Modelling of Tsunami Evacuation Behavior Accounting for Dynamics of Heterogeneity in Expected Utility

BinN International Research Seminar #07

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Kobe University

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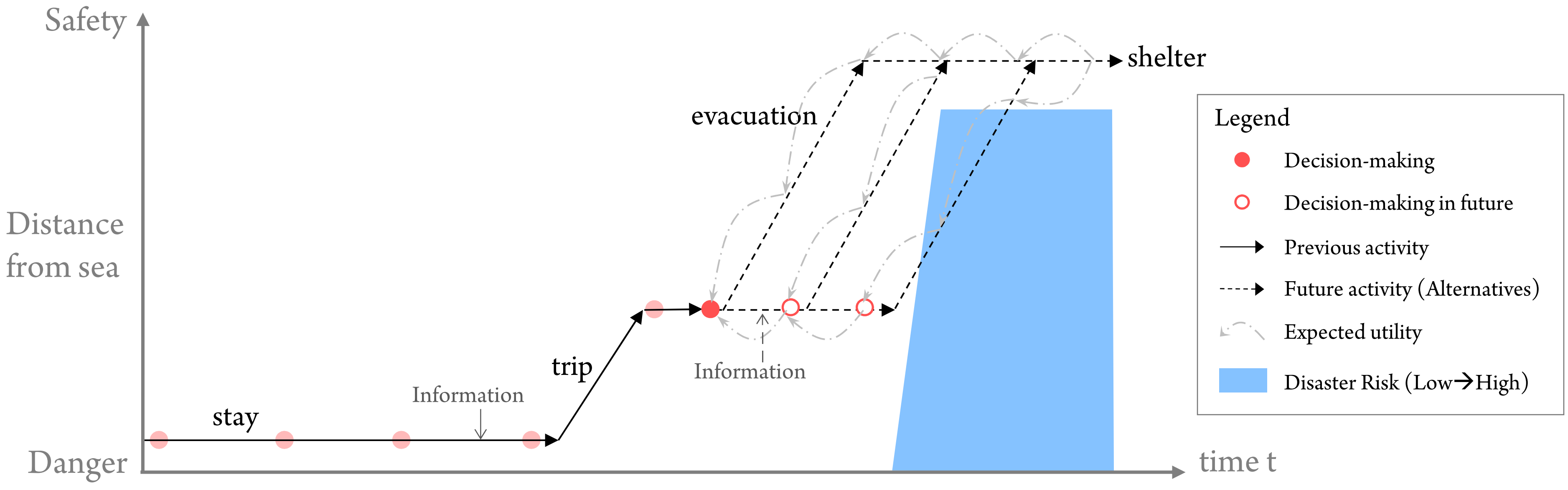
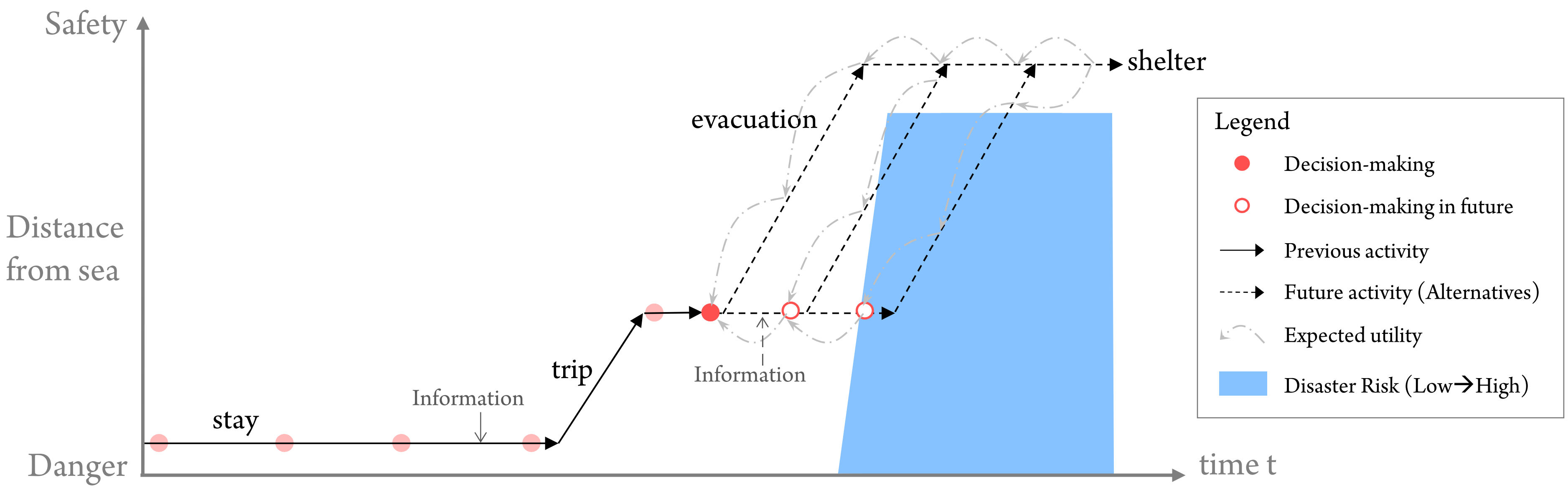
Choice of Evacuation Start Time



- The reason for evacuation is to avoid a future risk of their place.
- People choose an evacuation with an expected utility.

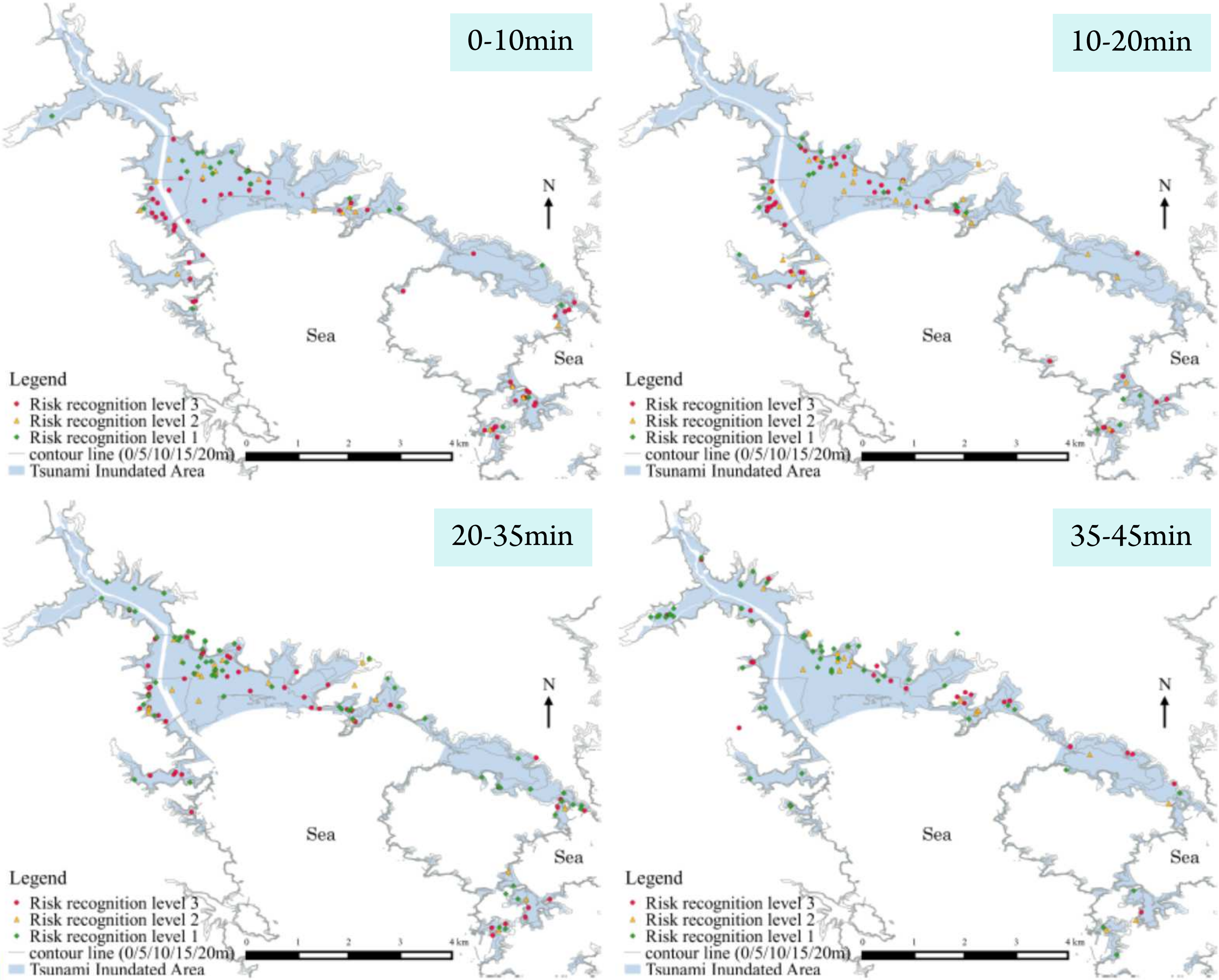
Dynamics of Heterogeneity in Expected Utility



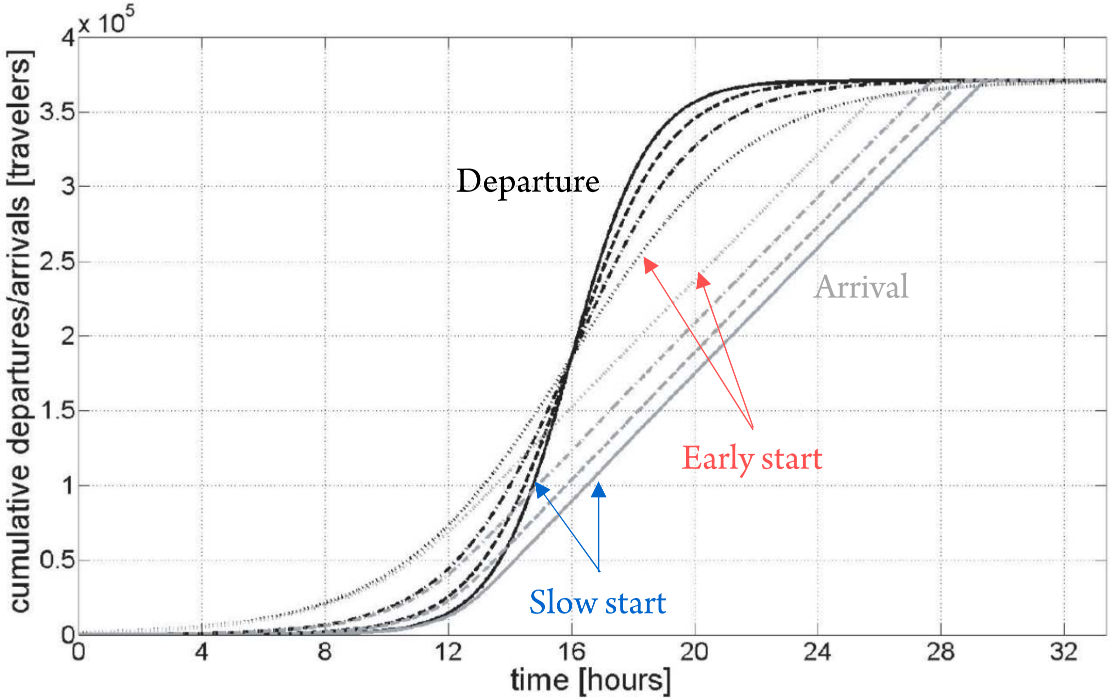
- People can't know their correct conditions under an extraordinary situation.
- However they have to decide to evacuate or not, they recognize their own expected utility and decide.
- This recognized expected utility is different from the correct one.
- The difference is defined as "Dynamics of Heterogeneity".

Difference of Recognition in Space and Time

- Dynamics of heterogeneity is influenced from space and time.
- People who stayed near a sea may recognized a low expected utility.



Importance of Evacuation Start Time



Pel et al.(2010) evaluate by DTA simulator on Rotterdam metropolitan area

- People can arrive safety places if they start to evacuate earlier and the effects will be amplified on network.
- A purpose of many disaster mitigation policies, emergency warnings and risk education, is to evacuate earlier.
- Evacuation choice model can evaluate these policies.

Purpose

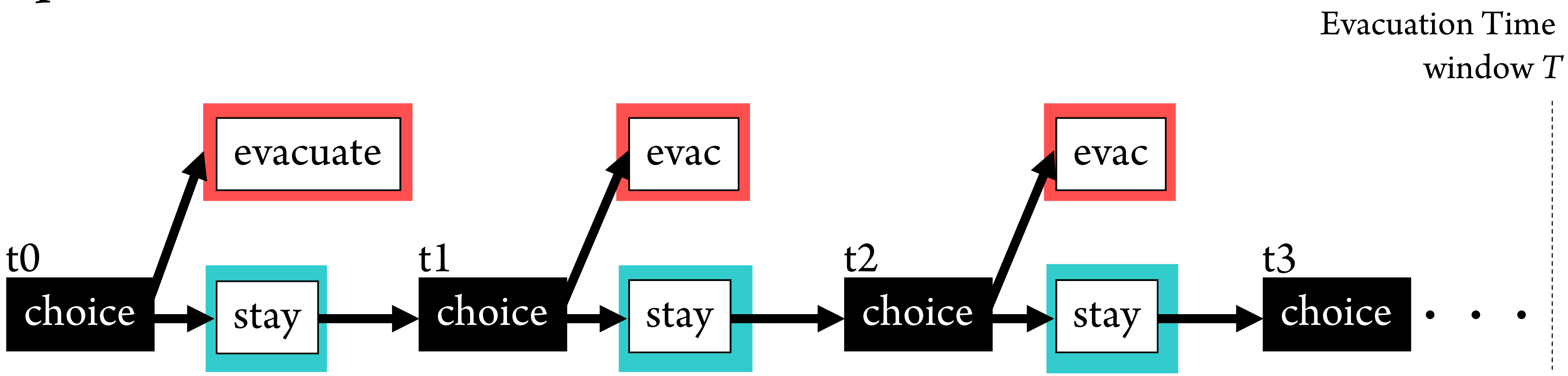
- Propose a formulation of a tsunami evacuation behavior model accounting for dynamics of heterogeneity in expected utility
- Construct an algorithm to estimate parameters of the proposed dynamic model
- Validation (parameter estimation)

Outline

- Background and Purpose
- Formulation of dynamics of heterogeneity
- Algorithm for parameter estimation
- Validation

Formulation 1: Sequential Choice

Sequential choice model Fu & Wilmot (2004)



Probability of evacuation at each time t'

$$P_{ev}(t') = P(d_{t'} = ev | x^{t'}, \theta) = \frac{\exp(v(x^{t'}, d_{t'}))}{\sum_{\forall d'} \exp(v(x^{t'}, d'_{t'}))} \quad (1)$$

Probability of evacuation at time t

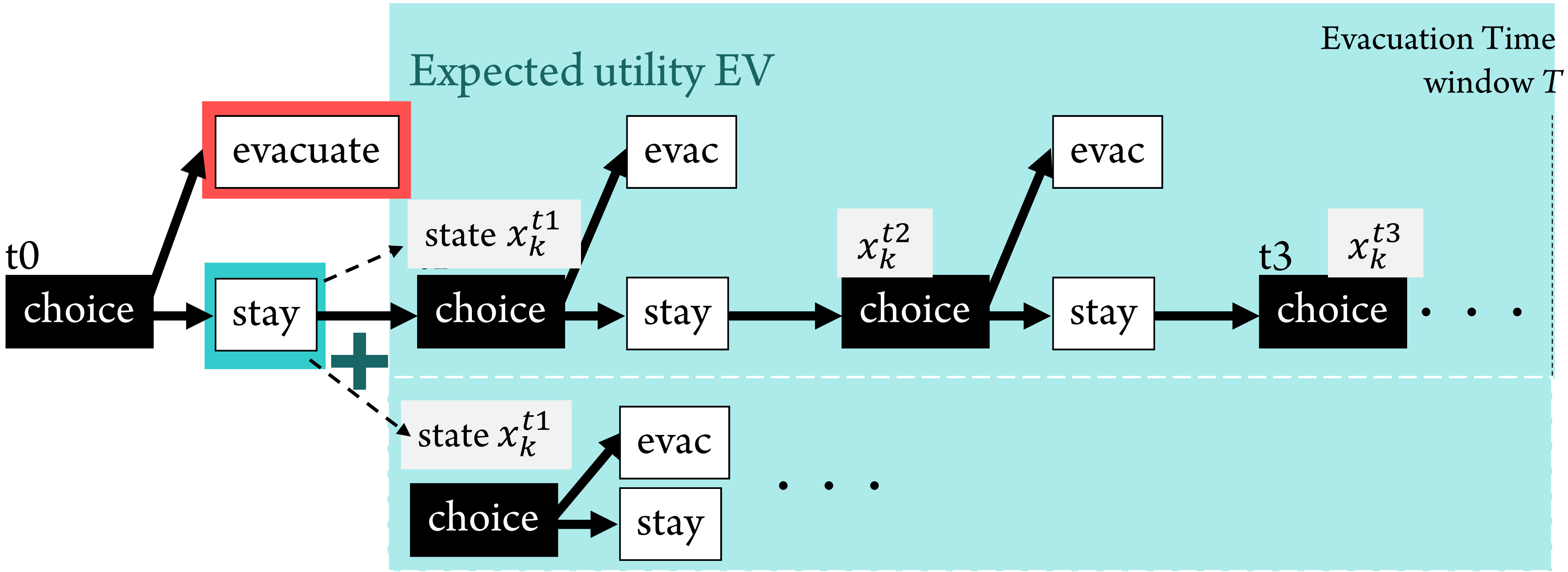
$$p_{ev}(t) = P_{ev}(t) \prod_{t'=1}^{t-1} (1 - P_{ev}(t')) \quad (2)$$

Log-likelihood

$$L(\theta) = \log \prod_{i}^{N} \prod_{t}^{T} p_{ev}(t) \quad (3)$$

d_t: choice(evacuation or not), x^t: observed state variable, θ: parameter, v: utility

Formulation 2: Expected Utility



Probability of evacuation at each time t'

$$P(d_{t'} = ev | x^{t'}, \theta) = \frac{\exp(v(x^{t'}, d_{t'}) + \beta EV(x^t, d_{t'}))}{\sum_{\forall d'} \exp(v(x^{t'}, d'_{t'}) + \beta EV(x^t, d'_t))} \quad (4)$$

Expected utility EV

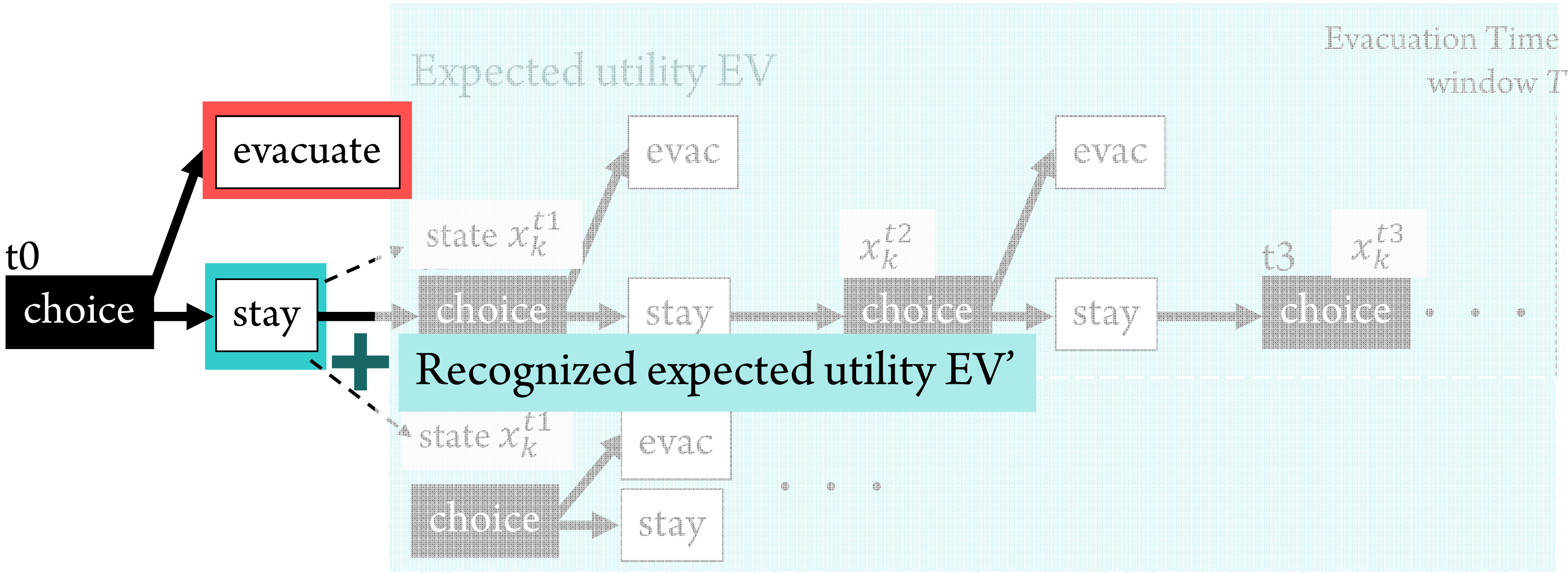
$$EV(x^t, d_t) - \sum_{j=0}^{J} \left\{ \left(\log \left(\sum_{\forall d'} \exp \left(v(x_j^{t+1}, d') + \beta EV(x_j^{t+1}, d') \right) \right) \right) \times p_3(x_j^{t+1} | x^t, d_t) \right\} = 0 \quad (5)$$

transition probability to next states x_j

utility at t+1

expected value function at t+1

Formulation 3: Dynamics of Heterogeneity



Recognized Expected utility *EV*

transition probability to next states x_j

$$EV(x^t, d_t) - \sum_{j=0}^{J} \left\{ \left(\log \left(\sum\nolimits_{\forall d'} \exp \left(v\left(x_j^{t+1}, d'\right) + \beta EV\left(x_j^{t+1}, d'\right) \right) \right) \right) \times p_3\left(x_j^{t+1} \middle| x^t, d_t\right) \right\} \neq 0 \quad (5)'$$

utility at t+1

expected value function at t+1

Formulation 4: Maximum Likelihood

- Su and Judd (2010) propose an estimation method for structural model using constrained optimization approach.
- This method regards EV as parameter in finite period problem:

$$\max_{\boldsymbol{\theta},\boldsymbol{EV}} L(\boldsymbol{\theta},\boldsymbol{EV})$$

subject to

$$c_i(\boldsymbol{\theta},\boldsymbol{EV}) = EV(x^t,d_t) - \sum_{j=0}^{J}\left\{\left(\log\left(\sum\nolimits_{\forall d'}\exp\left(v\left(x_j^{t+1},d'\right)+\beta EV\left(x_j^{t+1},d'\right)\right)\right)\right)\times p_3\left(x_j^{t+1}\middle|x^t,d_t\right)\right\} = 0 \tag{6}$$

$$i \in \forall(t,x_k,d)$$

Proposed approach

- The recognized expected utility will be similar to the correct expected utility
- This study propose that **c** is not equal to zero vector and is included in a range of constraint $\boldsymbol{\Omega}$:

$$\max_{\boldsymbol{\theta},\boldsymbol{EV'}} L(\boldsymbol{\theta},\boldsymbol{EV'})$$

$$\text{subject to} \quad \boldsymbol{c}(\boldsymbol{\theta},\boldsymbol{EV'}) \in \boldsymbol{\Omega} \qquad (\boldsymbol{\Omega}\text{ includes } \vec{0}\,) \tag{7}$$

Formulation 5: Range of Constraint

- Specialize the range of constraint for parameter estimation.
- The recognized expected utility of the respective states has a different divergence from the correct expected utility.
- This difference in the amount of divergence can be explained by this formulation :

$$\frac{\sum_{\forall i} |c_i(\boldsymbol{\theta}, \boldsymbol{EV})|}{N_c} \leq \tilde{\phi} \Leftrightarrow \sum_{\forall i} |c_i(\boldsymbol{\theta}, \boldsymbol{EV})| \leq N_c \tilde{\phi} = \Phi \qquad (8)$$

N_c: number of state i

$\tilde{\phi}$: upper constraint for the average amount of divergence from the corrected expected utility

- This setting allows the recognized expected utility to be distributed flexibly.
- The dispersion of the distribution of the recognized expected utility is more unformalized if an amount of each divergence of state i is limited : $|c_i(\boldsymbol{\theta}, \boldsymbol{EV})| < \phi_{max}, \forall i.$
- The analysis of distributions of *EV'* clarify a tendency of people to recognize the future states because this approach obtain *EV'* like a non parametric method.

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Proposed algorithm for parameter estimation

Proposed problem $\max_{\boldsymbol{\theta}, \boldsymbol{EV}'} L(\boldsymbol{\theta}, \boldsymbol{EV}')$

$$\text{subject to} \quad \sum_{\forall i} |c_i(\boldsymbol{\theta}, \boldsymbol{EV})| \leq \Phi \tag{9}$$

- However the inequality constraint is a non-linear function.
- Number of parameters is more than the number of constraints.
- Apply a heuristic algorithm to solve and obtain a local optimum.
- Proposed algorithm is based on SQP (sequential quadratic programming) and .

Apply SQP method

Primal Problem : Reformulated by using an exact penalty function as:

$$\min_{\gamma^k}\left(A(\gamma^k) + r^k \max(\sum_i |c_i| - \Phi, 0)\right) \quad (10)$$

$\gamma = (\theta, EV), A = -L$

k: number of iteration

r: penalty parameter

Update: $\gamma_{k+1} = \gamma_k + \alpha_k s_k$ (11)

Descent direction s_k

γ_k

Sub problem for the optimal search direction

$B^k(\gamma^k)$ hessian matrix of the Lagrangian function defined in the equation (9)

$$\min_{s_k} \nabla A(\gamma^k)^T s_k + \frac{1}{2} s_k^T B^k(\gamma^k) s_k \quad (12)$$

$$\text{subject to} \quad g(\gamma^k) + \nabla g(\gamma^k) s_k \leq 0$$

$$(g(\gamma^k) = \sum |c_i(\gamma^k)| - \Phi)$$

This equation (12) is reformulated the quadratic problem of s_k with no constraints.

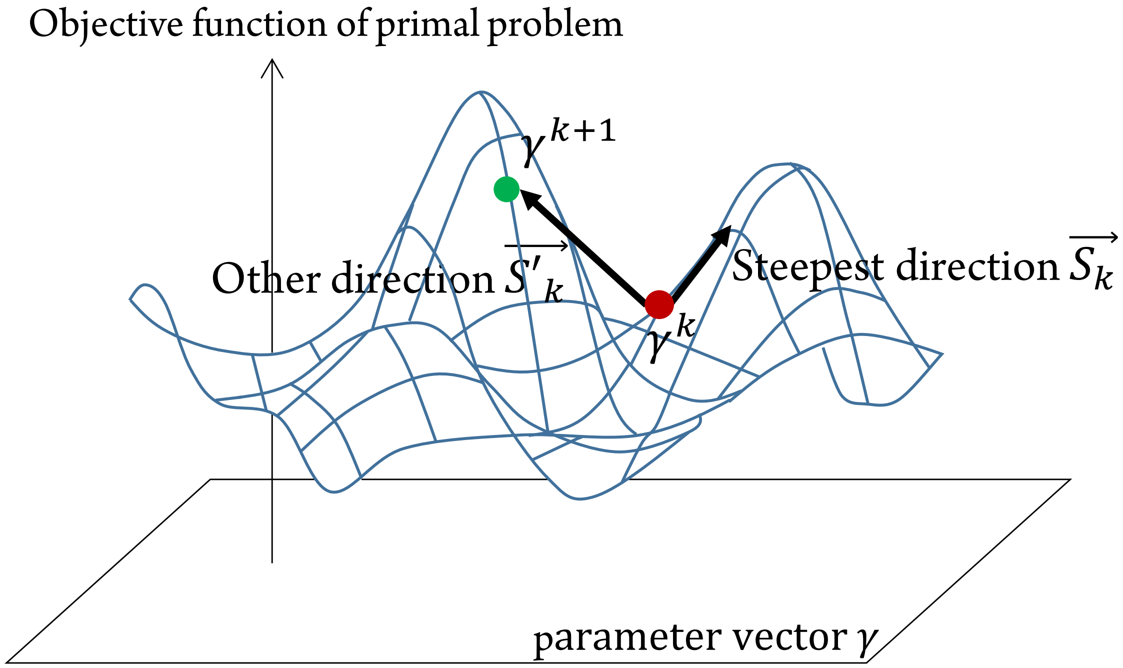
$$Q_b(s_k) = (\nabla A(\gamma^k)^T s_k + \frac{1}{2} s_k^T B^k(\gamma^k) s_k) + \frac{b_1}{2} (\max(g(\gamma^k) + \nabla g(\gamma^k) s_k, 0))^2 \quad (13)$$

Steepest descent direction $d_k = -\nabla Q_b(s_k)$ (14)

Line search $s_{k+1} = s_k + a_k d_k$ (15)

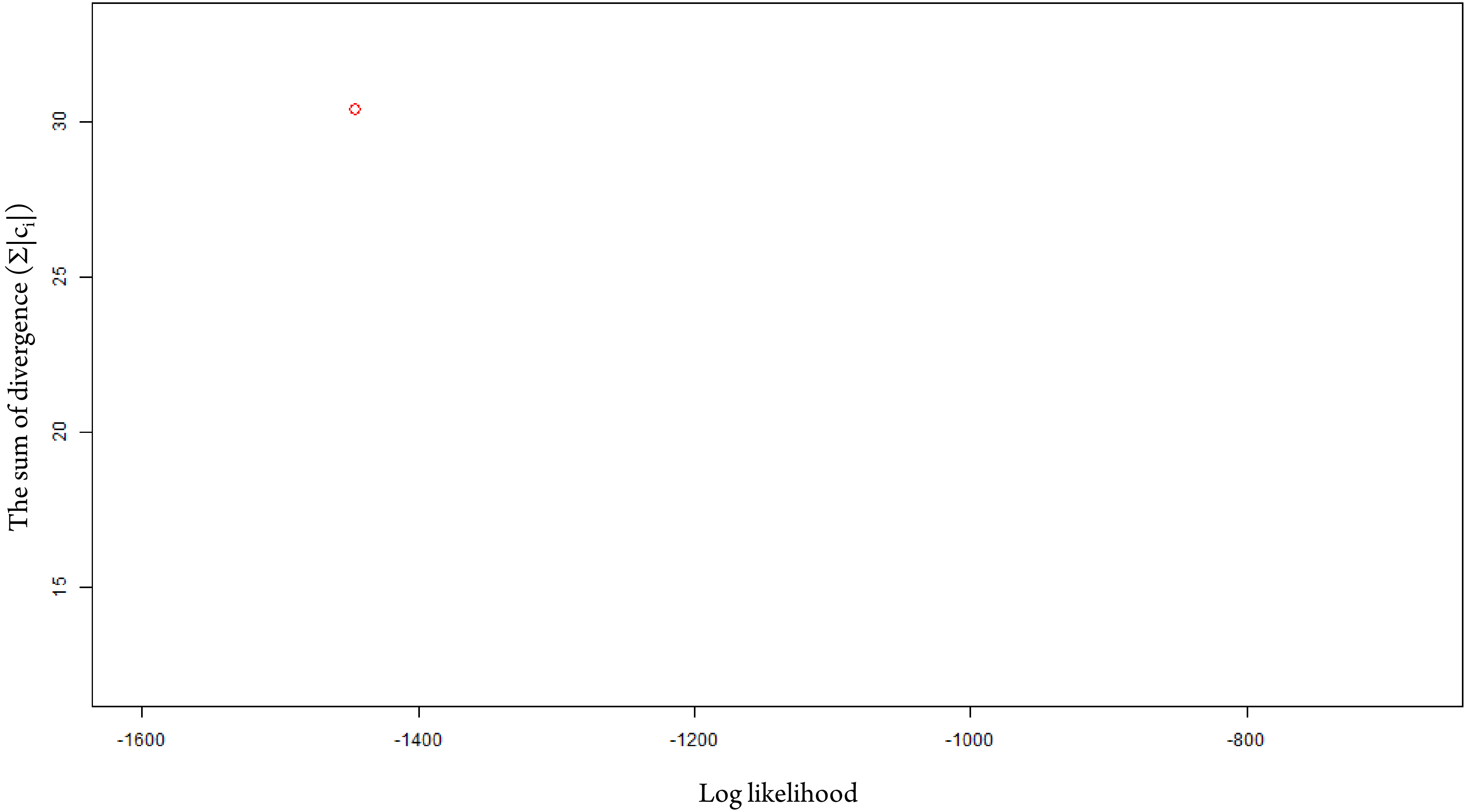
Avoid the convergence to a local solution

- The problem with non-linear constraints have many local solutions
- Proposed algorithm add other direction for avoiding the convergence to one local solution
- This heuristic searching algorithm is iterated and obtain the best solution



Example of Calculation Process

Computer : Intel Core(TM) CPU i5-4200M @ 2.50GHz & RAM 8.00GB
Language : C   One iteration : 5~60second



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Damage of Rikuzentakata city

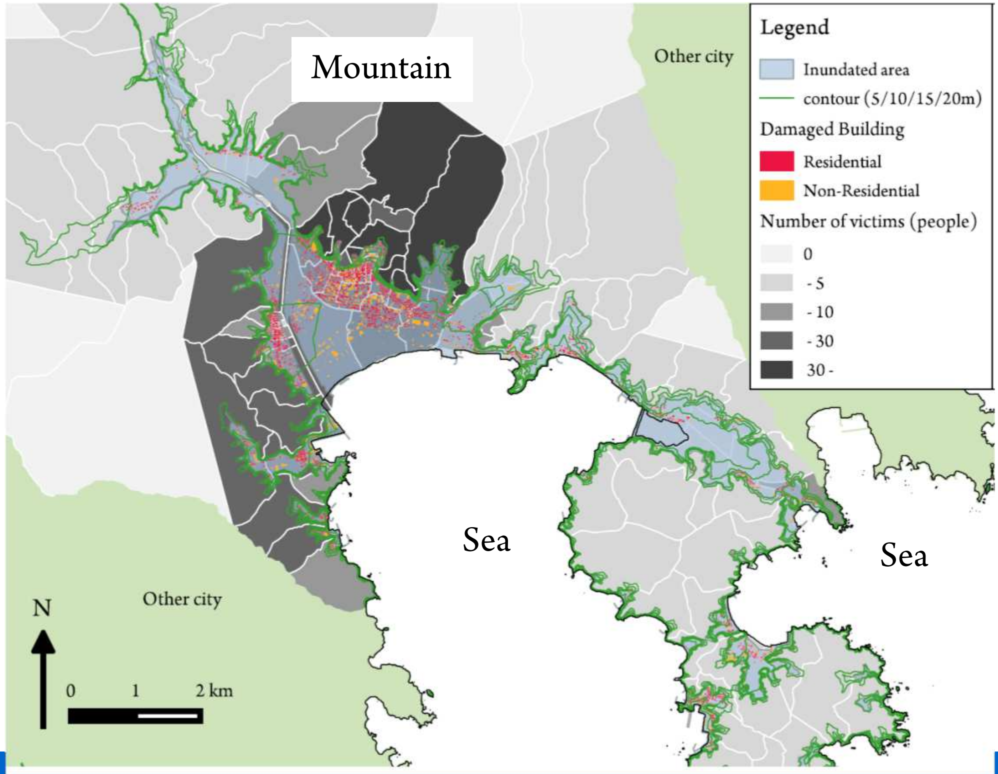
Damages of the city

population (people)	24,246
dead and missing (people)	1,732
Flooded area (km^2)	13
Structural damage to houses (houses)	3,368

City Feature

- City has ria coast and 2km square plain area
- Tsunami reached the coast about 37 - 45 minutes at the earthquake

Maps of Flooded area and Damaged building



Surveys and Behavioral Data

Evacuation behavior data in Rikuzantakata

1. Questionnaire by MLIT (Ministry of Land, Infrastructure and Transport of Japan)

Days: September – December 2011

Respondent: 10,603 people (510 people in Rikuzentakata)

Questions: Preparation of Tsunami before the day, Evacuation behavior of the day

2. Questionnaire by University of Tokyo

Days: September 2012

Respondent: 373 people in Rikuzenntakata (31 people by face-to-face survey)

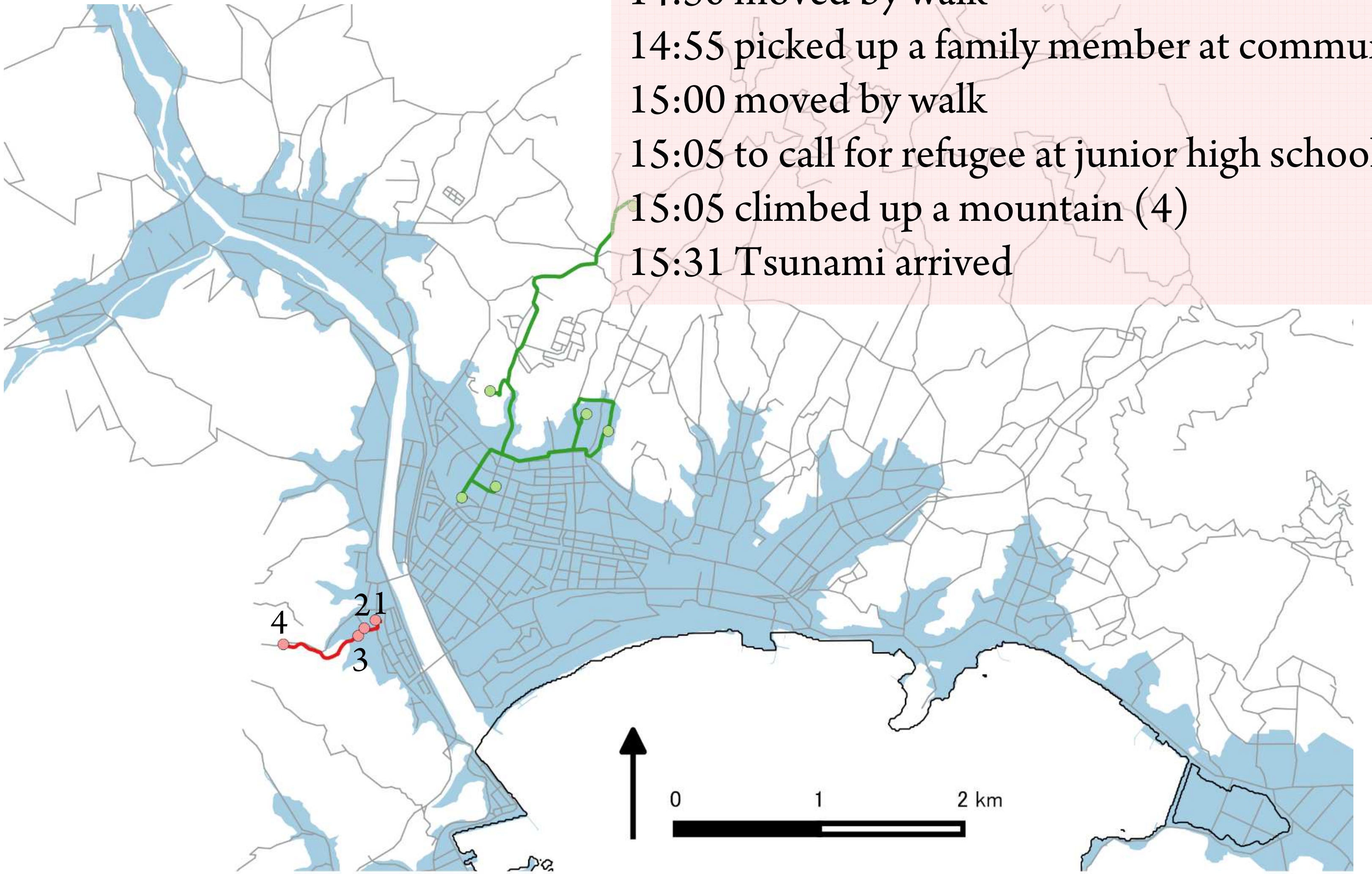
Questions: Evacuation behavior of the day

Dairy travel behavior in after-quake

Evacuation behavior of the day (Contents of Survey):
all trips after the quake; start and end time of each trip; trip purpose; route; mobility; traveling companion.

Behavior example from evacuation data

ID2: woman & elderly
14:46 (Earthquake occurred) at home (1)
14:50 moved by walk
14:55 picked up a family member at community center (2)
15:00 moved by walk
15:05 to call for refugee at junior high school (3)
15:05 climbed up a mountain (4)
15:31 Tsunami arrived



Setting: Utility function and State variables

Utility of Evacuation $v^{ev}(x_{j,t}) = \theta_{time} time_t + \theta_{dis} dis_{j,t}$

- $time_t$: Elapsed time after the quake [min] (Divide by four: 0-5; 5-15; 15-25; 25-45)
- $dis_{j,t}$: Distance from sea [m] (Divide by four: 0-400;400-1000; 1000-1500; 1500-)

Non-evacuation $v^{no}(x_{j,t}) = \theta_{wm} wm_j + \theta_{car} car_j + \theta_{with} with_j + \theta_{hm} hm_{j,t} + \theta_{old} old_j + \theta_{as} as_j$

- wm_j: Female
- car_j: Ride a car
- $with_j$: With someone
- $hm_{j,t}$: Had stayed home
- old_j: elderly
- as_j: Had assisted someone

Probability of Evacuation

$$P^{ev}(x_{j,t}, \theta) = \frac{\exp v^{ev}(x_{j,t})}{\exp v^{ev}(x_{j,t}) + \exp\left(v^{no}(x_{j,t}) + \beta EV(x_{j,t}, no)\right)}$$

Non-evacuation

$$P^{no}(x_{j,t}, \theta) = \frac{\exp\left(v^{no}(x_{j,t}) + \beta EV(x_{j,t}, no)\right)}{\exp v^{ev}(x_{j,t}) + \exp\left(v^{no}(x_{j,t}) + \beta EV(x_{j,t}, no)\right)}$$

likelihood

$$L(\theta) = \prod_j \prod_T (\delta^j_{t,ev} P^{ev} + \delta^j_{t,no} P^{no})$$

$\delta^j_{t,ev}$, $\delta^j_{t,no}$: Choice result on time *t* of individual *i*

Other Settings:

- People can choose to evacuate or not in 4 period.
- The number of observed state *i* is 386.
- EV at last period are given exogenously : EV(t4) = -0.01.
- The number of EV which are assumed as parameter is 288.
- Transition probability $p_3(x'|x_j)$ to next states is given as exogenously:
- Time discount rate is given as 0.80 exogenously.

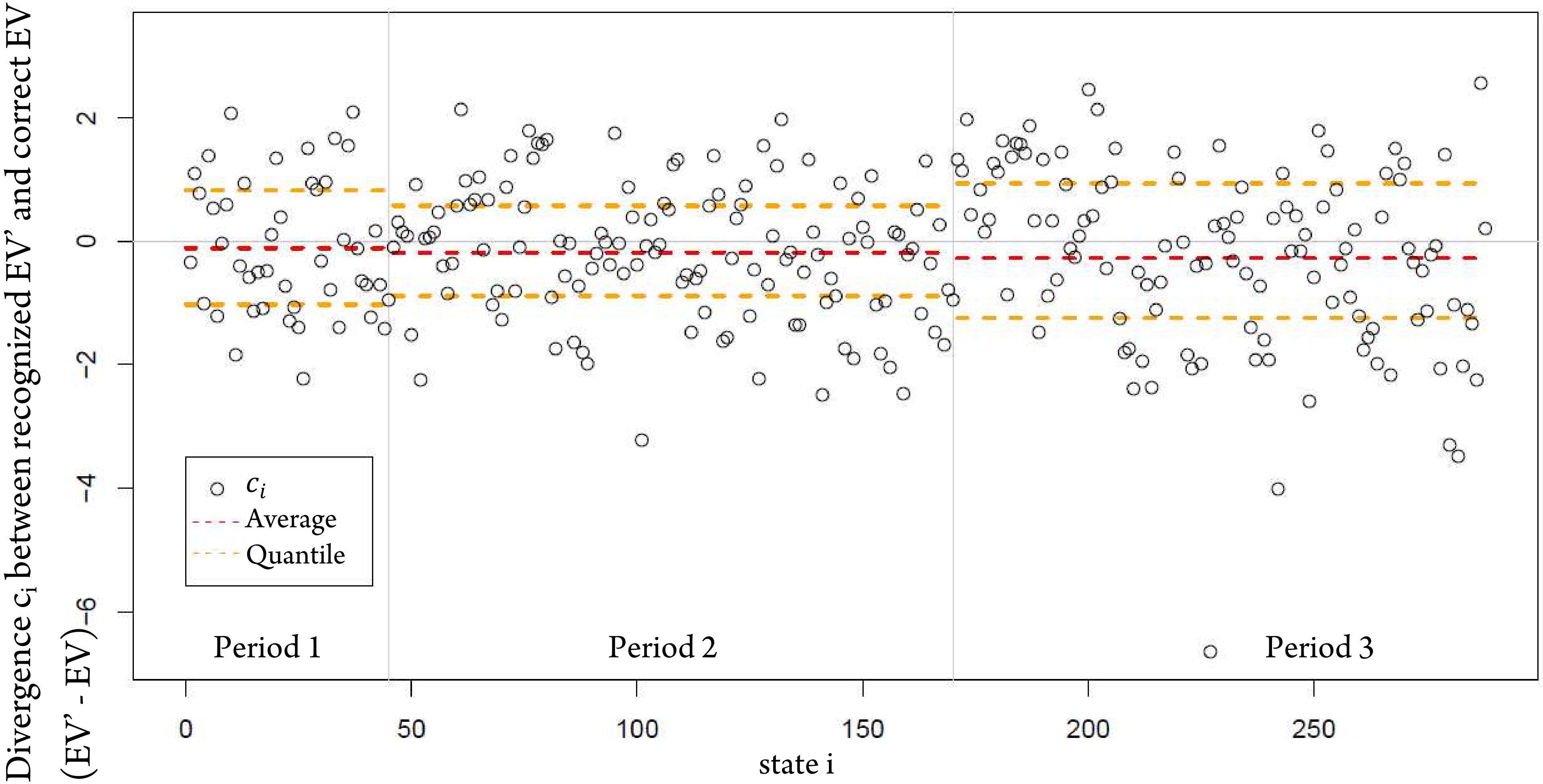
Estimation Result

Attributes	Dyanamic model & Heterogeneity($\Phi = 300$) Param.	t-Stat	Dynamic model & No heterogeneity Param.	t-Stat	Static model Param.	t-Stat
Elapsed time	0.584	8.27*	0.687	10.84*	0.838	12.72*
Distance from sea	-0.363	-8.04*	-0.369	-7.53*	-0.632	-14.51*
Female	0.227	1.77	-0.012	-0.09	0.426	4.98*
Ride a car	-0.039	-0.32	-0.087	-0.71	0.557	4.84*
With someone	-0.737	-4.74*	-0.327	-2.08*	0.185	1.43
Had stayed home	0.253	1.92	-0.026	-0.19	0.204	1.59
Elderly	-0.144	-0.81	-0.260	-1.52	-0.341	-1.97*
Had assisted	0.120	0.77	0.437	2.99*	0.615	4.55*
Observations		1591		1591		1591
Likelihood at 0		-1102.8		-1102.8		-1102.8
Final likelihood		-643.0		-732.0		-885.8
ρ^2		0.417		0.336		0.197
Adjusted ρ^2		0.410		0.328		0.190

*: significant at 0.05

Distribution of recognized expected utility

- Decrease of average shows that people evaluate a low expected utility by time.
- Wider distribution in period 3 shows that people recognized the different future in more urgent situation.



Size of constraint range Φ

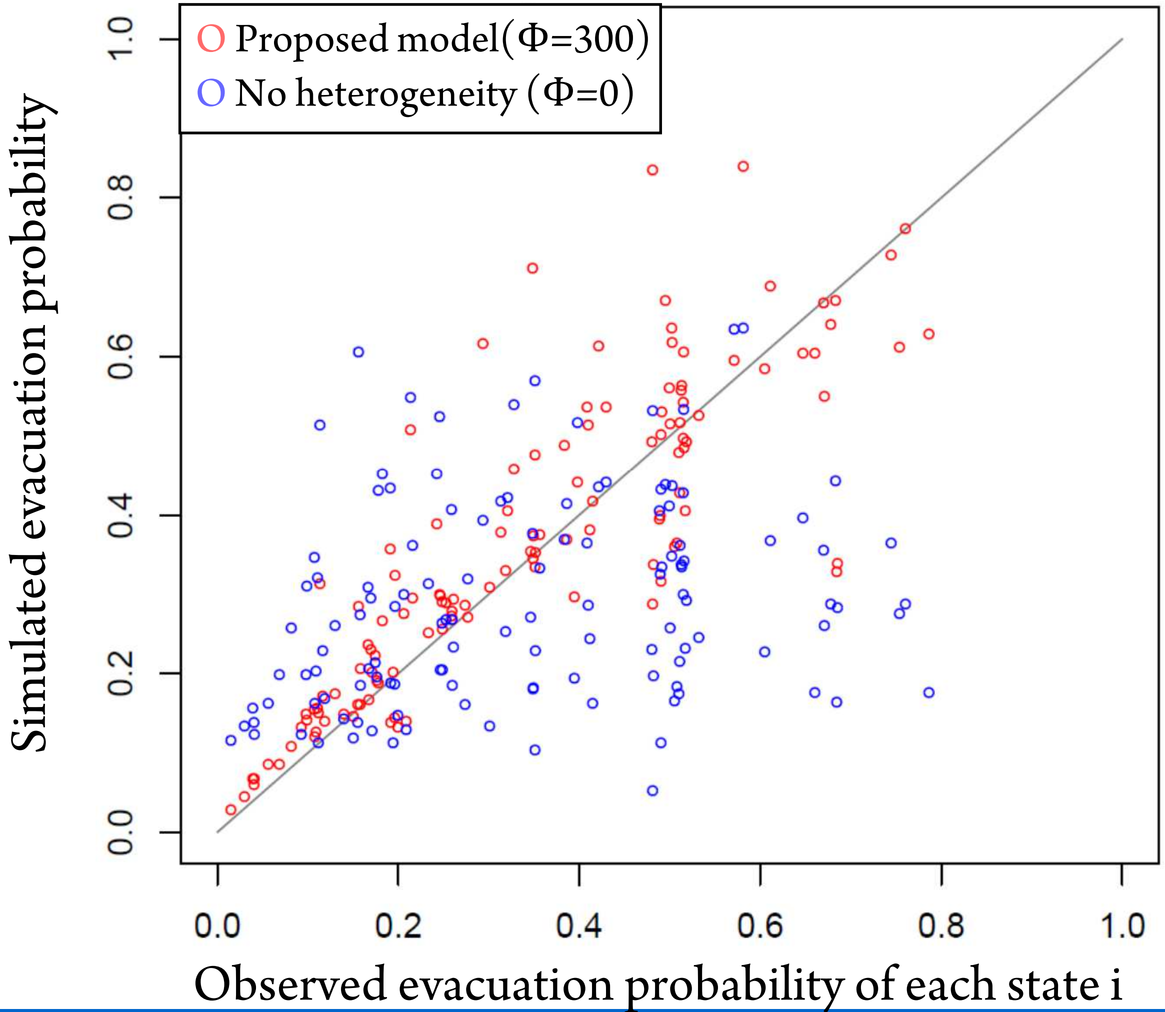
- "Φ = 400" is similar to a result of no constraint because the estimation result is far from the border of "Φ = 400".
- "Φ = 100" is a severe constraint because the s.d. of period 3 is small.
- Choose "Φ = 300" because the case is fitter.

Table Compare with the size of constraint range Φ

Value of Φ		0	100	200	300	400
Final likelihood		−732.0	−688.2	−657.5	−643.0	−630.9
Divergence c_i between recognized EV' and correct EV (EV'-EV)						
Period 1	Ave.	-	−0.17	−0.10	−0.10	−1.18
	s.d.	-	0.52	0.88	1.10	1.68
Period 2	Ave.	-	−0.21	−0.32	−0.18	0.12
	s.d.	-	0.38	0.71	1.08	1.65
Period 3	Ave.	-	0.11	−0.24	−0.26	−0.31
	s.d.	-	0.42	1.35	1.76	2.32

Flexibility for simulation

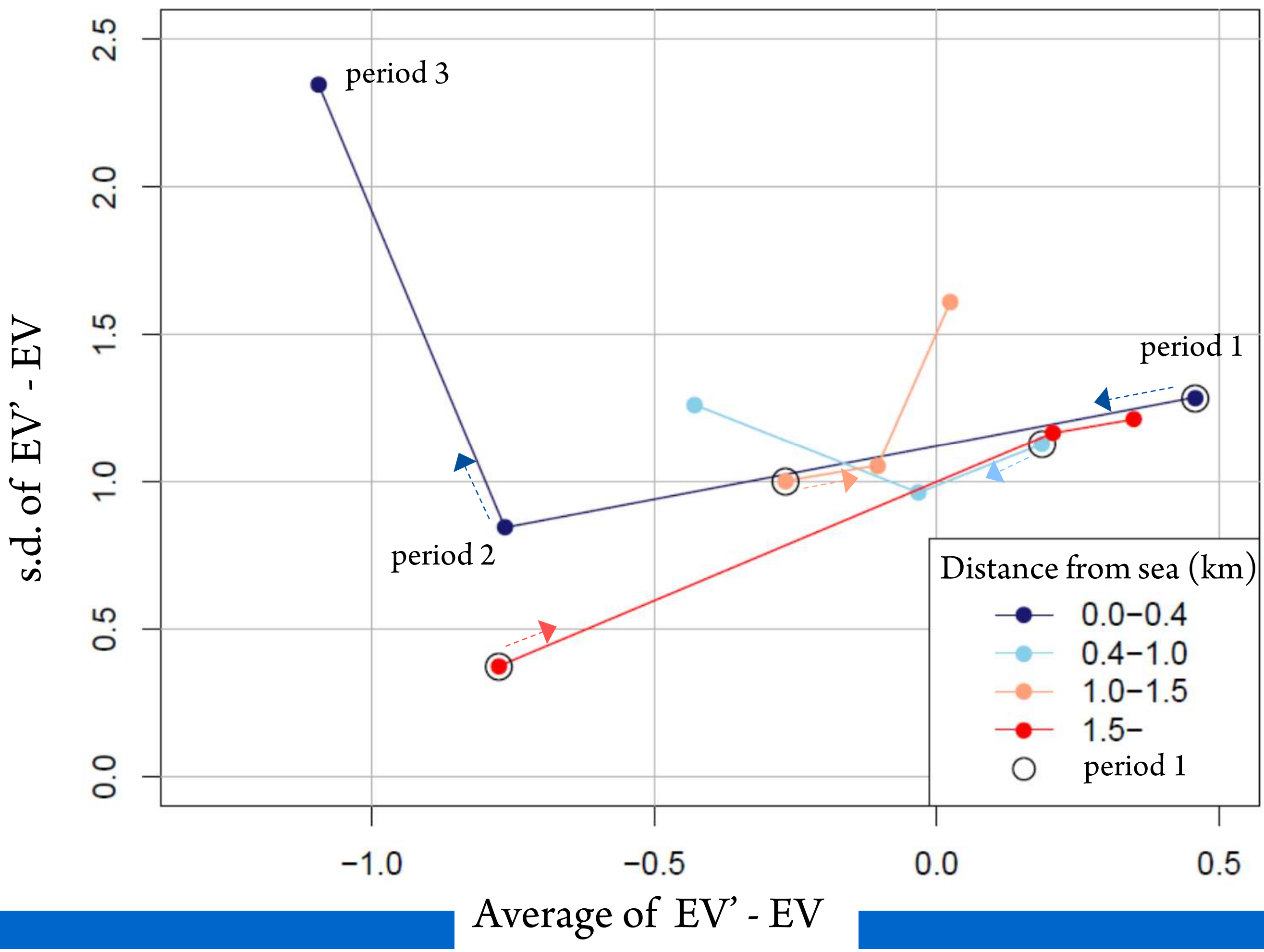
- Simulated probabilities by proposed model are closer to observed probabilities
- Proposed model have a flexibility of evaluation because of its less-parametrically



Transition of EV' in Space

Near sea : People gradually had small expected utility ; had small s.d. in period 2

Far from sea : People gradually had big expected utility and had big s.d.



Conclusion

Conclusions

- Formulate a dynamic discrete choice mode with dynamics of heterogeneity.
- Algorithm for parameter estimation can avoid the convergence to a local optimum.
- Proposed model provides a better goodness of fit and show the spatial and temporal characteristics of dynamics of heterogeneity.

Future works

- Need a sophisticated approach for exogenous variables :range of constraints, time window, transition probability and line search vector.
- The EV' in final period should be distributed, like a MXL model, to express time windows which people recognized are distributed.
- The dataset has only behaviors of survived people.

Thank you for your listening.

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