2015.6.13. The 4th International BinN research seminar “Dynamic modeling based on bounded rationality to understand diversifying travel behavior”

Modeling shopping behavior in a neighborhood with endogenous representation of retail attractiveness

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Motivation (1/2)

- Our ultimate goal:
  - Describing collective decisions through modeling social interactions
- Some examples in our mind:
  - Why some communities do better collective decisions (e.g., maintaining small market in the neighborhood), while some others do not?
  - Why some (most?) slums are in a kind of lock-in situation, while some others are not?
- These questions are not very new (e.g., Schelling, 1978), but we could do a better empirical analysis on this topic
  - Progress on modeling social interactions
  - Advancement of observation/estimation methods

Our focus: shopping behavior in a neighborhood

※ One-day travel diary survey in Hiroshima in 2008

Motivation (2/2)

- ✓ Many newtowns were built around 30-40 years ago in Japan
- ✓ Rapid aging population has been observed in these areas
- ✓ As decreasing mobility with aging, maintaining necessary facilities for daily life within the neighborhood becomes more important

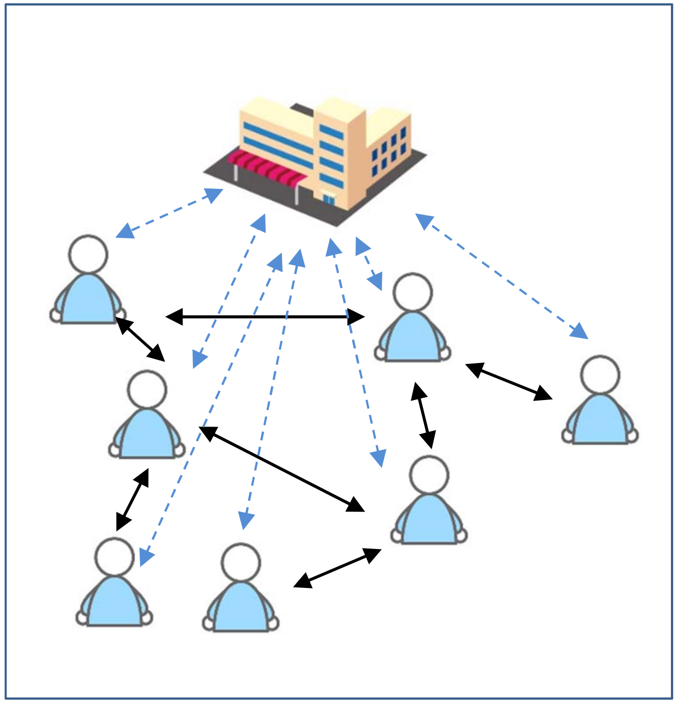
59% of residents do shopping within NT

13% of residents do shopping within NT

27% of residents do shopping within NT

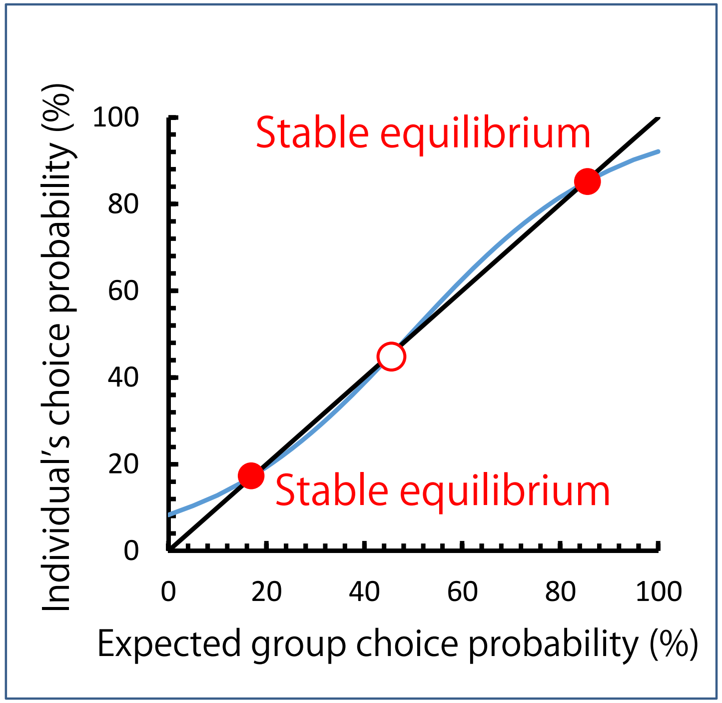
Modeling social interactions

- Social interactions in choice modeling and its macro behavior (i.e., collective decision)



Individual behavior
(individual decision)

When the degree of interactions are higher than a certain level under non-cooperative scheme



Macro behavior
(Collective decision)

Classification of social interactions

Social interactions

Market interactions

Differences in final consequences are understood as differences in initial conditions (Harris and Wilson, 1978; Fujita et al., 2001; Guevara, 2010)

Economical point of view

Market & non-market interactions

Differences in final consequences are understood as collective decisions (e.g., Putnam, 1993; Falk and Kilpatrick, 2000)

Sociological point of view

Classification of social interactions

Social interactions

- Market interactions
- Market & non-market interactions
  - **Local interactions**: Mostly cooperative scheme, usually not causing multiple equilibria
  - **Global interactions**: Mostly non-cooperative scheme, potentially causing multiple equilibria

We could have in-between models, but our current knowledge may be largely restricted partly due to observation issues of social networks/interactions

$$y_i = f(z_i, x_i, y_{-i}, x_{-i}, w_{i,-i})$$

- z_i: Environment factors
- x_i: Individual attributes
- y_{-i}, x_{-i}: Others' behavior/attributes
- $w_{i,-i}$: Relations with others

Classification of social interactions

Social interactions

Market interactions

Market & non-market interactions

Local interactions

Global interactions

Interactions through "average" behavior

Individual decisions are affected by the "average" behavior of social group (e.g., Brock&Durlauf, 2001; Fukuda&Morichi, 2007; Walker et al., 2011)

Interactions through "aggregate" behavior

Individual decisions are affected by the "aggregate" behavior of social group (e.g., Ueda, 1991)

Modeling interactions through "aggregate" behavior

Research purpose

- Developing a shopping destination choice model with social interactions
  - Modeling market/non-market interactions through "Aggregate behavior"
    - Similar with Brock and Durlauf's (2001) model
  - Confirming in what condition multiple equilibria happen
- Implementing empirical analysis
  - 10 newtowns in Hiroshima, Japan
    - Distinguishing endogenous effects from contextual/ correlated effects, by using a modified Rust's (1987) Nested Fixed Point algorithm (binary logit → a mixed binary logit)
    - Empirically confirm whether multiple equilibria exist or not

Model structure

Shopping destination choice model

Individual *i*'s choice probability of destination *j*

$$P_{ij} = \frac{\exp(V_{ij})}{\sum_{j'} \exp(V_{ij'})}$$

Unknown parameters

$$V_{ij} = \gamma S_j + \beta x_{ij} + \alpha_j$$

Retail attractiveness at destination *j*

Explanatory variables

Aggregation

Feedback to utility

Total shopping demand at destination *j*

$$D_j = D\bar{P}_j$$

Total shopping trips

Retail attractiveness

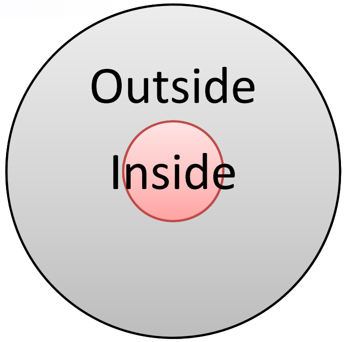
$$S_j = f(D_j)$$

A fixed point problem: $D_j = \sum_i TR_i \frac{\exp(\gamma S_j + \beta x_{ij} + \alpha_j)}{\sum_{j'} \exp(\gamma S_{j'} + \beta x_{ij'} + \alpha_{j'})}$

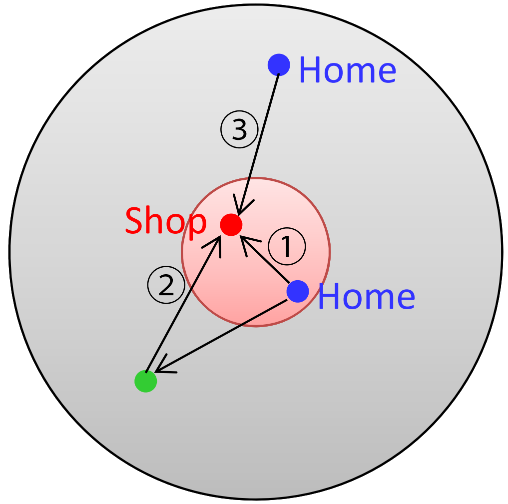
※ Similar with Ueda (1991)

Some assumptions

(a) There are two alternatives
→ inside and outside of the residential newtown



(b) Only newtown residents use shopping facilities in the newtown
(assuming ③ is zero)



(c) Total shopping demand (number of trips) is fixed

(d) The relationship between shopping demand and retail attractiveness follow a linear function

$$S_j = kD_j \ (k \geq 0)$$

Self-consistent equilibrium (1/2)

With the above assumptions, equilibrium properties are very similar with Brock and Durlauf (2001), in which the basic mathematical idea is the same with the mean field approximation of Ising model in Physics

$$P_{im1} = \frac{e^{\gamma k D_{m1} + \beta x_{im1} + \alpha_1}}{e^{\gamma k D_{m1} + \beta x_{im1} + \alpha_1} + e^{\gamma k (D - D_{m1}) + \beta x_{im2}}}$$

Assuming that ω_i represents the choice results of shopping destination where $\omega_i = 1$ when inside newtown is chosen and $\omega_i = -1$ when outside newtown is chosen (i.e., $\omega_{im} = 2P_{im1} - 1$). Under this specification, expectation of ω_i is:

$$E[\omega_{im}] = \frac{e^{h_{im} + \gamma k D_{m1}}}{e^{h_{im} + \gamma k D_{m1}} + e^{-(h_{im} + \gamma k D_{m1})}} - \frac{e^{-(h_{im} + \gamma k D_{m1})}}{e^{h_{im} + \gamma k D_{m1}} + e^{-(h_{im} + \gamma k D_{m1})}}$$

$$= \tanh\left(\frac{(\beta x_{im1} + \alpha_1) - (\gamma k D + \beta x_{im2})}{2} + \gamma k D_{1m}\right)$$

$$\left(h_{im} = \frac{(\beta x_{im1} + \alpha_1) - (\gamma k D + \beta x_{im2})}{2}\right)$$

Self-consistent equilibrium (2/2)

Based on the assumptions (b)"Only newtown residents use shopping facilities in the newtown", and (c)" Total shopping demand is fixed",

$$D_{m1} = TR_{m1}\bar{P}_{m1} = 1/2\,TR_{m1} + 1/2\,TR_{m1}E[\omega_i]$$

→ $$E[\omega_{im}] = tanh\left(\frac{(\beta(\mathrm{x_{im1}} - \mathrm{x_{im2}}) + \alpha_1 - \gamma kD + \gamma kTR_{m1}}{2} + \frac{\gamma}{2}kTR_{m1}E[\omega_{im}]\right)$$

Since (γ and k), and (α_1 and γkD) are cannot be distinguished,

$$\gamma' = \gamma k$$

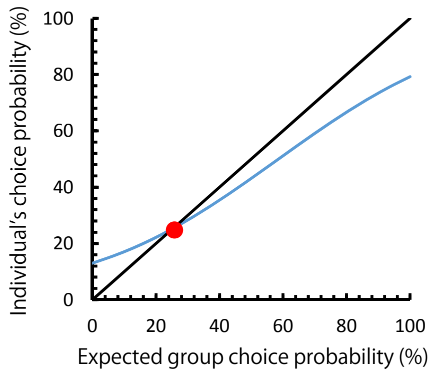
$$\alpha' = \alpha_1 - \gamma' D$$

are assumed, and finally we obtain:

$$\omega_m^* = tanh\left(\frac{(\beta(\mathrm{x_{im1}} - \mathrm{x_{im2}}) + \alpha' + \gamma' TR_{m1}}{2} + \frac{\gamma'}{2}TR_{m1}\omega_m^*\right)$$

Behavior of equilibria

Hypothetical settings: x_{im1}, x_{im2}: Generalized travel cost (x_{im2} is fixed as 1200 JPY), $\beta = -0.1, \alpha' = -3.0, \gamma' = 0.9$, Average number of shopping trips: 3 (i.e., total demand in NT is: TR_{m1}=pop. in NT ×3)
Note that ●: stable equilibria, ○: unstable equilibrium

<table>
<tr><th></th><th>Travel cost in NT:100JPY</th><th>Travel cost in NT:300JPY</th><th>Travel cost in NT:600JPY</th></tr>
<tr><td>Pop. in NT = 6,000</td>
<td>
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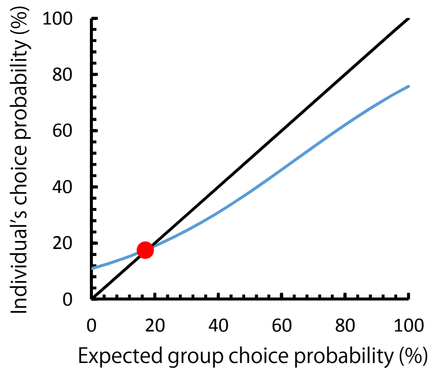
<td>
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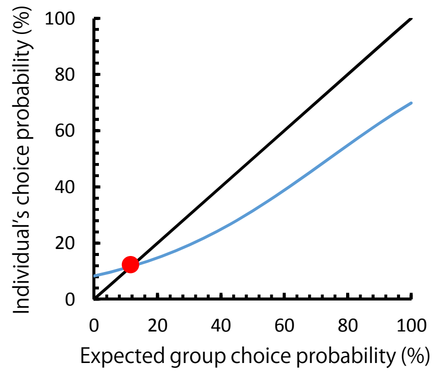
<td>
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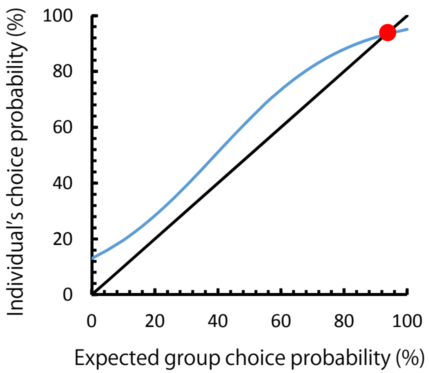
<td>
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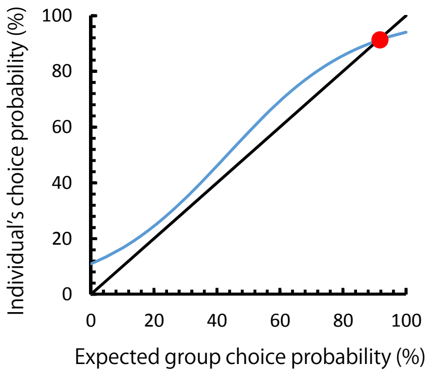
<td>
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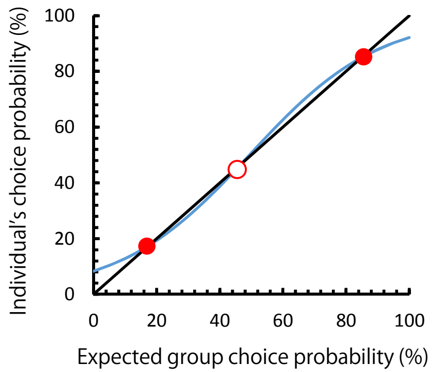
<td>
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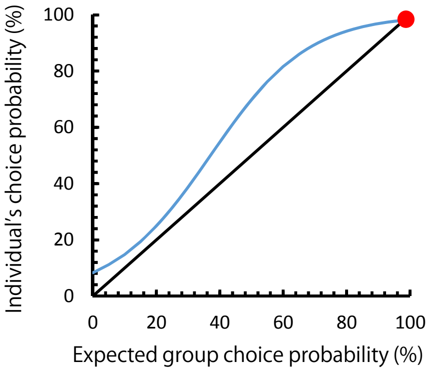
<td>
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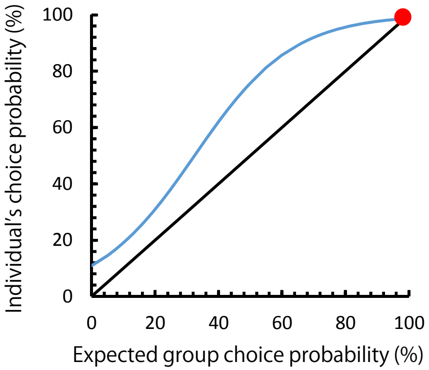
<td>
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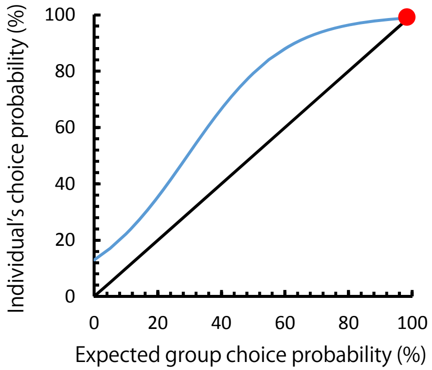
<td>
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Technical issues in model estimation

- Distinguishing endogenous effects from contextual/correlated effects (e.g., Manski, 1993)
  - BLP approach (Berry et al., 1995)
  - Control function approach
  - Full maximum likelihood approach
- Introducing the endogenous variable as an exogenous variable may not be self-consistent
  - Nested Fixed Point (NFXP) algorithm (Rust, 1987)
  - A bit more efficient NFXP algorithm (Aguirregabiria and Mira, 2002)
  - Bayesian estimation (Imai et al., 2009)
  - MPEC (Su and Judd, 2012)

Model estimation method

- NFXP(Nested Fixed Point) algorithm (Rust, 1987)

1. Given the observed choice probability ${P_{ij}}^{(0)}$, estimate a set of parameters $\theta^{(1)}$

2. Repeat the following steps until convergence

   (a) Inner fixed point algorithm:

   Calculate choice probability ${P_{ij}}^{(k)}$ with parameters $\theta^{(k)}$

   (b) Outer hill climbing algorithm:

   Given ${P_{ij}}^{(k)}$, estimate parameters $\theta^{(k+1)}$

When introducing random parameters in the 2(b) step, individual parameters (Train, 2003) are calculated and put in the 2(a) step

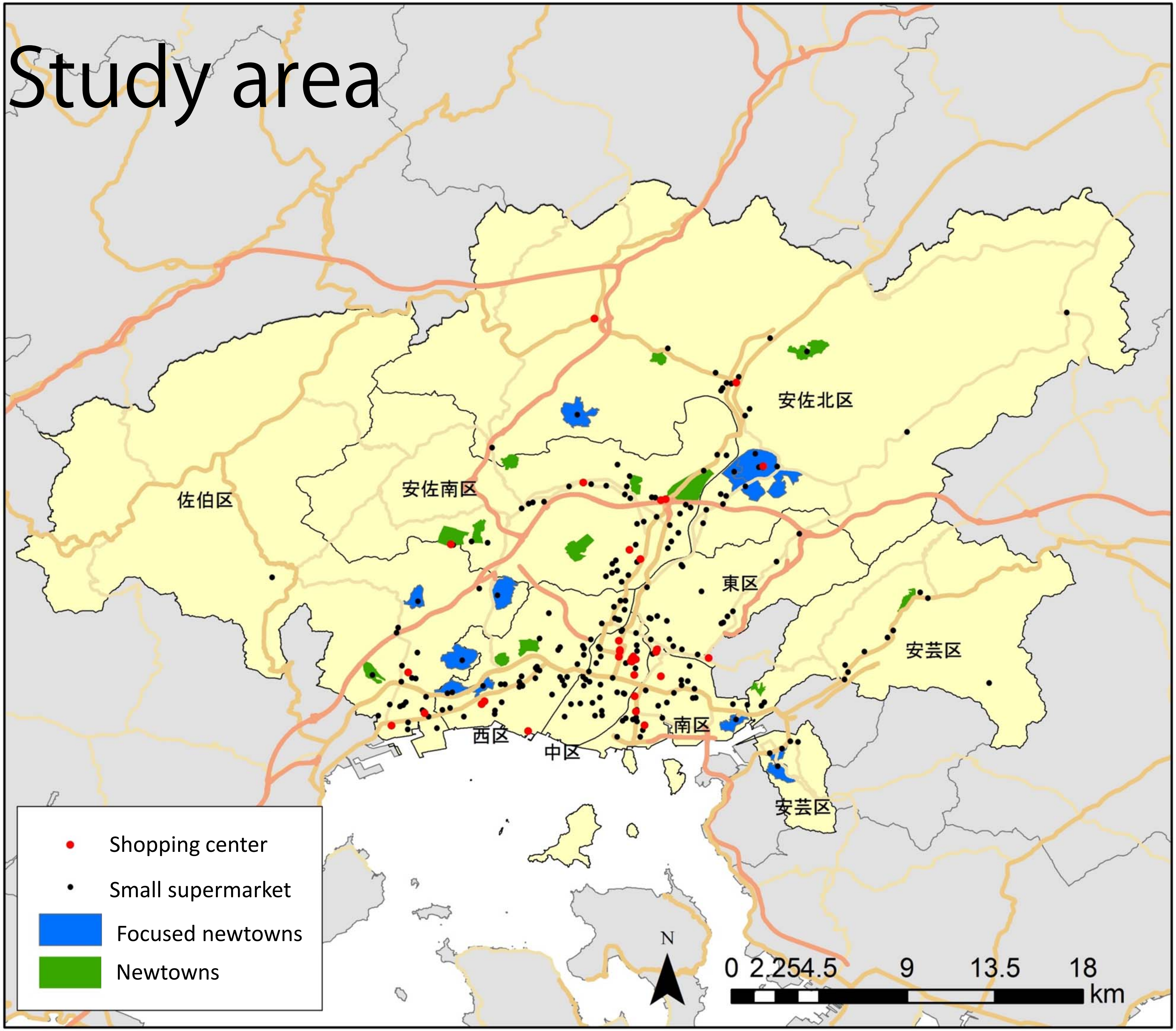
Empirical analysis

- One-day travel diary survey in Hiroshima in 2008
  - Sample size in the target area: 5,620 (1,453 shopping trips)
- Study area

※ Because the available spatial information is limited, surrounding areas are also included in some Newtowns.

List of newtown	Population in NT
あさひが丘	8155
美鈴が丘	10086
五月が丘	6925
藤の木	4948
向洋	14847
井口台・井口鈴が台	22544
山田新町・鈴が峰	11886
矢野	18617
高陽	39423
高陽第一	20437

Study area



安佐北区
安佐南区
佐伯区
東区
安芸区
西区
中区
南区
安芸区
Shopping center
Small supermarket
Focused newtowns
Newtowns
N
0 2.254.5 9 13.5 18
km

Basic statistics

	Sample size (persons)	Origin ＝ residential area			Origin ＝ non-residential area			Total	
		Shopping trips	Freq. per day per person	Share of inside newtown （%）	Shopping trips	Freq. per day per person	Share of inside newtown （%）	Freq. per day per person	Share of inside newtown （%）
あさひが丘	312	48	0.154	39.58	36	0.115	11.11	0.269	27.38
美鈴が丘	447	56	0.125	23.21	64	0.143	4.69	0.268	13.33
五月が丘	259	29	0.112	34.48	23	0.089	13.04	0.201	25.00
藤の木	143	11	0.077	18.18	22	0.154	0.00	0.231	6.06
向洋	485	64	0.132	28.13	45	0.093	4.44	0.225	18.35
井口台・井口鈴が台	728	102	0.140	50.98	79	0.109	24.05	0.249	39.23
山田新町・鈴が峰	408	55	0.135	21.82	55	0.135	3.64	0.270	12.73
矢野	656	80	0.122	28.75	69	0.105	15.94	0.227	22.82
高陽	1394	274	0.197	71.17	123	0.088	31.71	0.285	58.94
高陽第一	788	150	0.190	52.67	68	0.086	26.47	0.277	44.50
Total	5620	869	0.155	48.68	584	0.104	17.29	0.259	36.06

Travel cost (accessibility) calculation

1. Estimating travel mode choice
2. Calculating logsum
   - ✓ For inside of newtown, LOS variables are prepared for each 50m grid cell, and then take a population-weighted average (since we do not have detailed information of residential location)
   - ✓ For unchosen travel modes' LOS, we put an average value of others who live in the same newtown

	Parameter	t-value
Constant (Car)	2.239	6.73
Constant (Bicycle)	-1.204	-3.23
Constant (Walk)	0.540	1.78
Travel time (100 min)	-3.255	-2.28
Travel cost (1000 JPY)	-2.463	-1.78
Age>=75 dummy (car)	-0.071	-0.17
Initial log-likelihood	-1053.2	
Final log-likelihood	-539.0	
Adjusted rho-square	0.483	
Sample size	864	

Estimation results of shopping destination choice model

	No social interactions		With endogenous effects		With contextual/ correlated effects		With all effects	
	Parameter	t-value	Parameter	t-value	Parameter	t-value	Parameter	t-value
Constant	4.585	8.22 **	1.068	1.03	3.901	4.10 **	1.066	1.03
Travel cost (logsum)	-0.019	-1.98 *	-0.018	-1.81 +	-0.017	-1.68 +	-0.018	-1.81 +
Age <=30	-0.600	-1.78 +	-0.598	-1.75 +	-0.623	-1.83 +	-0.598	-1.75 +
Age >=65	-0.035	-0.20	0.057	0.31	0.007	0.04	0.057	0.31
Male	-0.202	-1.06	-0.271	-1.39	-0.250	-1.28	-0.271	-1.39
Housewife	-0.293	-1.47	-0.302	-1.50	-0.281	-1.39	-0.302	-1.50
Non-worker	-0.249	-1.12	-0.301	-1.34	-0.260	-1.14	-0.301	-1.34
ln(# of shops)	0.960	9.25 **	0.356	1.96 *	0.824	4.69 **	0.355	1.96 *
Endogenous								
Retail attractiveness			1.014	3.93 **			1.015	3.94 **
Contextual/correlated								
Random effect					0.095	[7.96] **	3.2.E-15	[0]
Sample size	864		864		864		864	
Initial log-likelihood	-598.88		-598.88		-598.88		-598.88	
Final log-likelihood	-546.40		-538.51		-542.42		-538.51	
AIC	1108.80		1097.03		1102.84		1099.03	

※ [] indicates the result of χ2 test

Based on AIC comparison, the model only with endogenous effects are selected

No multiple equilibria

Only if when $B = \frac{\beta'_1}{2} TR_1 > 1$, there is possibility to have multiple equilibria

	NT pop.	Freq. per day per person	B
あさひが丘	8,155	0.269	0.046
美鈴が丘	10,086	0.268	0.035
五月が丘	6,925	0.201	0.026
藤の木	4,948	0.231	0.011
向洋	14,847	0.225	0.049
井口台・井口鈴が台	22,544	0.249	0.165
山田新町・鈴が峰	11,886	0.270	0.042
矢野	18,617	0.227	0.069
高陽	39,423	0.285	0.470
高陽第一	20,437	0.277	0.185

The empirical results indicate that there are no newtowns which potentially have multiple equilibria
(though the significant social interactions exist)

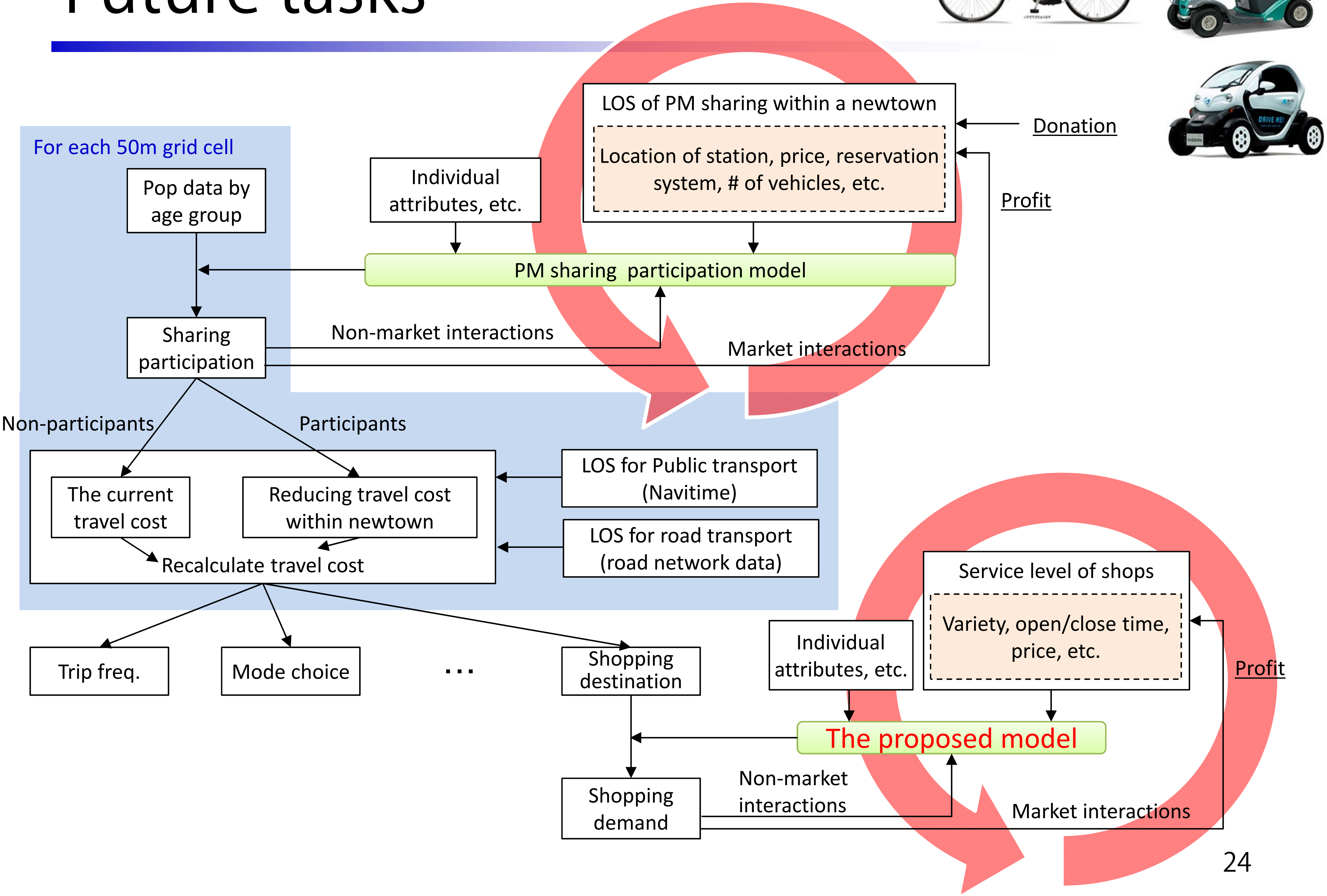
Conclusions

- Model development
  - Modeling shopping destination choice with social interactions
    - Representing retail attractiveness as endogenous
      - ➢ Brock and Durlauf (2001) → "average" behavior of others
      - ➢ This study → "aggregate" behavior of others
    - Model estimation
      - NFXP algorithm with a distinction between endogenous and contextual/correlated effects
- Empirical analysis
  - 10 newtowns in Hiroshima city
    - Confirming the existence of endogenous effects
    - But, the degree of endogenous effects are not big enough to cause multiple equilibria
      - The situation is not like "collective decisions" through equilibrium selection

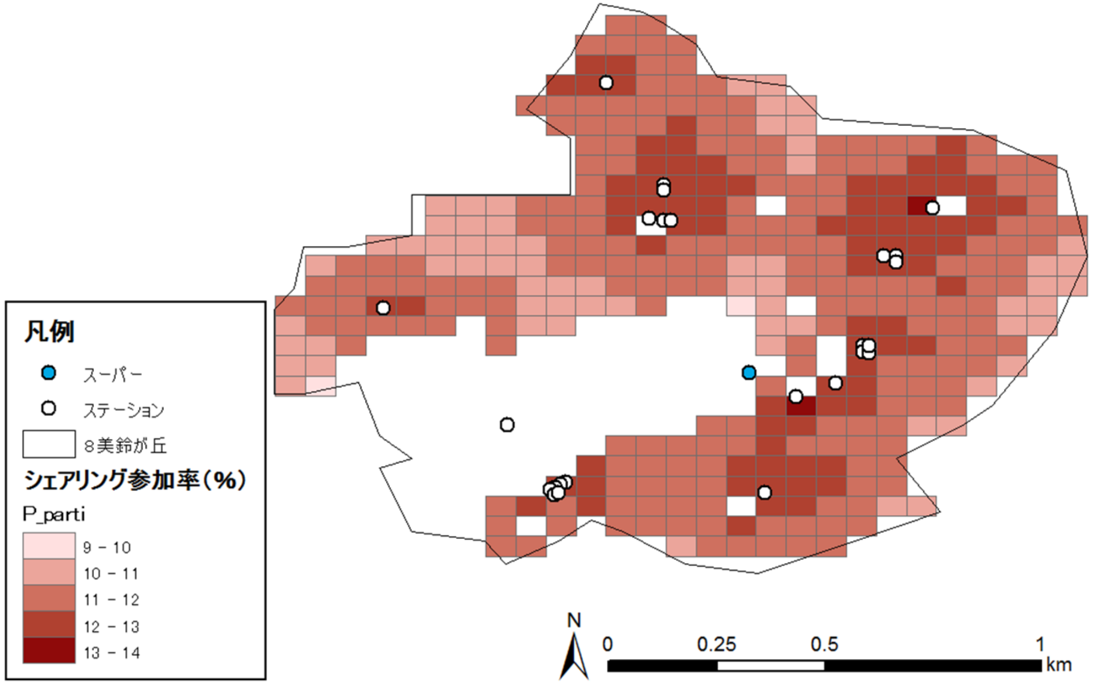
Future works

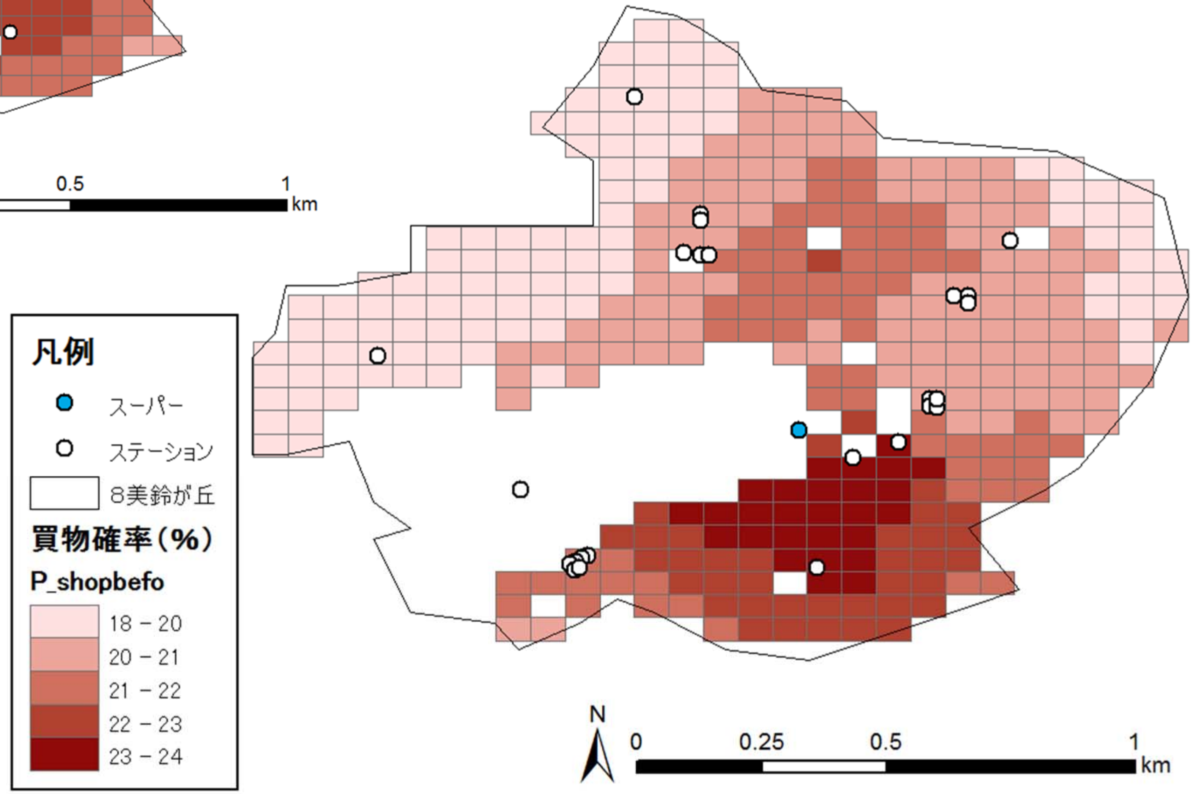
- Separating market interactions and non-market interactions
  - Interpretation of interactions, and possible policy discussions
- Modeling residents' shopping behavior from outside of newtown
  - Modeling trip chaining
- Modeling frequency of shopping trips and money they spent
  - Elderly may less participate in shopping activities
- Applying the model to evaluate the impacts of improving transportation system in newtown

Future tasks



Initial trial





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