Bounded Rationality in Travel Behavior Modeling

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What is “Rationality”?

1. Instrumental Rationality

2. Procedural Rationality

3. Expressive Rationality

Instrumental Rationality

- "Rational individuals" can 1) set the goals, 2) evaluate the alternatives according to the goals, and 3) rank the alternatives by the preference order.
- Rationality is defined as the "instrument" to achieve the goals.
- Since the preference rank is given by the order of "utility", rational individuals are expressed as the utility maximizers.
- It assumes that individuals 1) have all the attributes values in the utility functions of all the available alternatives, 2) know the probability distribution of the uncertain consequences, and 3) maximize the expected utility.

Critiques to Instrumental Rationality

- Many important decisions do not seem to use the instrumental rationality.
  - e.g., Follow traditional customs, other people's decision, fortune-tellers, etc.
- Social psychologists have shown many counter-examples in experimental environments.
  - Allais paradox, Ellsberg paradox, Framing effect, etc.
- Difficult to describe the information acquisition behavior.
  - When to stop obtain new information is very difficult to describe by instrumental rationality because information is highly heterogeneous.

Alternative Rationality: Procedural Rationality

- Acquisition and processing of information for decision makings require human resources.
  - A chosen alternative may not be the optimum in terms of achieving the goal, but may be the best decision if the information processing cost is considered.
  - "Satisfaction" may be more reasonable than optimization in the context of achieving the goals.
- "Bounded Rationality" (Simon, 1987) is a typical example of this category.
- "Following the social norm" may be categorized in this type of rationality.

Alternative Rationality: Expressive Rationality

- "Choice" itself can be an objective rather than achieving the goals.
- "Resolving cognitive dissonance" (Festinger, 1957) is a typical example of this category.
  - An individual who holds conflicting attitudes and behaviors feels uncomfortable and is motivated to resolve the dissonance by changing either attitudes or behaviors.

Bounded Rationality vs. Instrumental Rationality

Simon (1987) set up the following theoretical frameworks in contrast with the instrumental rationality.

(1) The choice set generation process should be explicitly considered rather than assuming the prespecified set.

(2) Heuristics should be considered to cope with the uncertainty of the consequences rather than assuming the prespecified probability distribution.

(3) The principle of satisfaction should be used rather than maximization of expected utility.

Review of Decision-Making Strategies (1)

Let's assume that every alternative is described by multiple attributes.

(1) Additive Rule

The utility of an alternative is given by the weighted sum of attribute values.

$$U_n(i) = b_1 X_{1n}(i) + b_2 X_{2n}(i) + \cdots + b_K X_{Kn}(i)$$

This rule is usually employed in utility maximization models.

Review of Decision-Making Strategies (2)

(2) <u>Rule of Maximizing Number of Attributes with Greatest Attractiveness</u>

Compare an attribute one by one among alternatives and choose the alternative with the greatest number of attributes that are most attractive.

3 Wins

Alt.1	$X_{1n}(1)$	$X_{2n}(1)$	$X_{3n}(1)$	$X_{4n}(1)$	$X_{5n}(1)$
	$\succ$	$\prec$	$\succ$	$\succ$	$\prec$
Alt.2	$X_{1n}(2)$	$X_{2n}(2)$	$X_{3n}(2)$	$X_{4n}(2)$	$X_{5n}(2)$

2 Wins

⇨ Alt.1 will be chosen.

Review of Decision-Making Strategies (3)

(3) Conjunctive Rule

The minimum requirement is assigned to each attribute and the alternatives that pass the requirements for all the attributes are chosen.

Alt.1	$X_{1n}(1)$	$X_{2n}(1)$	$X_{3n}(1)$	$X_{4n}(1)$	$X_{5n}(1)$
Alt.2	$X_{1n}(2)$	$X_{2n}(2)$	$X_{3n}(2)$	$X_{4n}(2)$	$X_{5n}(2)$
Alt.3	$X_{1n}(3)$	$X_{2n}(3)$	$X_{3n}(3)$	$X_{4n}(3)$	$X_{5n}(3)$

Red circled attributes satisfy the minimum requirement.

⇨ Alt.2 will be chosen.

Review of Decision-Making Strategies (4)

(4) Disjunctive Rule

The satisfactory level is assigned to each attribute and the alternatives that pass the satisfactory levels for any attributes are chosen.

Alt.1	$X_{1n}(1)$	$X_{2n}(1)$	$X_{3n}(1)$	$X_{4n}(1)$	$X_{5n}(1)$
Alt.2	$X_{1n}(2)$	$X_{2n}(2)$	$X_{3n}(2)$	$X_{4n}(2)$	$X_{5n}(2)$
Alt.3	$X_{1n}(3)$	$X_{2n}(3)$	$X_{3n}(3)$	$X_{4n}(3)$	$X_{5n}(3)$

Red circled attributes satisfy the satisfactory levels.

⇨ Alt.2 and Alt.3 will be chosen.

Review of Decision-Making Strategies (5)

(5) Lexicographic Rule

Assume that all the attributes can be sorted by the order of importance. The most important attribute is compared among all the alternatives and the champion will be chosen. If some alternatives are tied, then the second most important attribute will be compared, and so on.

Importance	1	2	3	4	5
Alt.1	$X_{1n}(1)$	$X_{2n}(1)$	$X_{3n}(1)$	$X_{4n}(1)$	$X_{5n}(1)$
	$\approx$	$<$			
Alt.2	$X_{1n}(2)$	$X_{2n}(2)$	$X_{3n}(2)$	$X_{4n}(2)$	$X_{5n}(2)$
	$>$				
Alt.3	$X_{1n}(3)$	$X_{2n}(3)$	$X_{3n}(3)$	$X_{4n}(3)$	$X_{5n}(3)$

⇨ Alt.2 will be chosen.

Review of Decision-Making Strategies (6)

(6) Elimination by Aspects (EBA)

Every attribute is screened by whether it has a certain aspect (e.g., “fare is less than 300 yen”, “can easily carry baggage”) and alternatives that don’t have the aspect are eliminated until the last alternative remains.

The order of attributes screened is not fixed but the attribute is chosen according to the probability that is proportional to the importance of attributes.

Compensatory and Non-Compensatory Rules

- By the compensatory rules, low-scored attributes of an alternative can be compensated by high-scored attributes, and vice versa.
  - e.g., high price of a car is compensated by its luxuriousness.
- By the non-compensatory rules, low-scored attributes of an alternative cannot be compensated by high-scored attributes, and vice versa.
  - e.g., omnibus type of transport is never chosen by a certain class of people even if the fare is very low.
- Rules (1) and (2) are compensatory while rules (3), (4), (5) and (6) are non-compensatory.

Choice Contexts and Decision-Making Strategies

- Which strategy is used will depend on the significance of the choice consequence and the magnitude of information processing load.
- In choice contexts of small number of alternatives, compensatory rules tend to be used.
- When the number of alternatives is large, non-compensatory rules may be employed to reduce the number of alternatives that will be considered more carefully, e.g., by compensatory rules. (Decision with mixed strategies)
  - e.g., in choosing the type and model of cars, a single attribute such as size of the engine is focused on to reduce the size of the choice set.

Bounded Rationality and Random Utility Models

- The framework of random utility models (RUM):

$$U_n(i) = V_n(i) + \varepsilon_n(i)$$

- The random term $\varepsilon_n(i)$ represents the unknown factors to the analyst. Those factors may include the decision strategy that the decision maker actually took.
- In that sense, it might be said that RUM can approximate the unknown decision strategies.
- But the additive form in the systematic part of the utility may contain a too strong assumption.

A Modeling Framework for Bounded Rationality

- A probabilistic choice model with latent classes:

$$P_n(i) = \sum_{s \in S} P_n(i|s) Q_n(s)$$

$P_n(i)$: Probability that individual *n* chooses alternative *i*

$P_n(i|s)$: Probability that individual *n* chooses alternative *i* given that *n* belongs to latent class *s*

$Q_n(s)$: Probability that individual *n* belongs to latent class *s*

S : Set of latent classes

Latent Choice Set Models

- Two-stage models with choice set formation (Manski 1977):

$$P_n(i) = \sum_{C \in G} P_n(i|C) Q_n(C)$$

$P_n(i)$: Probability that individual *n* chooses alternative *i*

$P_n(i|C)$: Probability that individual *n* chooses alternative *i* from choice set *C*

$Q_n(C)$: Probability that individual *n*'s choice set is *C*

G : The set of all the possible choice sets except null set

The choice model and choice set formation model may have different decision-making strategies.

Choice Set Formation Models

- Independent availability model (Swait & Ben-Akiva, 1987):

$$Q_n(C) = \prod_j \left\{ q_n(j)^{d_{jC}} \left(1 - q_n(j)\right)^{1-d_{jC}} \right\}$$

Conjunctive Rule

$$d_{jC} = \begin{cases} 1 : \text{if } j \in C \\ 0 : \text{otherwise} \end{cases}$$

$q_n(j)$: Probability that alternative *j* is included in the choice set

- If the choice model can be expressed by a logit model:

$$P_n(i) = \frac{1}{1 - Q_n(\phi)} \sum_{C \in G_n} \left[\frac{\exp(V_{in})}{\sum_{j \in C} \exp(V_{jn})} \prod_{j \in M_n} \left\{ q_n(j)^{d_{jC}} \left(1 - q_n(j)\right)^{1-d_{jC}} \right\} \right]$$

Latent Classes for Different Decision-Making Rules

- Classes may represent decision-making rules such as:

e.g., Logit model with linear-in-attribute utility function

$$P_n(i) = P_n(i \mid \text{compensatory}) Q_n(\text{compensatory})$$
$$+ P_n(i \mid \text{non-compensatory}) Q_n(\text{non-compensatory})$$

e.g., Semi-ordered lexicographic model

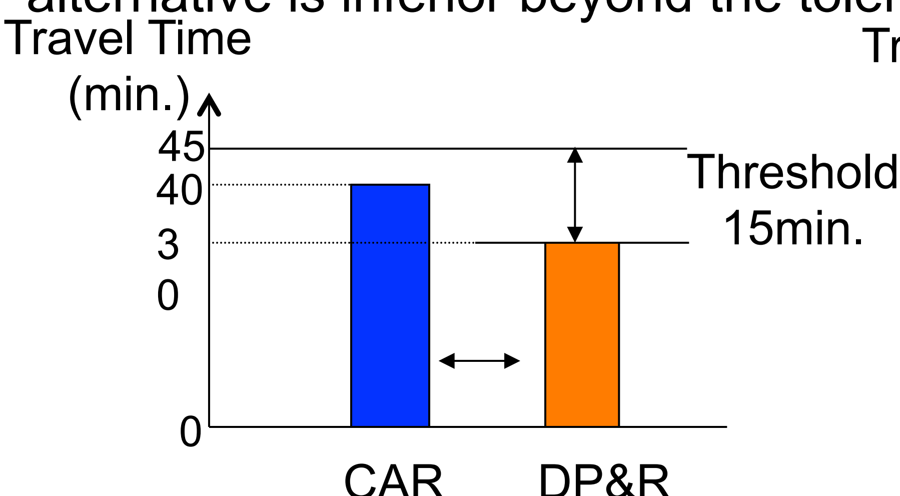
CASE STUDY #1

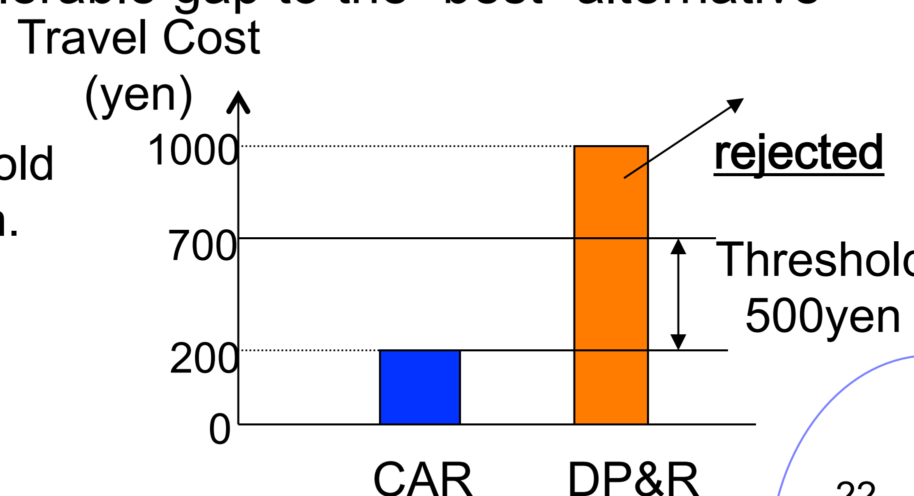
Semi-ordered Lexicographic Rule

Example: CAR vs. Dynamic Park & Ride (DP&R)

	CAR	DP&R	Importance	Threshold
t : Travel Tme	40 min.	30 min.	1	15 min.
c : Travel Cost	200 yen	1000 yen	2	500 yen.
d : Distance	-	Near	3	Far

- Evaluation is conducted in the attribute-by-attribute lexicographic order.
- An alternative is rejected if the concerned attribute value of the alternative is inferior beyond the tolerable gap to the “best” alternative





Model Formulation (1)
Relative Evaluation of Attribute Value

percentage deviated from the most desirable alternative

$$\tilde{Z}_{nil} = \frac{\max\limits_{k \in \{i,j\}} \left(X_{nkl}\right) - X_{nil}}{\max\limits_{k \in \{i,j\}} \left(X_{nkl}\right)}$$

<u>Example</u>

Car: 40min   Rail: 30min

$$\tilde{Z}_{car,time} = \frac{40-30}{30} = 0.33$$

$$\tilde{Z}_{rail,time} = \frac{30-30}{30} = 0$$

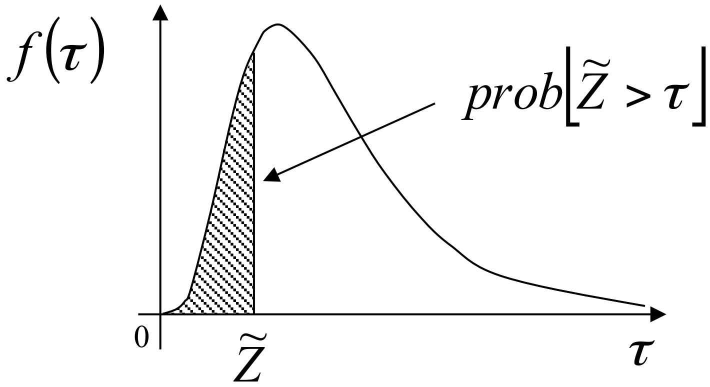
Model Formulation (2)
Threshold of Attributes

probability of alternative *i* being rejected:

$$q_{ni}(l) = prob\left[\tilde{Z}_{nil} > \tau_{nl}\right]$$

τ_{nl}: log-normal distribution

$$q_{ni}(l) = \Phi\left(\frac{ln\tilde{Z}_{nil} - \mu_l}{\sigma_l}\right)$$



Model Formulation (3)
Membership Function for Classification

The hierarchy of attributes may vary across individuals and is often unobservable for the analyst .

Probabilistic representation by Rank Logit Model

e.g.) Travel Time (t) , Travel Cost (c) , Distance to the Station (d)

Membership Function:

$$Y_{nl}^{*} = \boldsymbol{\Gamma}_l \boldsymbol{s}_{nl} + \xi_{nl}$$

Probability that Individual *n*'s First Ranked Attribute being Travel Time (*t*):

$$Q_n(t) = \frac{exp(\boldsymbol{\Gamma}_t \boldsymbol{s}_{nt})}{\sum_k exp(\boldsymbol{\Gamma}_k \boldsymbol{s}_{nk})}$$

Probability that Hierarchy of Attributes for Individual *n* being *t*, *c*, *d*:

$$Q_n(t,c,d) = \frac{exp(\boldsymbol{\Gamma}_t \boldsymbol{s}_{nt})}{\sum_{k\in\{t,c,d\}} exp(\boldsymbol{\Gamma}_k \boldsymbol{s}_{nk})} \cdot \frac{exp(\boldsymbol{\Gamma}_c \boldsymbol{s}_{nc})}{\sum_{k\in\{c,d\}} exp(\boldsymbol{\Gamma}_k \boldsymbol{s}_{nk})}$$

Model Formulation (4)
Choice Probability

$$P_n(i) = Q_n(t,c,d)\{\bar{q}_{ni}(t)q_{nj}(t) + \bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(c)q_{nj}(c) + \bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(c)\bar{q}_{nj}(c)\bar{q}_{ni}(d)q_{nj}(d)\}$$
$$+ Q_n(t,d,c)\{\bar{q}_{ni}(t)q_{nj}(t) + \bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(d)q_{nj}(d) + \bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(d)\bar{q}_{nj}(d)\bar{q}_{ni}(c)q_{nj}(c)\}$$
$$+ Q_n(c,t,d)\{\bar{q}_{ni}(c)q_{nj}(c) + \bar{q}_{ni}(c)\bar{q}_{nj}(c)\bar{q}_{ni}(t)q_{nj}(t) + \bar{q}_{ni}(c)\bar{q}_{nj}(c)\bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(d)q_{nj}(d)\}$$
$$+ Q_n(c,d,t)\{\bar{q}_{ni}(c)q_{nj}(c) + \bar{q}_{ni}(c)\bar{q}_{nj}(c)\bar{q}_{ni}(d)q_{nj}(d) + \bar{q}_{ni}(c)\bar{q}_{nj}(c)\bar{q}_{ni}(d)\bar{q}_{nj}(d)\bar{q}_{ni}(t)q_{nj}(t)\}$$
$$+ Q_n(d,t,a)\{\bar{q}_{ni}(d)q_{nj}(d) + \bar{q}_{ni}(d)\bar{q}_{nj}(d)\bar{q}_{ni}(t)q_{nj}(t) + \bar{q}_{ni}(d)\bar{q}_{nj}(d)\bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(a)q_{nj}(a)\}$$
$$+ Q_n(d,a,t)\{\bar{q}_{ni}(d)q_{nj}(d) + \bar{q}_{ni}(d)\bar{q}_{nj}(d)\bar{q}_{ni}(a)q_{nj}(a) + \bar{q}_{ni}(d)\bar{q}_{nj}(d)\bar{q}_{ni}(a)\bar{q}_{nj}(a)\bar{q}_{ni}(t)q_{nj}(t)\}$$

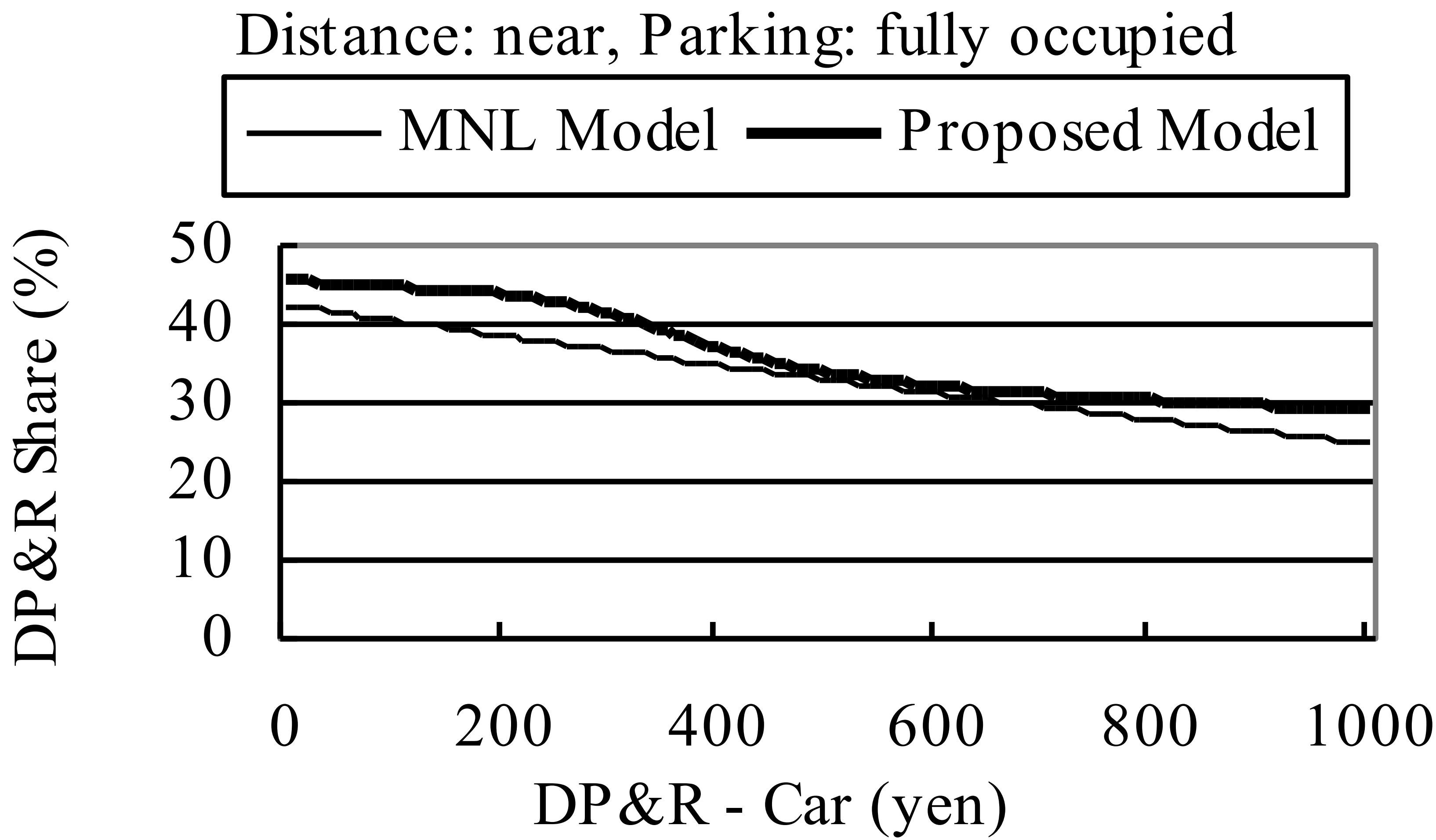
$$+ \bar{q}_{ni}(t)\bar{q}_{nj}(t)\bar{q}_{ni}(c)\bar{q}_{nj}(c)\bar{q}_{ni}(d)\bar{q}_{nj}(d)\frac{exp(V_{ni})}{exp(V_{ni}) + exp(V_{nj})}$$

All Thresholds → 0 : Non-compensatory Lexicographic Model

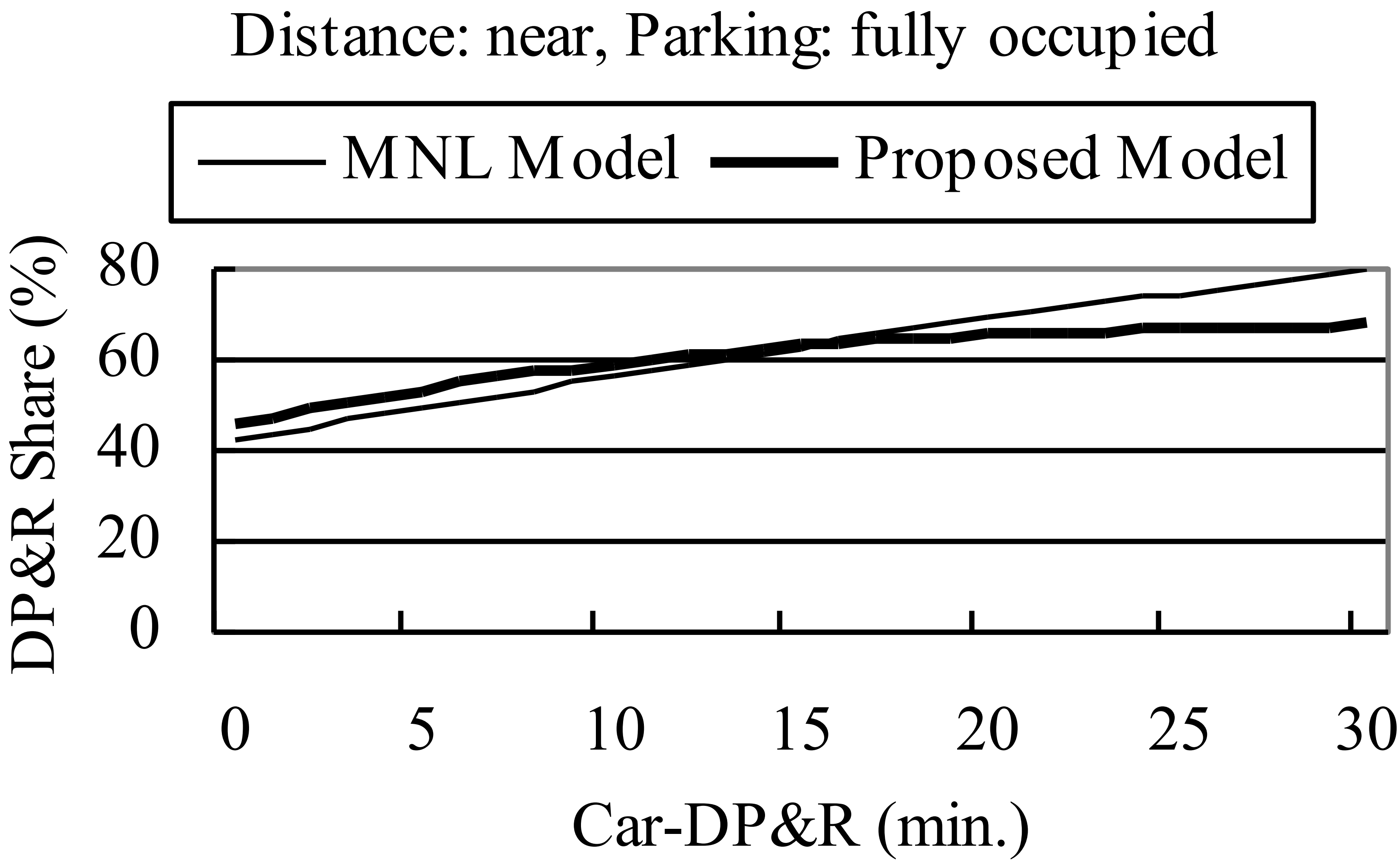
→ ∞ : Ordinary MNL Model

NU TREND Nagoya University TRansport and ENvironment Dynamics

Model Performance（1）



Model Performance(2)



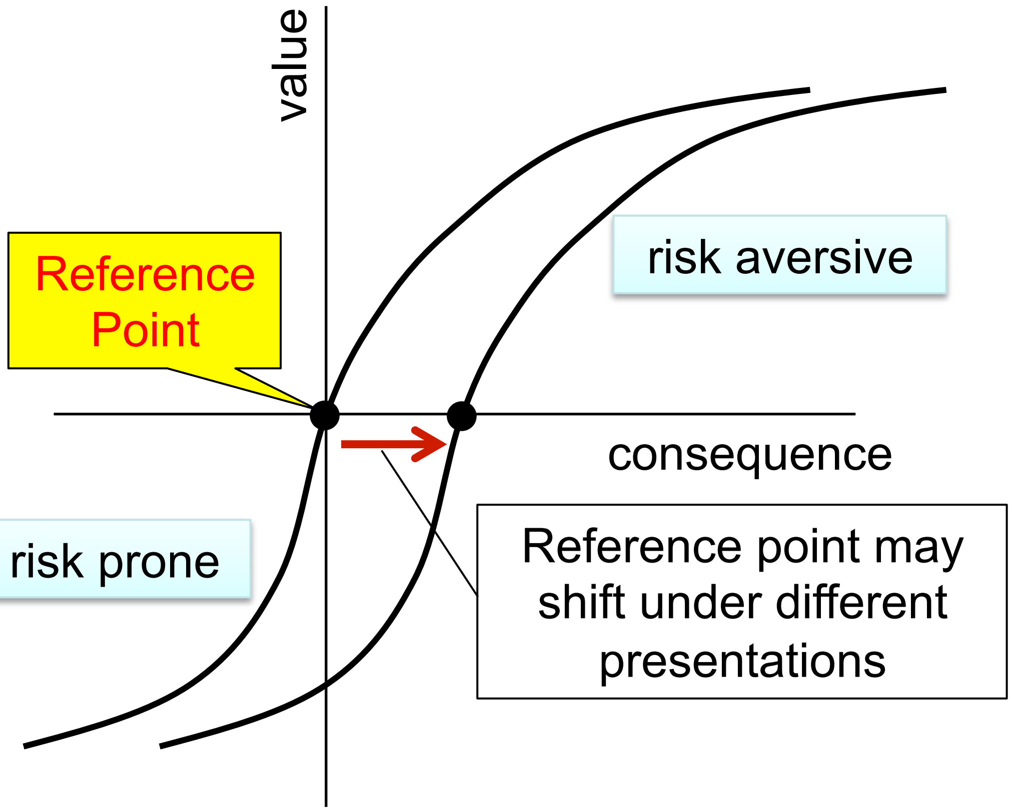
Findings from the Case Study

- Developed travel mode choice model including both compensatory and non-compensatory decision making rules.
- Analyzed model performance and confirmed that the aggregate share dramatically changes around the threshold values.

More Psychological Approach

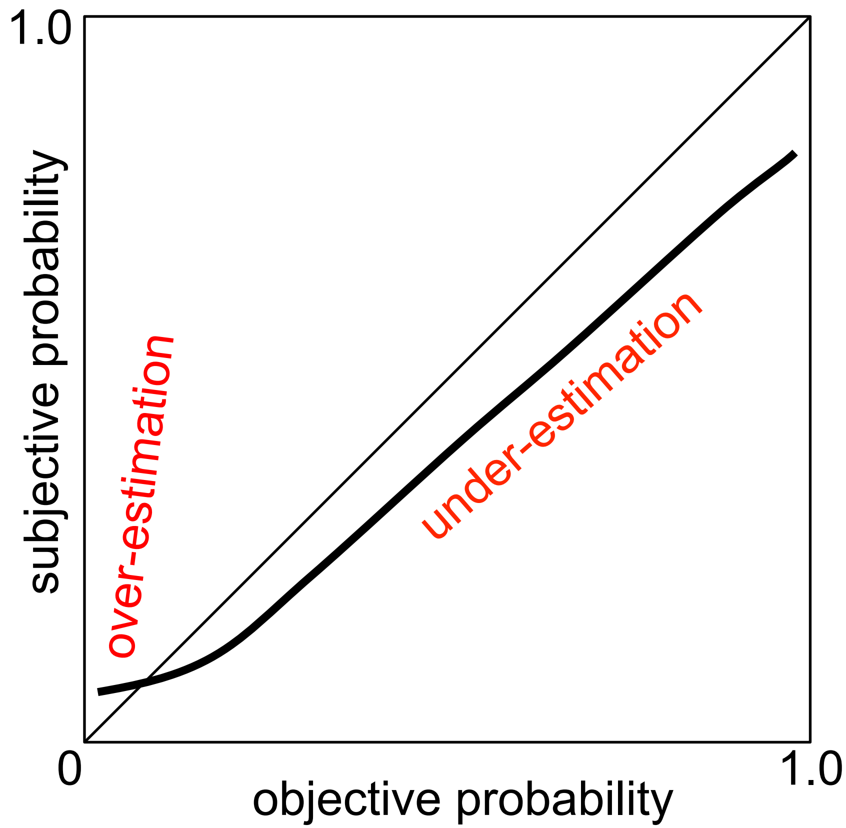
Prospect Theory (1) (Kahneman & Tversky, 1979)

- Decision-making is assumed to have two stages:
  ① Editing: cognitive process of information



Prospect Theory (2) (Kahneman & Tversky, 1979)

② Evaluating: decision under subjective consequences and subjective probability



CASE STUDY #2

Mental Accounting Theory

The total utility is composed of the “acquisition utility” and the “transaction utility” (Thaler (1985) .

Acquisition Utility

$$U = AU(\overline{p}, -p) + \beta TU(-p : -p^*)$$

Transaction Utility ：
Perceived gain or loss in transaction

where

AU : Acquisition Utility

TU : Transaction Utility

p : charged price of the good

$\overline{p}$: value of the good

p^* : refernce price of the good

β : weight

Reference Price (*P**)

Reference Price: The price that the purchaser believes to be fair.

We assume that the reference price for transit ride is equal to the fare that the riders are paying.

Objective of the Study

Analyze the effect of the Ride Point Program (RPP) (or Eco Point) in the context of discrete choice travel behavior

Tested hypothesis:

The RPP is more efficient than the ordinary fare reduction to promote ridership at the same operating cost.

Experiences from marketing research:
FFP or FSP is known as a powerful marketing tool.

Utility Change by the Two Policies

Fare Reduction: Fare p → (p-Δp)

Prior to implementation: $U^{pr} = AU(\overline{p}, -p)$

Right after impl.: $U_d^{af} = AU(\overline{p}, -(p-\Delta p)) + \beta_d TU_d(-(p-\Delta p) : -p^*)$

The reference price right after the implementation is the same as the charged fare before the implementation.（p*=p）

RPP: Fare p, Reward Δp

Prior to implementation: $U^{pr} = AU(\overline{p}, -p)$

Right after impl.: $U_p^{af} = AU(\overline{p}, -p) + \beta_p TU_p(-(p-\Delta p) : -p^*)$

Assuming the reference price is the same as the charged fare（p*=p）

Time Dependent Utility

Fare Reduction:

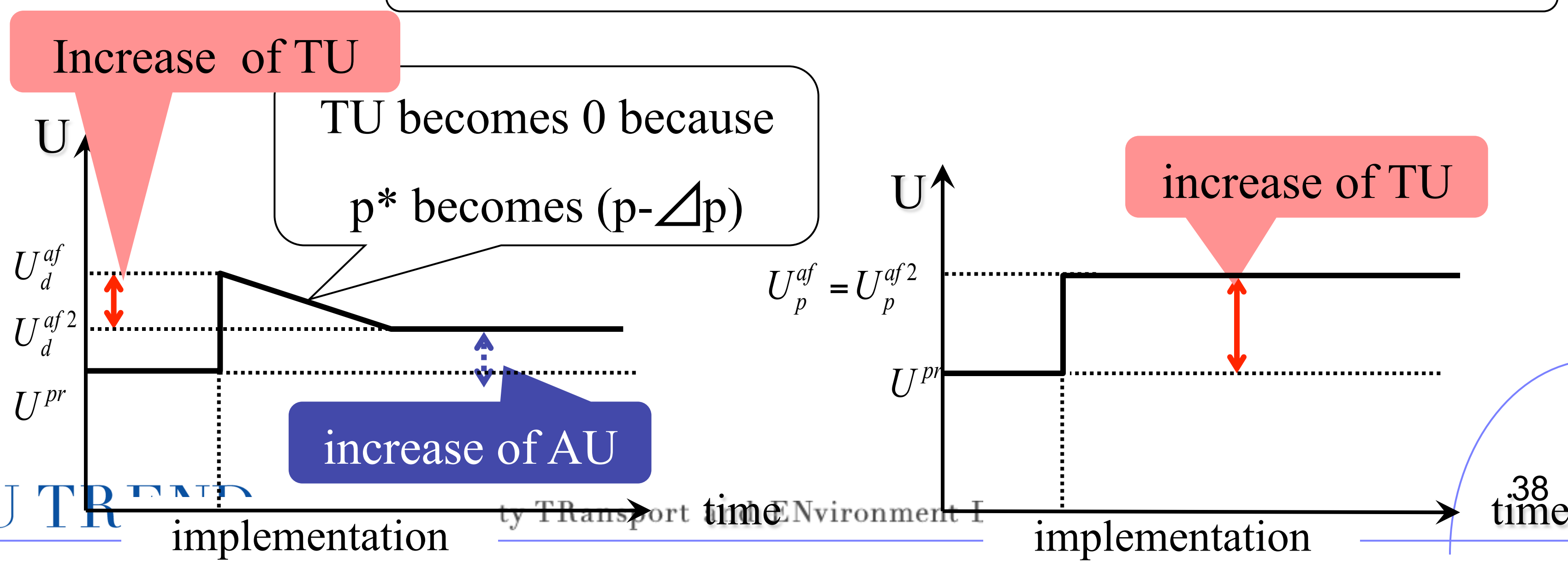
$$U_d^{af2} = AU(\overline{p}, -(p-\Delta p)) + \beta_d TU_d(-(p-\Delta p) : -p^*)$$

The reference price of FR converges into p-⊿p in the long run →TU=0

RPP:

$$U_p^{af2} = AU(\overline{p}, -p) + \beta_p TU_p(-(p-\Delta p) : -p^*)$$

The reference price of RPP is unchanged （p*=p）



Empirical Study

RPP social experiments were conducted in Nagoya to promote subway usage.

Data for the analysis

October, 2005
3000 households (2 questionnaires per household)
Citizens in Nagoya city
659 households, 948 individuals (response rate: 22.0 %)

Ranking Data on RPP

Rank the preference of the options

	Type of policies	Level of variables
Option #1	Fare reduction	5% reduction
Option #2		10% reduction
Option #3		20% reduction
Option #4	Stored fare card with premium	2,300 yen value for 2,000 yen
Option #5		2,400 yen value for 2,000 yen
Option #6	Ride point program	500 yen transit voucher per 100 points
Option #7		1,000 yen transit voucher per 100 points

Most preferred	2nd	3rd	4th	5th	6th	Least preferred
( )	( )	( )	( )	( )	( )	( )

Rating Data for RPP

Intention to use public transportation to the city center

Most preferred	2nd	3rd	4th	5th	6th	Least preferred
(option1)	( )	( )	(option7)	( )	( )	(option4)

Most preferred	4th	Least preferred
( )	( )	( )

1) I am already using by public transportation, bicycle or walk
2) I will use
3) I may use
4) not sure
5) I may not use
6) I will not use

Using only current car users' data (sample size: 144)

Ranking data → Rank logit model

Rating data → Ordered-response logit model

Specification of Utility Function

【Conventional model】

Amount of fare reduction

Part-worth of fare reduction $\beta_c \times (p - \Delta p)$

Part-worth of RPP $\beta_c \times (p - \Delta p)$

Amount of Reward

【 Mental Accounting Theory model (MAT model)】

Part-worth fare reduction $\beta_c \times (p - \Delta p) + \beta_d \times (\Delta p)$

Part-worth of RPP $\beta_c \times (p) + \beta_p \times (\Delta p)$

TU

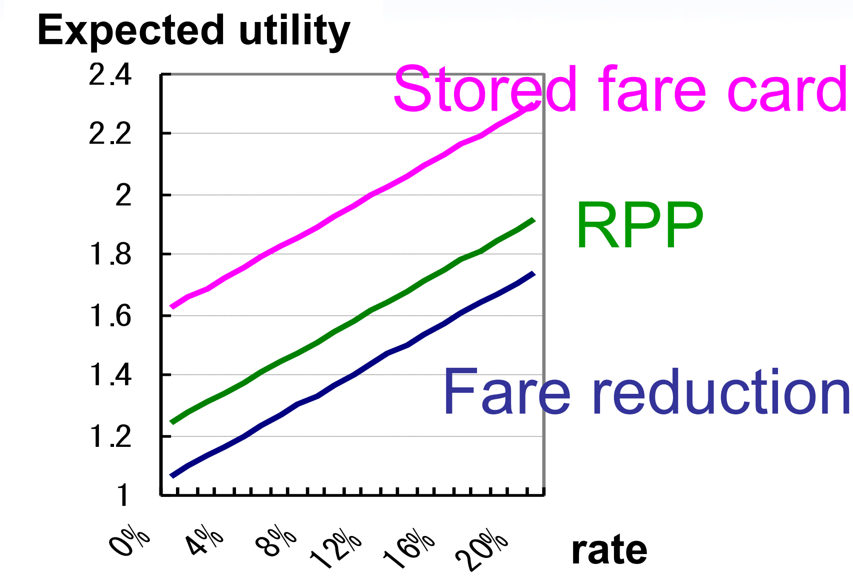
Estimation Results

Variables	Estimates (t-statistic)	
	Conventional	MAT model
Travel time	-0.217 (-0.4)	-0.449 (-0.8)
Travel cost (1,000 yen)	-11.5 (-9.4)	-3.02(-2.5)
Dummy for fare reduction scheme	0	0
Dummy for stored fare card with premium scheme	0.560(6.217)	0.081 (0.31)
Dummy for ride point program scheme	0.177 (2.24)	0.221(1.326)
Amount of fare reduction (1,000 yen)	-	44.1 (17.6)
Amount of premium for stored fare card (1,000 yen)	-	37.4 (7.8)
Amount of reward of ride point program(1,000 yen)	-	63.4 (5.9)
AIC	2093.1	1907.9

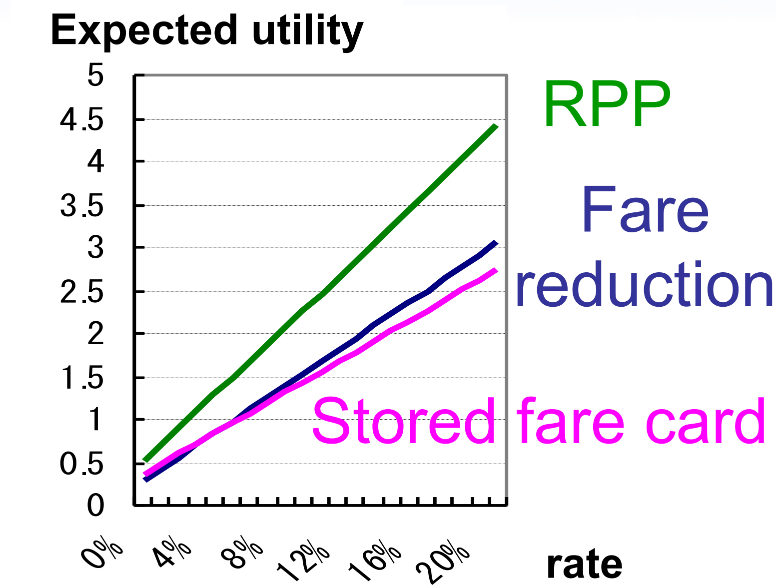
- ✓ The MAT model shows significantly better fit than the conventional one.
- ✓ Parameters of TUs are positive, implying that individuals seem to feel psychological gains.
- ✓ Parameters of TUs are 12-20 times greater than the 'travel cost' parameter.

Utility Change with the Two Policies

Conventional model



MAT model



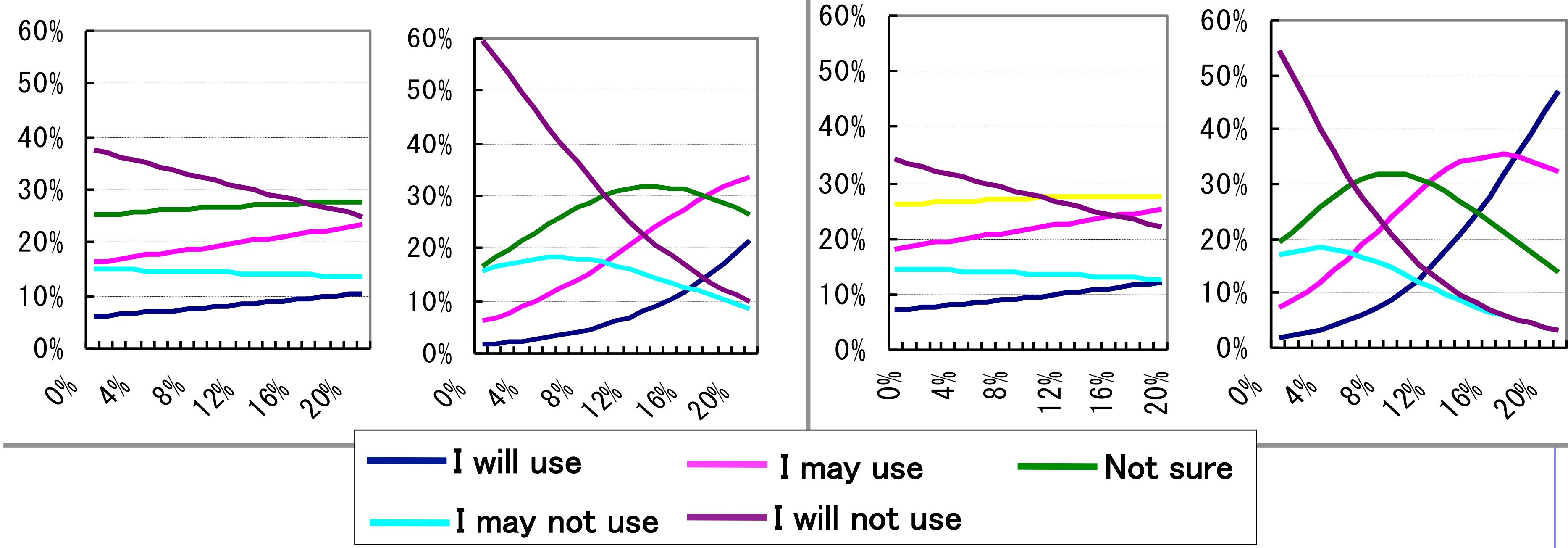
<Conventional model>
Preference for the three promotion schemes is determined by the alternative specific constants.

<MAT model>
RPP dominates the other two schemes for any reward rate.

Predicted Probabilities of Transit Usage

Fare Reduction | RPP

Conventional | MAT | Conventional | MAT



- By the conventional model, public transportation usage monotonically increases according to reduction rate.
- By the MAT model, the strong intention ("I will use") sharply increases for high reduction rates. ← more intuitive than conventional model

Findings from the Case Study

- Including the transaction utility may significantly improve the goodness-of-fit of discrete choice models, especially in the applications of usage promotions such as price reduction and frequent user program.
- Magnitude of perceived gain represented by the transaction utility may differ among the promotion schemes.
- In our study, it is found that the RPP is most preferred for any rate of reward over fare reduction and stored fare card with premium. Since operating cost of the RPP is lowest, RPP's may be the most cost-effective promotion scheme.

Thank you for your attention.