (2) incorporates a trade-off within a market, (3) endogenizes all markets $\Rightarrow$ enables merger simulation.



Motivation for Multi-Store Model

- Dense configuration of stores in Okinawa



Computational Challenges

Issues

1. Number of possible network choices is too large to evaluate:
   Five choices, 834 markets $\Rightarrow 5^{834} = 8 * 10^{582}$
2. Need to solve for a Nash Equilibrium of the game
   Possible outcomes: $(5^{834})^2 = 6.4 * 10^{1165}$

Use lattice theory to develop iterative algorithms under K-choice to

1. search for the profit maximizing network choice and
2. solve for a Nash Equilibrium.

Supermodular Game and Existence of Equilibrium

Definition (Supermodular Game)

A game is supermodular if (1) $\Pi_i(N_i, N_j)$ is supermodular in N_i for fixed N_j, and (2) $\Pi_i(N_i, N_j)$ has increasing differences in N_i and N_j.

Theorem (Topkis 1979)

The set of Nash Equilibria of a supermodular game is non-empty.

Analytical Results (1)

Lemma

The chain-entry game with K-choice is supermodular if $\delta_{own,adj} \leq \alpha_{saving,adj}$.

Remark: There are no restrictions on the within-market effect among own stores in a market. Within any given market, either positive spillover (delivery costs savings) or own business-stealing effect can dominate.

Algorithm to Calculate Nash Equilibrium

Theorem (Round-Robin Algorithm to Compute a Nash Equilibrium [Topkis 1998])

Each player proceeds to update her strategy by choosing a best response. This iterative decision-making process will converge to a Nash Equilibrium that yields the highest profits for the first mover in the algorithm.

Steps

1. Given $N^0_{LS} = (0, 0, \ldots .0)$, compute the best response of Family Mart $N^1_{FM} = \arg\max_{N_{FM}} \sum_{m=1}^{M} \pi_{FM,m}(N_{FM}, N^0_{LS})$.
2. Given N^1_{FM}, compute the best response of LAWSON N^1_{LS}.
3. Iterate 1 and 2 for T times until we get convergence of either N^T_{FM} or N^T_{LS}.

Issue

- Calculating the best response is burdensome.

Best Response Algorithm: Tarski's Fixed Point Theorem

Theorem (Fixed Point Theorem [Tarski 1955])

A set of fixed points of an increasing function V that maps a lattice into itself is a lattice and has a greatest point and a least point.

- Consider the profit maximizing vector: $N_i^* = \arg\max_{N_i} \Pi_i(N_i, N_j)$.
- According to Tarski's FPT, we know

$$N_i^{UB} \geq N_i^* \geq N_i^{LB},$$

  where N_i^{UB} and N_i^{LB} are, respectively, the greatest and least fixed points of increasing function V.
- Define a mapping $V : N_i \rightarrow N_i$ that updates $N_{i,m}^0$ given $N_{i,l \neq m}^0$ and N_j^0:

$$N_{i,m}^1 = V_m(N_i^0) = \underset{N_{i,m} \in \{0,1,..,4\}}{\text{argmax}} \Pi_i(N_{i,l}^0, N_{i,m}, N_j^0).$$

- The profit maximizing vector N_i^* satisfies $V(N_i^*) = N_i^*$.

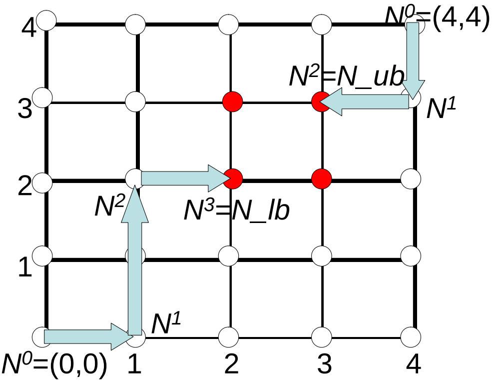
Analytical Results (2)

Lemma (Nondecreasing Coordinatewise Optimality Condition)

$V_i(N_i)$ is nondecreasing in N_i if $\delta_{own,adj} \leq \alpha_{saving,adj}$.

Algorithm to Find Best Response: Example

- Two markets, up to 4 stores: How do we find the maximizer?
  1. Brute force: check all 5*5=25 possibilities
  2. Or we can narrow down to 4 by calculating lower and upper bound: $N_i^{UB} = (3,3), N_i^{LB} = (2,2)$
     $\Rightarrow N^*$ is one of $\{(2,2),(2,3),(3,2),(3,3)\}$.



Data

- Market definition: 1km^2 grid, 834 markets in total
- Cross-sectional market-level data
  1. # of Convenience Stores: Convenience Store Almanac, 2001
  2. Aggregate sales: Census of Commerce, 2002
  3. Distance to distribution center
  4. # of people living: Census of Population, 2000
  5. # of people working: Establishment Census, 2001
  6. Land-use regulation status: Ministry of Land, Infrastructure and Transport, 2005

Estimation Methodology: Method of Simulated Moments

- Construct population and sample moment conditions:

$$g_{i,store}(\theta) \equiv E[(N_{i,m} - E[N_{i,m}(X, \epsilon, \theta|X)]) * f_m(X)|X]$$

$$g_{i,store,M}(\theta) \equiv \frac{1}{M}\sum_{m=1}^{M}(N_{i,m} - E[N_{i,m}(X, \epsilon, \theta)|X]) * f_m(X).$$

- Use a simulator for number of stores to obtain

$$\hat{g}_{i,store,M}(\theta) = \frac{1}{M}\sum_{m=1}^{M}(N_{i,m} - \frac{1}{S}\sum_{s=1}^{S} N^s_{i,m}(X, \epsilon^s, \theta)) * f_m(X).$$

- Parameter estimates are obtained by solving

$$\hat{\theta}_{MSM} = \arg\min_{\theta}\,[\hat{g}_M(\theta)]'\mathbf{W}[\hat{g}_M(\theta)],$$

where **W** is a weighting matrix.

Use of Revenue Data: Moment Conditions for Revenue

- Construct population and sample moment conditions:

$$
\begin{aligned}
g_{rev}(\theta) &\equiv E[(I_m R_m^* - E[I_m R_m^*(X, \epsilon, \theta|X)]) * f_m(X)|X] \\
g_{rev,M}(\theta) &\equiv \frac{1}{M}\sum_{m=1}^{M}(I_m R_m^* - E[I_m R_m^*(X, \epsilon, \theta)|X]) * f_m(X).
\end{aligned}
$$

- Use a simulator for aggregate revenue at the market level to obtain

$$
\hat{g}_{rev,M}(\theta) \equiv \frac{1}{M}\sum_{m=1}^{M}(I_m R_m^* - \frac{1}{S}\sum_{s=1}^{S} I_m^s R_m^{*,s}(X, \epsilon^s, \theta)) * f_m(X).
$$

Avoiding Selectivity Problem

- Post-entry outcome is available only for the market where a firm decided to open
- Example: a revenue function

$$(Total\ \ revenue)_m = \theta_a + \theta_b N_{i,m} + \epsilon_m$$

- My approach uses (1) and (2) jointly to estimate $\theta = (\theta_1, \theta_2)$

$$\text{outcome } \mathbf{E}[g_1(\theta_1)] = 0 \quad (1)$$

$$\text{selection } \mathbf{E}[g_2(\theta_1, \theta_2)] = 0 \quad (2)$$

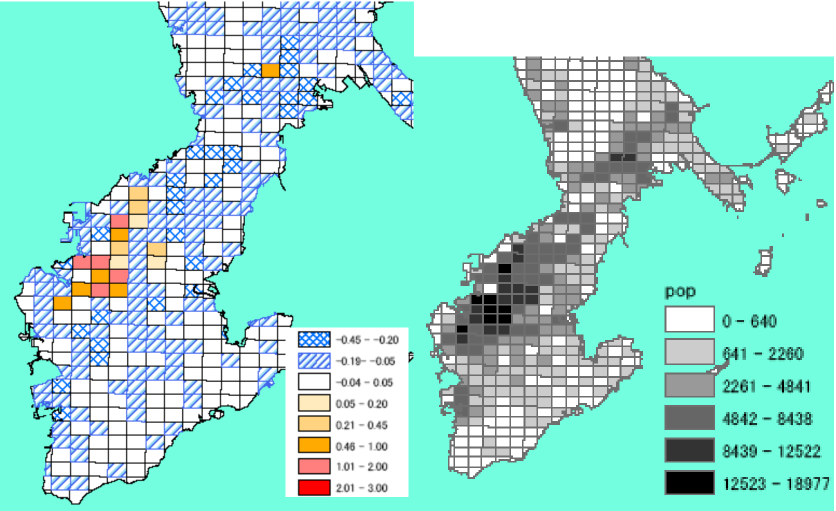
Revenue Equation (thousand USD)

Variable	Estimate	SE
Nighttime Population (β_{pop})	69.1	26.3
Daytime Population (β_{bus})	46.7	14.4
Business-Stealing Effect by		
Own Chain Store, within a Market ($\delta_{own\ within}$)	280.1	133.4
Own Chain Store, Adjacent Markets ($\delta_{own\ adj}$)	33.0	111.0
Rival Chain Store, within a Market ($\delta_{rival\ within}$)	364.2	180.0
Rival Chain Store, Adjacent Markets ($\delta_{rival\ adj}$)	1.1	11.9
Local Store, within a Market ($\delta_{local\ within}$)	24.4	81.8
Local Store, Adjacent Markets ($\delta_{local\ adj}$)	0.1	1.41
LAWSON Store (μ_{LAWSON})	4.7	38.5
Constant in Revenue Equation ($\mu_{revenue}$)	512.5	475.9
Correlation Parameter in Revenue Shocks (ρ_I)	0.89	0.31
Standard Deviation of the Unobserved Revenues (λ_I)	215.3	76.5

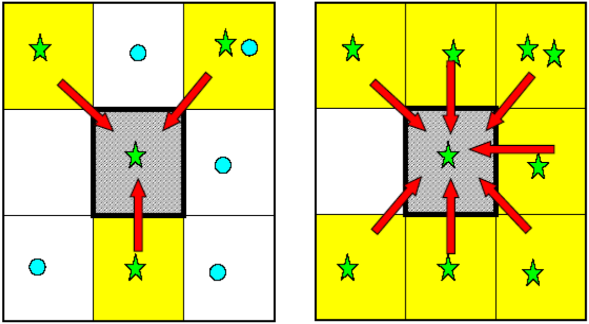
Cost Equation & Model Fit (thousand USD)

Variable		Estimate	SE
Cost-Savings Effect by			
Own Chain Store, within a Market (α *saving within*)		125.3	127.5
Own Chain Store, Adjacent Markets (α *saving adj*)		37.6	122.8
Distance from the Distribution Center (μ *distance*)		16.2	42.3
Zoned Area (γ)		41.4	45.4
Constant in Cost Equation (μ *cost*)		1,038.7	255.0
Correlation Parameter in Cost Shocks (ρ_2)		0.02	0.25
Standard Deviation of the Unobserved Costs (λ_2)		229.6	118.6
Model Prediction	**Data**	**Prediction**	**Std.Dev**
Number of Stores			
Family Mart	139	139.9	8.7
LAWSON	100	97.1	9.8
Number of Stores in Adjacent Markets			
Family Mart	1041	1023.4	67.4
LAWSON	725	705.6	80.0
Sales (thousand USD)	169,334	173,992	11,506

Differences in # of Stores and Population Density



Why Increase in # of Stores after Merger?



Marginal profits from one more store, before merger:

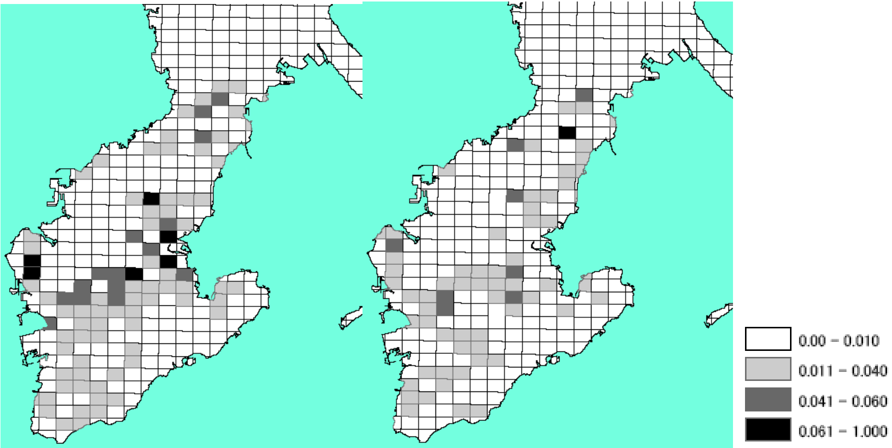
$$\Delta\pi_{5,before} = 3 * (spillovers) - 1 * (business\ stealing)$$

After merger:

$$\Delta\pi_{5,after} = 6 * (spillovers) - 1 * (business\ stealing)$$

Increase in # of Stores: before and after Deregulation

Family Mart LAWSON



Conclusion

This paper

1. Develops a new framework to solve and estimate a general class of chain-entry games.
2. Applies the model to the convenience-store industry in Okinawa.
3. Answers merger and deregulation exercises, which cannot be dealt with otherwise.

Findings

- The chain-entry model with K-store openings allows for a trade-off due to clustering being positive or negative.
- Trade-off due to clustering stores is important for a chain.
- Merger: Acquirer increases the total number of stores in city centers but decreases the total number of stores in rural markets.

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Applications to Other Contexts

1. **ATM location choice**
2. **Product-line decision**: Extend Moorthy (1984) to duopoly setting.

Extensions

1. Strategic pricing in the U.S. airline industry
   - A market is a city pair (e.g., New York to Chicago).
   - Pricing in a market can depend on pricing in other markets (spillovers):

$$\begin{aligned} P_{United} &= [P_{u,1}, ..., P_{u,M}] \\ P_{American} &= [P_{a,1}, ..., P_{a,M}]. \end{aligned}$$

   - Research questions: Is the industry competitive or collusion? Predicted pricing after merger?
2. Relaxing the "# of players $\leq$ 2" restriction
   - In reality, we observe more than two players.
   - Will exploit other classes of games.

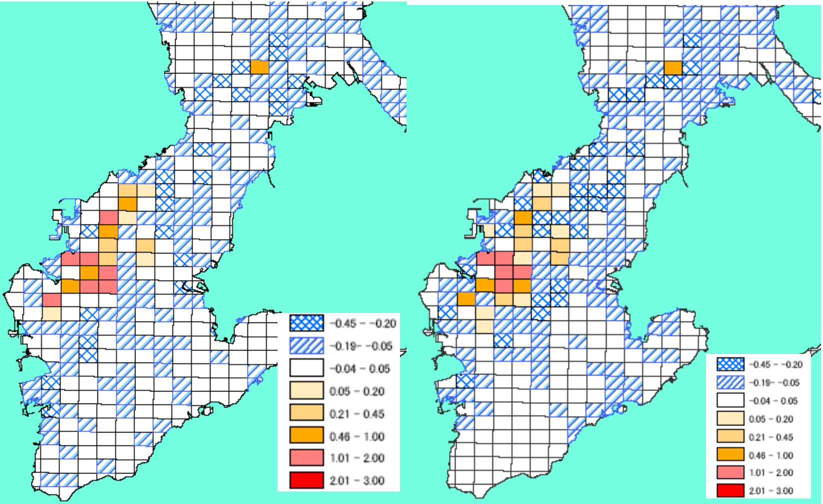
Summary Statistics

Variable	Mean	Std. Dev.	Min	Max	Total
Number of Stores					
Family Mart	0.17	0.55	0	7	142
LAWSON	0.12	0.43	0	6	102
Number of Stores in Adjacent Markets					
Family Mart	1.248	2.675	0	19	1,041
LAWSON	0.869	1.923	0	15	725
Geographical Distance to Its Distribution Center (kilometer)					
Family Mart	29.7	20.8	0.35	84.86	-
LAWSON	30.8	21.0	0.55	86.18	-
Nighttime Population	1,434	2,588	0	18,977	1,195,787
Daytime Population	580	1,612	0	32,776	484,097
Store-level Sales (=Total Sales / # of Stores), thousand US dollars					
Family Mart	1,430				
LAWSON	1,456				

Before and after Merger (million USD)

	Baseline	No Costs		Closing: US $100K Remodeling: US $50K	
Variable	Prediction	Prediction	% Δ	Prediction	% Δ
Total Number of Stores	237.0	207.9	-12.3%	215.4	-9.1%
Number of Stores to:					
Maintain (Own Chain)				139.9	
Open (Own Chain)				25.3	
Close (Own Chain)				0.0	
Close (Rival Chain)				46.9	
Remodel Rival Stores				50.2	
Total Sales	$234.6	$209.9	-10.5%	$214.6	-8.5%
Sales per Store	$0.97	$1.01	4.2%	$1.00	2.8%
Total Profits	$58.7	$65.9	12.3%	$58.5	-0.2%
Profits per Store	$0.24	$0.32	34.1%	$0.27	15.0%

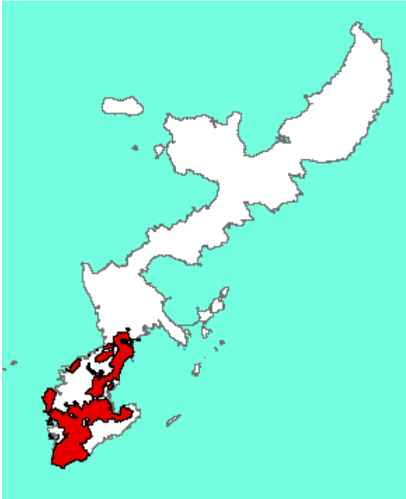
Robustness Check: Costs(left) & LAWSON(right)



1968 Urban Planning Law

- Permission system for developing a store in zoned area
- Procedures:
  1. Submit preliminary application [applicant]
  2. Receive application, send to civil engineering bureau [city]
  3. Review application, conduct a field survey [prefecture]
  4. Notify the applicant of the outcome and issues, if any [prefecture]
  5. Submit final application [applicant]

Zoned Areas (Red)



Before and after Deregulation (million USD)

	Baseline	No Zoning		Zoning in All Markets	
Variable	Prediction	Prediction	% Δ	Prediction	% Δ
Number of Stores					
Family Mart	139.9	143.2	2.3%	123.2	-11.9%
(in originally zoned 140 markets)	11.9	15.0	26.9%	11.8	-0.5%
LAWSON	97.1	99.2	2.2%	86.0	-11.4%
(in originally zoned 140 markets)	8.3	10.4	26.2%	8.2	-0.3%
Sales					
Family Mart	$135.6	$137.9	1.7%	$124.0	-8.6%
(in originally zoned 140 markets)	$10.1	$12.5	23.1%	$10.1	-0.3%
LAWSON	$99.0	$100.6	1.7%	$90.9	-8.2%
(in originally zoned 140 markets)	$7.5	$9.1	22.6%	$7.4	-0.2%
Total Profits					
Family Mart	$33.1	$33.6	1.6%	$29.1	-11.9%
LAWSON	$25.6	$26.0	1.5%	$22.7	-11.5%
Costs of Zoning					
All Stores	-$2.1	$0.0	-100%	-$17.5	742.6%
Family Mart and LAWSON	-$0.8	$0.0	-100%	-$8.7	940.5%

Convenience-Store Industry in Okinawa