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Empirical analysis on value of time and value of travel time savings for leisure activities of non-work day

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Contents of today's presentation

- Introduction: what is the value of time?
- Technical problems in parameter estimation of resource allocation model for non-work activities
- Empirical application to valuation of VTTS for private travels
- Discussions

Introduction: what is the value of time?

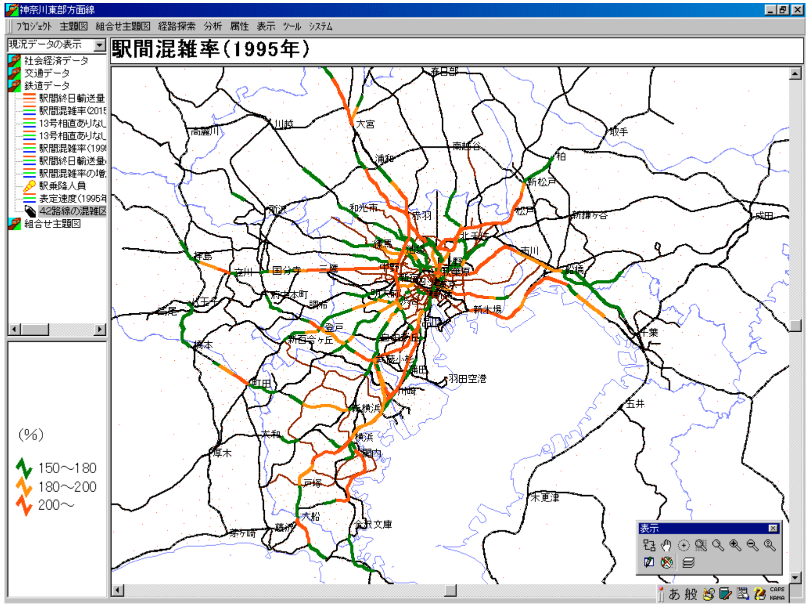
Importance of Value of Time

Transport investment

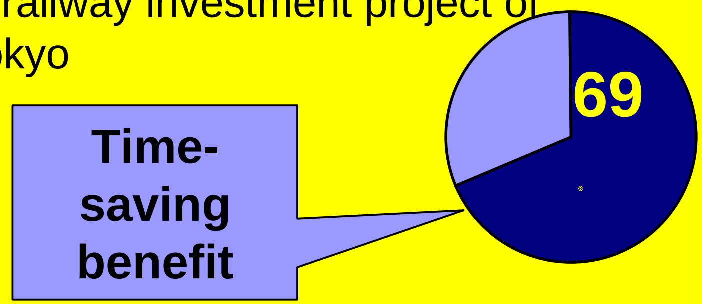
Time-saving plays an important role in benefit

Calculated based on value of time

To measure the VOT is essential for better Cost Benefit Analysis



Example of share of time-saving benefit from transport investment of railway investment project of Tokyo



Definition of value of time (assigned to a specific activity)

The amount of money which is required in order to recover his/her utility into indifferent situation from the initial one when the time assigned to a specific activity is decreased (or increased) marginally from the initial situation.

$$\text{VOT} = \boxed{\frac{\text{Marginal utility w.r.t. time}}{\text{Marginal utility w.r.t. cost}}}$$

Researches on Value of Travel Time (VOTT)

- VOTT can be derived theoretically from the resource allocation model

What is the resource allocation model?

The model in which a consumer allocates his/her time and cost to several activities by maximizing his/her utility under time and budget constraints

- Many types of time/resource allocation models have been suggested so far.

Becker (1965) type model

$$\underset{G,T}{Max}\, U = U(G, T)$$

Leisure time

Leisure cost

$$G + c = I$$

Budget constraint

Travel cost

$$T + t = T^0$$

Time constraint

Travel time

Becker model

•Utility function includes both amount of goods and time

•Not only budget but time are included as constraints

Derivation of VOT from Becker model

Lagrange Function

$$L = U(G,T) + \lambda(I - G - c) + \mu(T^o - T - t)$$

First-order condition

$$\frac{\partial L}{\partial T} = \frac{\partial U}{\partial T} - \mu = 0$$

$$\frac{\partial L}{\partial G} = \frac{\partial U}{\partial G} - \lambda = 0$$

$$VOT = \frac{\partial U / \partial T}{\partial U / \partial G} = \frac{\mu}{\lambda}$$

The VOT derived from this formula
is not for travel time but leisure activity time

Derivation of VOTT from Becker model

Indirect utility function $V\left(c, t, I, T^{o}\right)$

•In general, the sensitivity analysis for the optimized value w.r.t. a corresponding parameter in the objective function can be conducted by the Envelope Theorem (Varian, 1984)

•From the Envelope Theorem

$$\frac{\partial V}{\partial t} = \frac{\partial U}{\partial t} - \mu^{*} \frac{\partial\left(T^{o} - T - t\right)}{\partial t} = \mu^{*}$$

$$\frac{\partial V}{\partial c} = \frac{\partial U}{\partial c} - \lambda^{*} \frac{\partial\left(I - G - c\right)}{\partial c} = \lambda^{*}$$

Value of travel time

$$\frac{\partial v / \partial t}{\partial v / \partial c} = \frac{\mu^{*}}{\lambda^{*}}$$

Extension of Becker type model

Based on the Becker model, various types of models have so far been proposed by many researchers

Johnson(1966). incorporating the working time into the model

Oort(1969). incorporating the travel time into the model

Small(1982). incorporating the scheduling into the model

Jara-Diaz(2000). generalized model is proposed

Jara-Diaz(2003). more generalized model is proposed

Definitions of VOTs by DeSerpa(1971)

Traditional definition of VOTT

VOT = the substitution ratio between the marginal utility w.r.t time to the marginal utility w.r.t. income

$$VOTT = \left.\frac{\partial U/\partial t}{\partial U/\partial c}\right|_{U=U^{\max}}$$

or

$$VOTT = \frac{\partial v/\partial t}{\partial v/\partial c}$$

De Serpa (1971) proposes three types of VOTs

- Value of Travel Time Saving
- Value of Time as a Resource
- Value of Time as a Commodity

De Serpa (1971) type model

$$\underset{G,T,t}{Max}\,U = U(G,T,t)$$

$$G + c = I$$ Budget constraint

$$T + t = T^0$$ Time constraint

$$t \geq \hat{t}$$ Time consumption constraint

What is the time consumption constraint?

This constraint is considered as the minimum requirement for a specific activity. This is determined by the technical or the institutional constraints.

Derivation of value of travel time savings from De Serpa model

Lagrange function

$$L = U(G,T,t) + \lambda(I - G - c) + \mu(T^o - T - t) + \kappa_t(t - \hat{t})$$

$$\frac{\partial U}{\partial t} = \mu - \kappa_t$$ (one of the first-order conditions)

$$\kappa_t/\lambda = \mu/\lambda - (\partial U/\partial t)/\lambda$$

This may be the one that should be used for the project evaluation!!

Value of travel time savings

Definition of the VTTS（De Serpa,1971）

Value of saving time ＝ **VOT as a resource** － **VOT as a commodity**

$$\frac{\kappa^*}{\lambda^*} = \frac{\mu^*}{\lambda^*} - \frac{\partial U^* / \partial t}{\lambda^*}$$

t ：travel time

μ^* ：marginal utility w.r.t. available time

λ^* : marginal utility w.r.t. available income

What is the VTTS?

The marginal utility converted into monetary term when the time consumption constraint w.r.t. travel time is relaxed.

Derivation of VOTT from De Serpa Model

Lagrange function

$$L = U(G,T,t) + \lambda(I - G - c) + \mu(T^o - T - t) + \kappa_t(t - \hat{t})$$

$$\frac{\partial U}{\partial t} = \mu - \kappa_t$$ (one of the first-order conditions)

By applying the Envelope Theorem to the indirect utility function

$$\frac{\partial V}{\partial c} = \frac{\partial U}{\partial c} - \lambda^* \frac{\partial (I - G - c)}{\partial c} = \lambda^*$$

The VOTT is derived as

$$\left.\frac{\partial U}{\partial t}\right|_{U^*} \Big/ \frac{\partial V}{\partial c} = \frac{\mu^* - \kappa_t}{\lambda^*}$$

This is equal to the value of time as a resource defined by De Serpa

Technical problems in parameter estimation of resource allocation model for non-work activities

Measurement of VOT/VTTS based on the discrete choice model

In transportation research, the discrete choice modeling is familiar to valuate the VTTS empirically

Valuation of VTTS by the discrete choice model

•Train and McFadden(1978) challenged first

•Academic disputes between Truong and Hensher(1985) and Bates(1987)

•The discrete choice model is now widely used in practice to evaluate the VTTS

I will not use the discrete choice model but resource allocation model in this presentation

Discrete choice model can be derived from the time allocation model!!

Why not discrete choice model?

- Trip-based discrete choice model usually has an implicit assumption: “the consumers TRAVEL!!”
  - The data used for the modal choice model is always the sub-sample of travelers
- However, many transportation policies may impact not only the traveler’s behavior but also the non-traveler’s decision-making of generation especially for non-work travel.
  - For example, people may choose their activities of non-work day: whether out-home-activity with travel or in-home activity without travel.
  - Recently Travel Demand Management is very important. Some of TDMs intend to control/manage the trip generation.
- In order to deal with a trade-off between travel and non-travel, one of the most appropriate techniques is the resource allocation model based on activity-based approach.

Multi-activities resource allocation model

$$\underset{\{\mathbf{T}_n, \mathbf{C}_n\}}{Max}\ U_n = U\left(\mathbf{T}_n, \mathbf{C}_n\right)$$

subject to

$$\sum_{i \in I} T_{ni} + \sum_{j \in J} t_{nj} = T_n^o \qquad T_{ni} \geq 0 \quad (\forall i)$$

$$\sum_{i \in I} C_{ni} + \sum_{j \in J} c_{nj} = I_n \qquad C_{ni} \geq 0 \quad (\forall i)$$

Lagrange function

$$L_n = U\left(\mathbf{T}_n^*, \mathbf{C}_n^*\right) + \lambda_n\left(T_n^o - \sum T_{ni} - \sum t_{ni}\right)$$

$$+ \mu_n\left(I_n - \sum C_{ni} - \sum c_{ni}\right) + \sum \kappa_{ni}^T T_{ni} + \sum \kappa_{ni}^C C_{ni}$$

Derivation of VOT and zero-allocation problem

First order condition

$$\frac{\partial L(\mathbf{T}_n^*,\mathbf{C}_n^*)}{\partial T_{ni}} = \frac{\partial U(\mathbf{T}_n^*,\mathbf{C}_n^*)}{\partial T_{ni}} - \lambda_n + \kappa_{ni}^T = 0 \qquad \kappa_{ni}^T \cdot T_{ni}^* = 0 \qquad \kappa_{ni}^T \geq 0$$

$$\frac{\partial L(\mathbf{T}_n^*,\mathbf{C}_n^*)}{\partial C_{ni}} = \frac{\partial U(\mathbf{T}_n^*,\mathbf{C}_n^*)}{\partial C_{ni}} - \mu_n - \kappa_{ni}^C = 0 \qquad \kappa_{ni}^C \cdot C_{ni}^* = 0 \qquad \kappa_{ni}^C \geq 0$$

Value of time assigned to activity i

$$VOT_{ni} = \left.\frac{\partial U/\partial T_{ni}}{\partial U/\partial C_{ni}}\right|_{U^*} = \frac{\lambda_n}{\mu_n} \qquad \text{if} \qquad T_{ni}^* > 0 \text{ and } C_{ni}^* > 0$$

$$VOT_{ni} = \left.\frac{\partial U/\partial T_{ni}}{\partial U/\partial C_{ni}}\right|_{U^*} \leq \frac{\lambda_n}{\mu_n} \qquad \text{if} \qquad T_{ni}^* = 0 \text{ or } C_{ni}^* = 0$$

VOTs are equal to value of time as the resource if and only if both allocated times and costs are positive, otherwise they are equal to or less than that.

Introduction of Tobit model (Tobin, 1958) to deal with zero-allocation

For example

If we introduce an error term ε_{ni}^{T} following independent normal distribution $N\left(0,\sigma^{T}\right)$

$$T_{ni}^{*}=\begin{cases}\theta_i^T\left[T_n^o-\sum t_{ni}\right]+\varepsilon_{ni}^T & \text{if } \theta_i^T\left[T_n^o-\sum t_{ni}\right]+\varepsilon_{ni}^T>0\\ 0 & \text{if } \theta_i^T\left[T_n^o-\sum t_{ni}\right]+\varepsilon_{ni}^T\leq 0\end{cases}$$

We can estimate the parameters by maximizing the following log-likelihood function

$$\ln L_n=\begin{cases}\ln\left[\dfrac{1}{\sigma}\phi\left(\dfrac{T_{ni}^{*}-\theta_i^T\left[T_n^o-\sum t_{ni}\right]}{\sigma}\right)\right] & \text{if } T_{ni}^{*}>0\\ \ln\Phi\left(\dfrac{T_{ni}^{*}-\theta_i^T\left[T_n^o-\sum t_{ni}\right]}{\sigma}\right) & \text{if } T_{ni}^{*}=0\end{cases}$$

Parameter identification problem

Example: Cobb-Douglas type utility function with two activities

$$\max U_n = \xi_1^T \ln T_{n1} + \xi_2^T \ln T_{n2} + \xi_1^C \ln C_{n1} + \xi_2^C \ln C_{n2}$$

s.t.
$$T_{n1} + T_{n2} + t_{n1} + t_{n2} = T_n^o \qquad T_{ni} \geq 0, \quad C_{ni} \geq 0 \qquad (\forall i)$$
$$C_{n1} + C_{n2} + c_{n1} + c_{n2} = I_n$$

Optimal solutions

$$T_{ni}^* = \begin{cases} \dfrac{\xi_i^T}{\xi_1^T + \xi_2^T}\left[T_n^o - t_{n1} - t_{n2}\right] & if\ T_{ni}^* > 0 \\ 0 & if\ T_{ni}^* = 0 \end{cases} \qquad C_{ni}^* = \begin{cases} \dfrac{\xi_i^C}{\xi_1^C + \xi_2^C}\left[I_n - c_{n1} - c_{n2}\right] & if\ C_{ni}^* > 0 \\ 0 & if\ C_{ni}^* = 0 \end{cases}$$

We can estimate only
the ratios of parameters

$$\xi_1^T / \xi_2^T \qquad \xi_1^C / \xi_2^C$$

We cannot estimate the VOT!!

$$VOT_n = \left.\frac{\partial U / \partial T_{ni}}{\partial U / \partial C_{ni}}\right|_{U = U_{\max}} = \frac{C_{ni}}{T_{ni}} \cdot \frac{\xi_i^T}{\xi_i^C}$$

Background of the identification problem

$$\max \xi_1^T \ln T_{n1} + \xi_2^T \ln T_{n2} + \xi_1^C \ln C_{n1} + \xi_2^C \ln C_{n2}$$
$$= \underbrace{\max\left(\xi_1^T \ln T_{n1} + \xi_2^T \ln T_{n2}\right)} + \underbrace{\max\left(\xi_1^C \ln C_{n1} + \xi_2^C \ln C_{n2}\right)}$$

Utility maximization w.r.t. time

$$\max\left(\xi_1^T \ln T_{n1} + \xi_2^T \ln T_{n2}\right)$$

s.t.

$$T_{n1} + T_{n2} + t_{n1} + t_{n2} = T_n^o$$

Utility maximization w.r.t. cost

$$\max\left(\xi_1^C \ln C_{n1} + \xi_2^C \ln C_{n2}\right)$$

s.t.

$$C_{n1} + C_{n2} + c_{n1} + c_{n2} = I_n$$

Main optimization problem can be divided into two independent sub-optimization problems!!

Two approaches for solving identification problem of resource allocation model

- Approach 1: modification of utility function
  - Utility function will be changed into the one which has a cross effect between time and cost

- Approach 2: modification of constraints
  - New constraints will be introduced into the relationship between cost and time

One of the solutions for the identification problem of work-day resource allocation

- For the work-day resource allocation, Jara-Diaz et al.(2004) solved this problem by introducing the working time into both utility function and time & budget constraints.

$$\max U_n = \xi_1^T \ln T_{n1} + \xi_2^T \ln T_{n2} + \xi_W^T \ln WT_n + \xi_1^C \ln C_{n1} + \xi_2^C \ln C_{n2}$$

s.t.

$$T_{n1} + T_{n2} + t_{n1} + t_{n2} + WT_n = T_n^o$$

$$C_{n1} + C_{n2} + c_{n1} + c_{n2} = \omega \, WT_n$$

How can we solve this problem for resource allocation of non-work activities?

Proposed model: resource allocation model for leisure activities of non-workday

Assumptions

- Income is given and fixed. (due to non-workday)
- Leisure activities are classified into two types: out-of-home activity and in-home activity.
- Out-of-home activity requires travel while in-home activity does not.
- Time and cost of out-of-home activity are non-negative while those of in-home activity are positive.

Non-work day Model:

introduction of number of travels into the model

Original problem

$$\max U_n = \xi_1^T \ln T_{n1} + \xi_2^T \ln T_{n2} + \xi_1^C \ln C_{n1} + \xi_2^C \ln C_{n2}$$

s.t.

$$T_{n1} + T_{n2} + t_{n1} = T_n^o \qquad T_{ni} \geq 0, \quad C_{ni} \geq 0 \qquad (\forall i)$$

$$C_{n1} + C_{n2} + c_{n1} = I_n$$

Introducing the number of travels
and expected unit time & cost
consumed in out-of-home leisure activity

1: out-of-home leisure activity
2: in-home leisure activity

$$\max U_n(N_{n1}, T_{n2}, C_{n2}) = \xi_{n1}^T \ln N_{n1}\overline{T_{n1}} + \xi_{n2}^T \ln T_{n2} + \xi_{n1}^C \ln N_{n1}\overline{C_{n1}} + \xi_{n2}^C \ln C_{n2}$$

s.t.

$$N_{n1}\left(\overline{T_{n1}} + \overline{t_{n1}}\right) + T_{n2} = T_n^o \qquad N_{n1} \geq 0$$

$$N_{n1}\left(\overline{C_{n1}} + \overline{c_{n1}}\right) + C_{n2} = I_n \qquad T_{n2} > 0, \quad C_{n2} > 0$$

transformed into

$$\max U_n(N_{n1}, T_{n2}, C_{n2}) = \left(\xi_{n1}^T + \xi_{n1}^C\right)\ln N_{n1} + \xi_{n2}^T \ln T_{n2} + \xi_{n2}^C \ln C_{n2}$$
$$= \xi_{n1} \ln N_{n1} + \xi_{n2}^T \ln T_{n2} + \xi_{n2}^C \ln C_{n2}$$

Lagrange function

$$\boxed{\begin{aligned} L_n = U_n + \lambda_n \left[T_n^o - N_{n1}\left(\overline{T_{n1}} + \overline{t_{n1}}\right) - T_{n2}\right] \\ + \mu_n \left[I_n - N_{n1}\left(\overline{C_{n1}} + \overline{c_{n1}}\right) - C_{n2}\right] + \kappa_n N_{n1} \end{aligned}}$$

Estimation Method 1

Optimal solution

$$N_{n1}^* = \begin{cases} \dfrac{X + \sqrt{X^2 + 4\xi_{n2}^T \xi_{n2}^C T_n^o I_n \left(\overline{T_{n1}} + \overline{t_{n1}}\right)\left(\overline{C_{n1}} + \overline{c_{n1}}\right)}}{2\left(\xi_{n1} + \xi_{n2}^T + \xi_{n2}^C\right)} & if \quad N_{n1}^* > 0 \\ 0 & if \quad N_{n1}^* = 0 \end{cases}$$

where $X = \left(\xi_{n1} + \xi_{n2}^T\right)\left(\overline{T_{n1}} + \overline{t_{n1}}\right)I_n - \left(\xi_{n1} + \xi_{n2}^C\right)\left(\overline{C_{n1}} + \overline{c_{n1}}\right)T_n^o$

We can apply the estimation technique of Tobit model by introducing error term for the optimal solution

Estimation Method 2

$$
\boxed{\begin{aligned} L_n = U_n + \lambda_n \left[T_n^o - N_{n1}\left(\overline{T_{n1}} + \overline{t_{n1}}\right) - T_{n2} \right] \\ + \mu_n \left[I_n - N_{n1}\left(\overline{C_{n1}} + \overline{c_{n1}}\right) - C_{n2} \right] + \kappa_n N_{n1} \end{aligned}}
$$

One of the first-order conditions

$$
\frac{\partial L_n}{\partial N_{n1}} = \frac{\xi_1}{N_{n1}} - \lambda_n\left(\overline{T_{n1}} + \overline{t_{n1}}\right) - \mu_n\left(\overline{C_{n1}} + \overline{c_{n1}}\right) \begin{cases} = 0 & if \quad N_{n1} > 0 \\ \leq 0 & if \quad N_{n1} = 0 \end{cases}
$$

Introduce the error term into one of the parameters!!

$$
\xi_1 \begin{cases} = N_{n1}\left[\lambda_n\left(\overline{T_{n1}} + \overline{t_{n1}}\right) - \mu_n\left(\overline{C_{n1}} + \overline{c_{n1}}\right)\right] + \varepsilon_{n1} \\ \leq N_{n1}\left[\lambda_n\left(\overline{T_{n1}} + \overline{t_{n1}}\right) - \mu_n\left(\overline{C_{n1}} + \overline{c_{n1}}\right)\right] + \varepsilon_{n1} \end{cases}
$$

By the error term introduced into the parameter, we can consider individual heterogeneity. We can estimate it by maximizing the likelihood function.

Problem of the proposed non-work day model

How should we define the expected unit time and cost consumed in out-of-home leisure activity?

$$\max U_n = \xi_{n1}^T \ln N_{ni} \overline{T_{n1}} + \xi_{n2}^T \ln T_{n2} + \xi_{n1}^C \ln N_{ni} \overline{C_{n1}} + \xi_{n2}^C \ln C_{n2}$$

s.t.

$$N_{n1}\left(\overline{T_{n1}} + \overline{t_{n1}}\right) + T_{n2} = T_n^o \qquad N_{n1} \geq 0$$

$$N_{n1}\left(\overline{C_{n1}} + \overline{c_{n1}}\right) + C_{n2} = I_n \qquad T_{n2} > 0, \quad C_{n2} > 0$$

We may need some additional model for estimating the expected unit time and cost.

Empirical application of the proposed method to valuation of VTTS for private travels (Kato and Imai, 2004)

Aims of the empirical analysis

- To formulate a resource allocation model to valuate the value of travel time savings (VTTSs) for private travel*

- To analyze the VTTS empirically by applying the model to the daily private activities and trips of people in the Tokyo Metropolitan Area

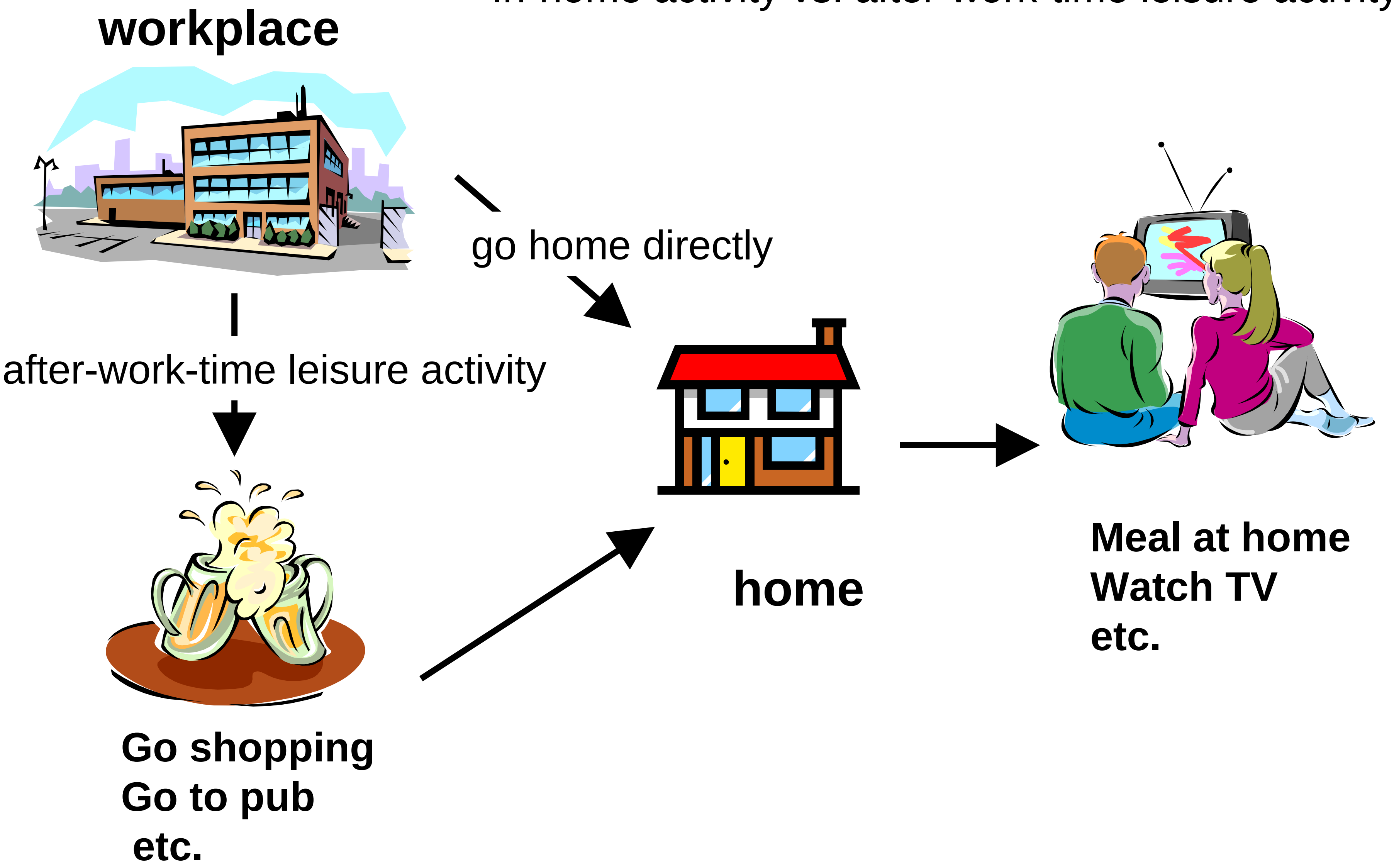
*Private travel is defined as the travel by which one can reach a place where the leisure activity is conducted

Assumptions on allocation of time and cost for leisure activities

- Consumers' time allocation decision on work day and that on non-work day are not independent
- The time allocation model to discretionary leisure activities is formulated for the consumers' behavior of allocating their non-work time *in a week*
- Working time are given and fixed due to the working practice of Japan's society. This leads to the constant income assumption.
- The non-work activity is categorized into three types
  - in-home leisure activity
  - after-work-time leisure activity (on work days)
  - out-of-home leisure activity (on non-work days)

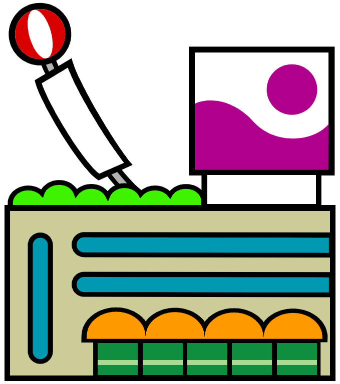
Choice of activities on work day

In-home activity vs. after-work-time leisure activity



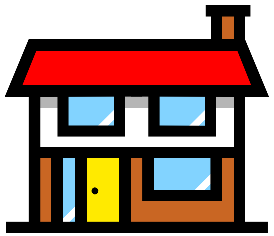
Choice of activities on non-work day

In-home activity vs. out-of-time leisure activity



Go shopping
Go to restaurants
etc.

out-of-home leisure activity



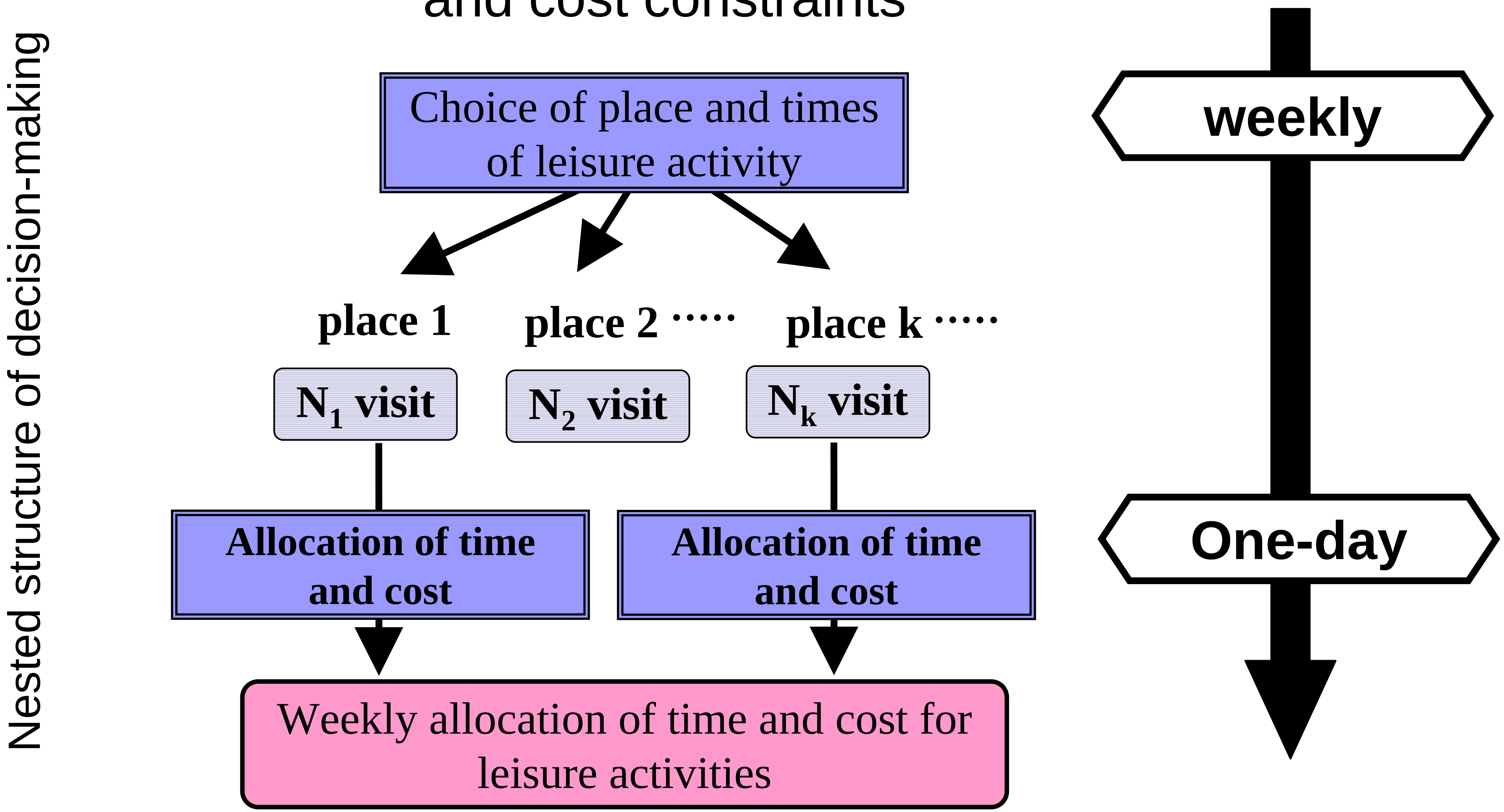
home

Meal at home
Watch TV
etc.

Basic structure of the model

Consumer's behavior

Maximization of utility subject to available time and cost constraints



One-day activity model

Allocation of time and cost under the condition that the activity is conducted at the place k

Max. of utility

$$\max_{C_k, T_k, C_{home}, T_{home}} U_{day}\left(C_k, T_k, C_{home}, T_{home}, X_k, Y_n\right)$$

$$subject\ to$$

Budget constraint

$$C_k + C_{home} = I_{day}$$

Time constraint

$$T_k + T_{home} = T_{day}^{o}$$

Non-negative conditions

$$T_k > 0,\ C_k > 0,\ T_{home} > 0,\ C_{home} > 0$$

T_k, C_k : time and cost consumed for out-of-home activity

X_k : characteristics of place k

T_{home}, C_{home} : time and cost consumed for in-home activity

Y_n : individual attributes

Specification of the model

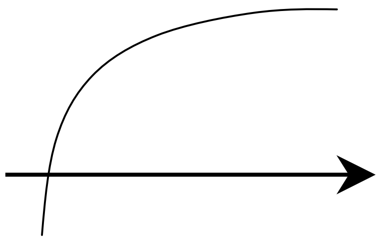
Functional form of utility function in one-day model

Linear function of partial utilities stemming from time and cost of activities

$$U = U_{Tk}(T_k) + U_{Ck}(Z_k) + U_{Th}(T_{home}) + U_{Ch}(Z_{home})$$

$$\begin{cases} U_{Tk} = \exp(AX_k + \varepsilon_{Tk}) \cdot \ln(T_k) \\ U_{Ck} = \exp(BX_k + \varepsilon_{Ck}) \cdot \ln(C_k) \\ U_{Th} = \exp(CY_n) \cdot \ln(T_{home}) \\ U_{Ch} = \exp(DY_n) \cdot \ln(C_{home}) \end{cases}$$

- **Monotonic increase of utility w.r.t. time and cost**
- **Decrease of marginal utility**



A, B, C, D : parameter vectors

$\varepsilon_{Tk}, \varepsilon_{Ck}$: error terms

Weekly activity model

allocation of time and cost by deciding the place and times of leisure activities in a week

Max. of utility

$$\max_{\mathbf{N},T_{week},C_{week},\mathbf{t}} U\left(\mathbf{N},T_{week},C_{week},X_k,Y_n,\mathbf{t}\right)$$

$$subject\ to$$

Budget constraint

$$\sum_k \left[N_k^W\left(C_k^W + c_k^W\right)\right] + \sum_k \left[N_k^H\left(C_k^H + c_k^H\right)\right] + C_{week} = I_{week}$$

Time constraint

$$\sum_k \left[N_k^W\left(T_k^W + t_k^W\right)\right] + \sum_k \left[N_k^H\left(T_k^H + t_k^H\right)\right] + T_{week} = T_{week}^o$$

Non-negative constraints

$$N_k^W \geq 0,\ N_k^H \geq 0,\ T_{week} > 0,\ C_{week} > 0$$

Time consumption constraint

$$t_k \geq \hat{t}_k$$

$N_k^W,\ N_k^H$: times of leisure activities conducted at place k

$T_{week},\ C_{week}$: time and cost consumed for in-home activity

t_k, c_k : travel time and cost

$$\mathbf{N} = \{N_1, N_2, \ldots, N_K\}, \mathbf{t} = \{t_1, t_2, \ldots, t_K\} \quad W: Weekday,\ H: Holiday$$

Specification of the model

Functional form of utility function in weekly model

$$U = \sum_k U_{Nk}^W(N_k^W) + \sum_k U_{Nk}^H(N_k^H) + U_{Tw}(T_{week}) + U_{Cw}(C_{week})$$

$$U_{Nk}^W(N_k^W) = \underline{\exp(E^W Y_n + F^W X_k + \beta_t^W (t_k^W - t_R) + \varepsilon_{Nk}^W)} \cdot \ln(N_k^W + 1)$$

$$U_{Nk}^H(N_k^H) = \underline{\exp(E^H Y_n + F^H X_k + \beta_t^H \cdot t_k^H + \varepsilon_{Nk}^H)} \cdot \ln(N_k^H + 1)$$

Attractiveness of place k

- **Monotonic increase of utility w.r.t. time and cost**
- **Decrease of marginal utility**

E, F, G, H, β_t : parameter vectors

ε_{Nk} : error term

t_k : travel time when out-of-home activity is conducted

t_R : travel time when no out-of-home activity is conducted

Expected unit time and the expected unit cost

They are derived from the one-day model

Expected time $$T_k^{\ *} = T_{day}^{o} \cdot \int_{-\infty}^{+\infty} \frac{e^{AX_k + \varepsilon_T}}{e^{AX_k + \varepsilon_T} + e^{CY_n}} \cdot f\left(\varepsilon_T\right)$$

Expected cost $$C_k^{\ *} = I_{day} \cdot \int_{-\infty}^{+\infty} \frac{e^{BX_k + \varepsilon_C}}{e^{BX_k + \varepsilon_C} + e^{DY_n}} \cdot f\left(\varepsilon_C\right)$$

➡ These expected time and cost are simulated based on the estimated parameters of one-day model and are used for weekly model

Estimation of the model

Optimal conditions

One-day model

$$\begin{cases} \varepsilon_T = \ln(T_k^{\ *}) - \ln(T_{home}^{\ *}) + CY_n - AX_k \\ \varepsilon_C = \ln(C_k^{\ *}) - \ln(C_{home}^{\ *}) + DY_n - BX_k \end{cases}$$

Weekly model

$$\begin{cases} \varepsilon_{Nk}^{W} \begin{cases} = \ln(N_k^{W*}+1) + \ln S_k^{W*} & (N_k^{W*} > 0) \\ < \ln(N_k^{W*}+1) + \ln S_k^{W*} & (N_k^{W*} = 0) \end{cases} & (\forall k) \\ \varepsilon_{Nk}^{H} \begin{cases} = \ln(N_k^{H*}+1) + \ln S_k^{H*} & (N_k^{H*} > 0) \\ < \ln(N_k^{H*}+1) + \ln S_k^{H*} & (N_k^{H*} = 0) \end{cases} & (\forall k) \end{cases}$$

➡ Likelihood maximization

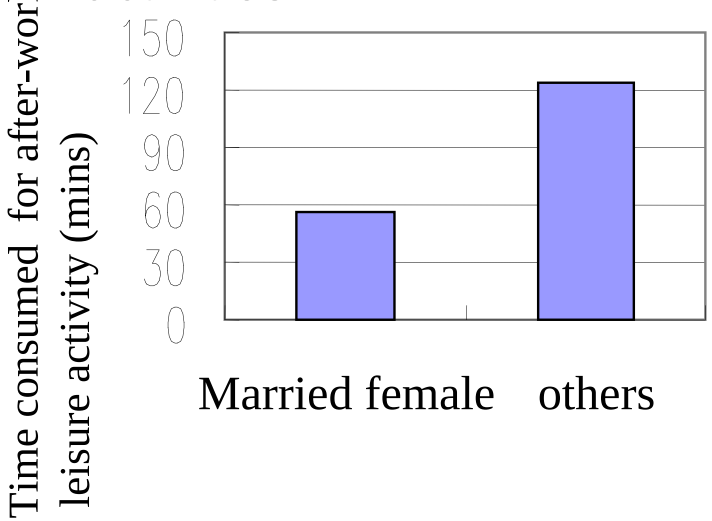
Data used for the model estimation

Weekly time-use diary RP data from the 2001 Tokyo Metropolitan Area of Japan
(EAST JAPAN MARKETING & COMMUNICATIONS, INC., 2001)

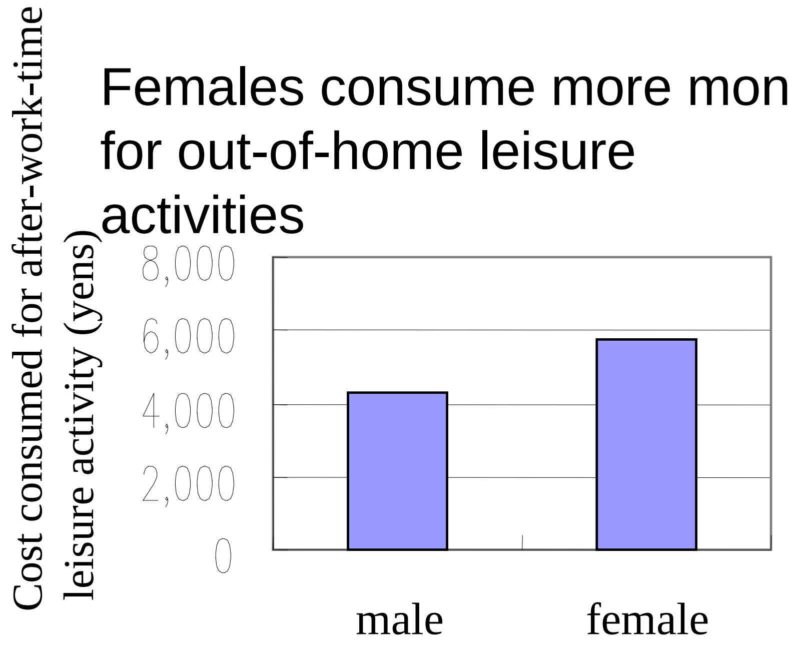
- Period of survey March 1 to 7, 2001
- Area Tokyo Metropolitan Area (residents living within 70 km from the center of Tokyo)
- Surveyed data
  - Individual weekly diary activity
    ; includ. travel time, travel cost, purpose, places of start and destination of travel, etc.
  - Consumption activities related with travel
    ; place and types of activities
- Number of samples
  3047 individuals includ. 923 rail-use commuters

Result of Estimation (one-day model)

Married females conduct less after-work-time activities



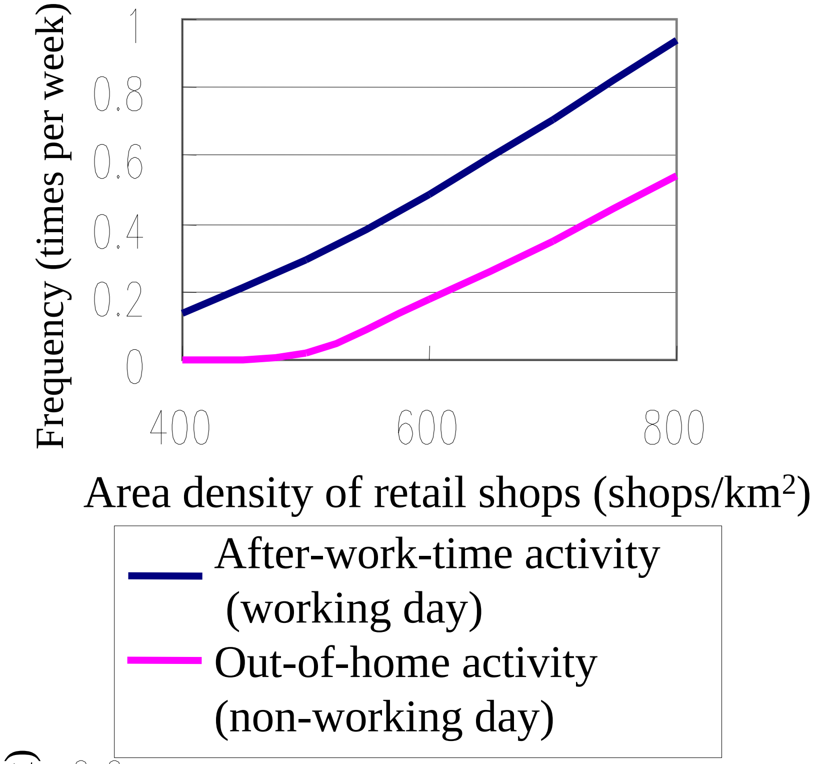
Females consume more money for out-of-home leisure activities



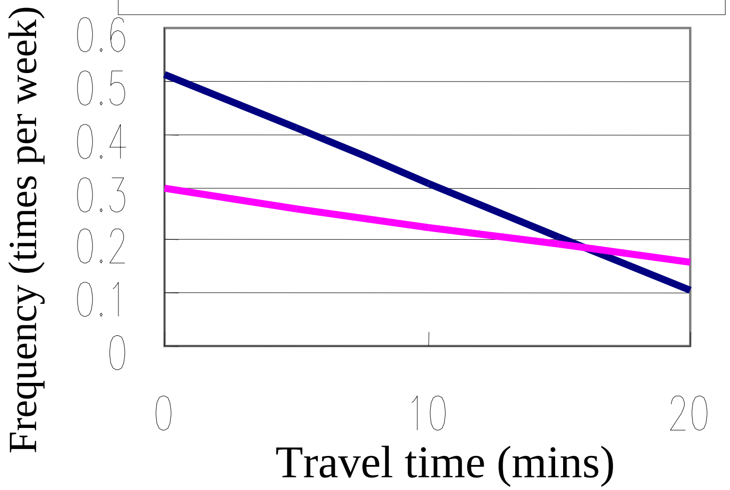
Time consumed for after-work-time is longer at the place where more retail shops are located

Result of estimation (weekly model)

- **The more the density of retail shops, the more frequent visit for leisure activities**

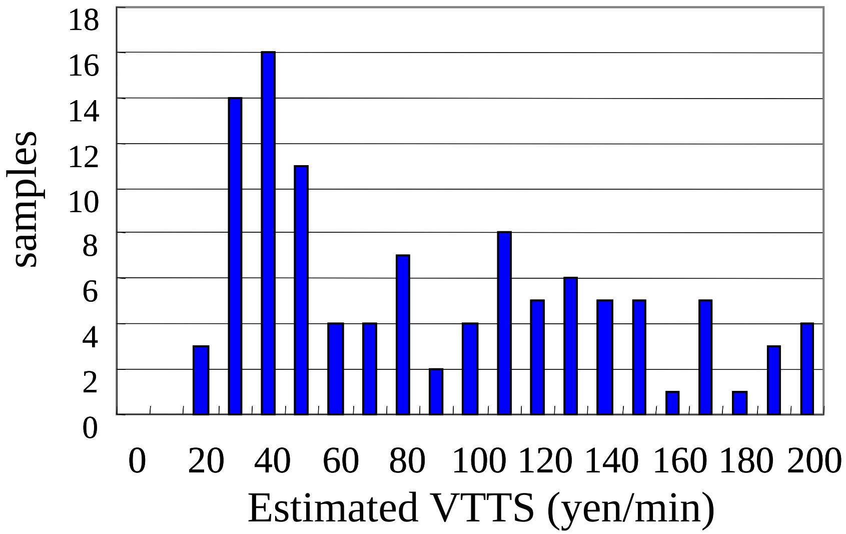


- **The longer the travel time is, the less frequent visit for leisure activities**

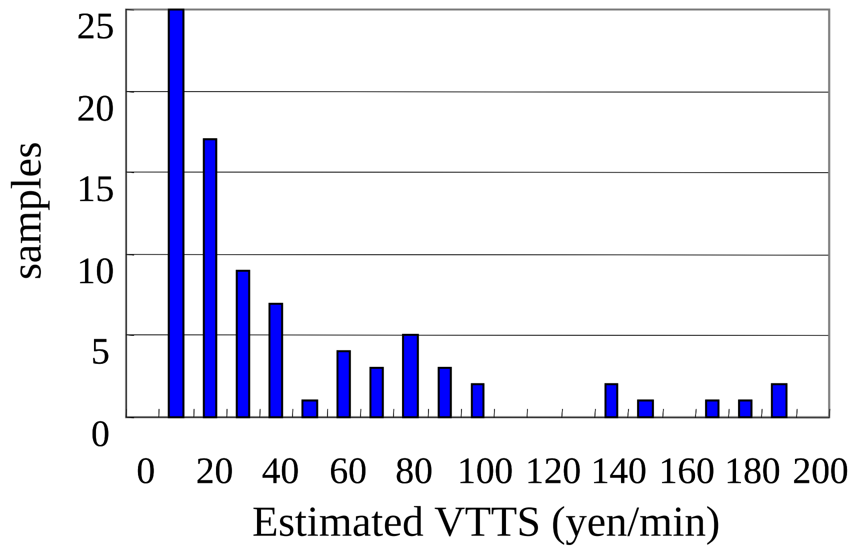


Results of valuation of VTTS for sample data

Travel for after-work-time leisure activity by rail (working day)



Travel for out-of-home leisure activity by rail (non-working day)



1 SFr. = 90 yen
1 Euro = 130 yen

Cf. Morichi et. al (2000) estimates VOTs by MNP for urban rail users in Tokyo 45yen/min (commuting travel) and 23 yen/min (private travel)

Summary of empirical study on VTTS of Tokyo

- The resource allocation model is formulated and estimated for private travel in Tokyo

  The model incorporates

  - activities both on working day and non-working day
  - both in-home activities and out-of-home activities
  - both time constraint and budget constraint

- the VTTSs are estimated empirically based on De Serpa's definition

Discussions

Discussions and further study

- time allocation model vs. discrete choice model
- reality of rational decision-making of time allocation

- negative VOT & VTTS
- wage rate vs. VOT & VTTS
- travel distance and VOT & VTTS
- VOT on non-work day vs. VOT on work day
- value of assigned time vs. value of schedule delay value
- value of time in joint decision-making of multi-travelers

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Thank you for your attention.

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