Behavioral mechanism design for transportation system

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What is mechanism design??

What is “Mechanism Design”?

- A field in economics and game theory
  - Hurwicz, Maskin and Myerson received Nobel economics prize in 2007.

- What type of problems?
  - Auction theory
    - Mirrlees and Vickrey received Nobel economic prize in 1996.
  - Matching theory
    - Roth and Shapley received Nobel economic prize in 2012.
  - Public goods supply problem

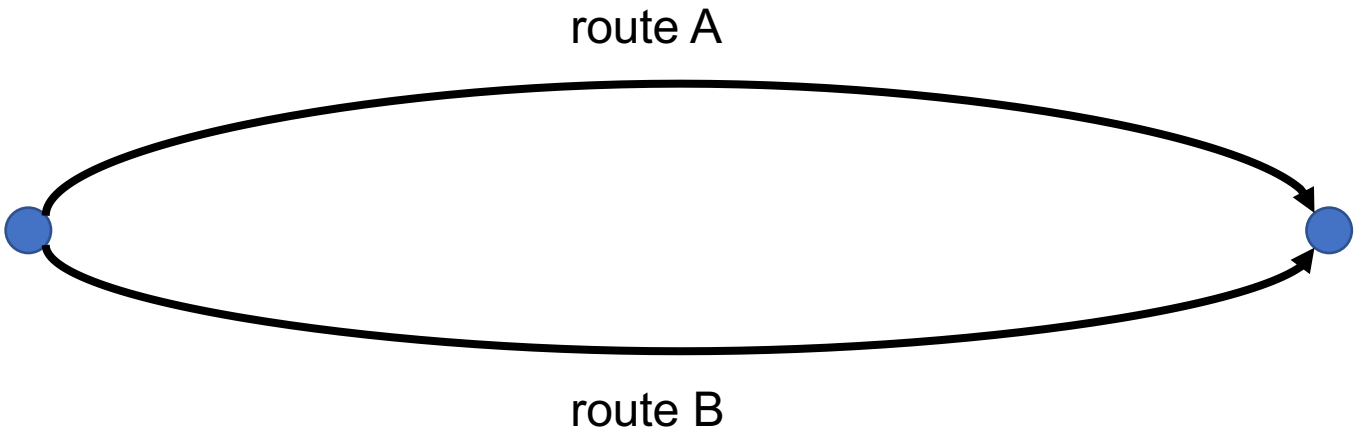
The overview of Mechanism Design

- Developing mechanisms for allocating limited resources efficiently.
  - Applied field of game theory

- Game Theory
  - Under a game setting, we analyze the Nash equilibrium.

- Mechanism Design
  - To implement an optimal equilibrium (target), we make a rule of game in the game theory.
  - Key concepts
    - Efficiency (Maximizing the social welfare)
    - Strategy-proofness (Avoiding the strategic behavior)

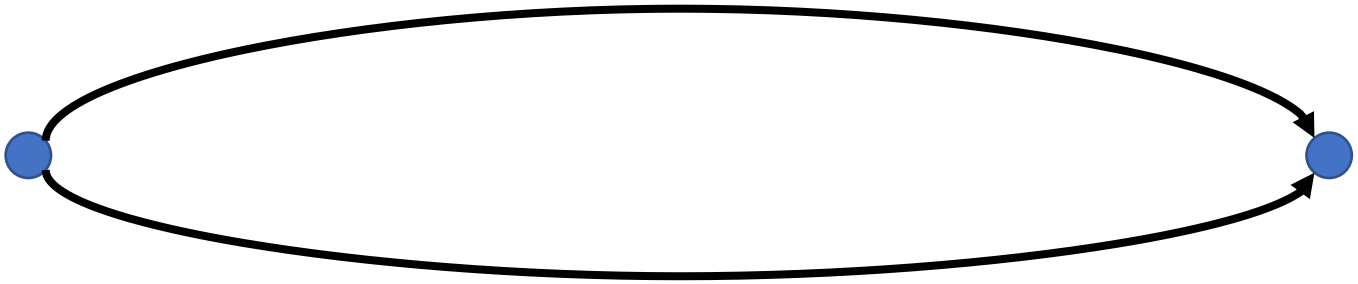
Simple example in transportation



- Wardrop's first principle
  - It is the concept of equiribrium.
  - No driver can unilaterally reduce his/her travel costs by shifting to another route.
  - This is equivalent to Nash equilibrium in game theory.

But….

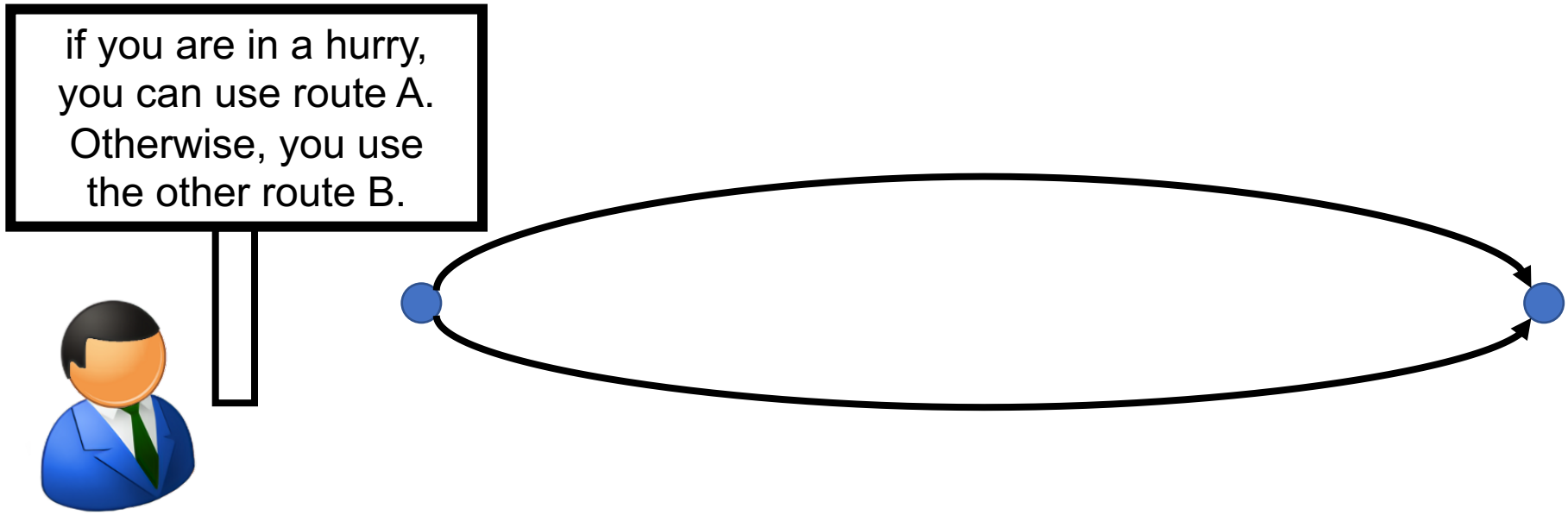
Non busy traveller



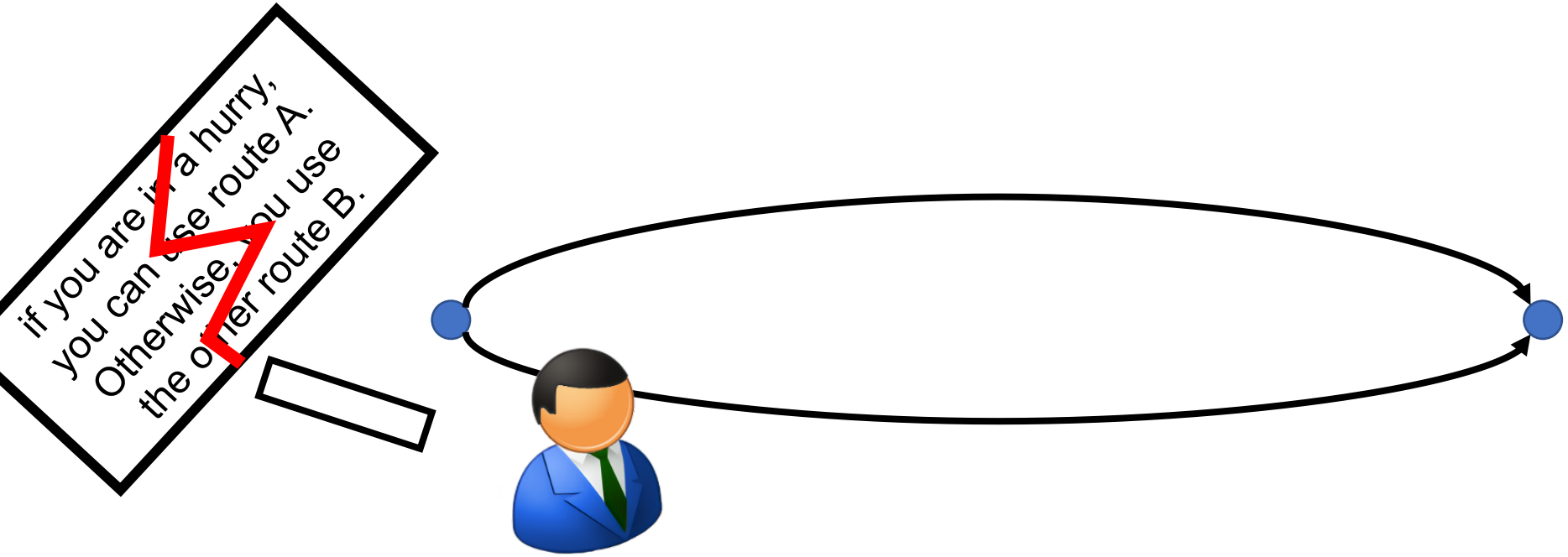
Busy traveller

- How should we solve this problem?

1st idea: Sign board

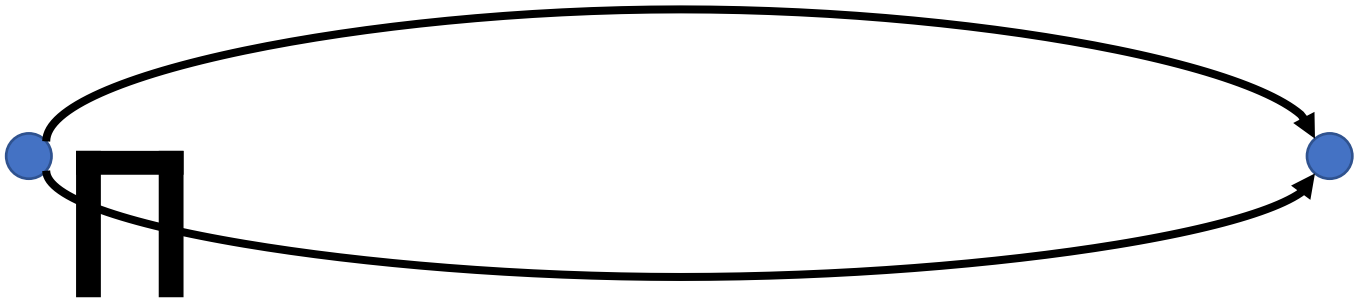


If you are not honest,…



- Are you an honest person?

2nd idea: pricing



- How should we decide the price?
- In general, it is difficult to know each traveler's willingness to pay (WTP).

3rd idea: tradable permit (auction)

- Akamatsu (2007) proposed tradable bottleneck permit system.
- Every driver bids a permit to use road network (link level or path level).
  - It means they state the information about their value of time (VOT) and desired arrival time.
- After bidding, the policy maker determine the allocation through a mechanism. In general, VCG auction mechanism is used.
  - This mechanism has a good characteristics.
    - Efficiency: The final result is the most efficient allocation.
    - Strategy-proofness: This mechanism eliminates drivers' lie.

All problems are solved?

- VCG mechanism satisfies efficiency and strategy-proofness (truth telling).
- Mechanism design approach can work well.

- But,

- Do you want to bid every time slots of every transportation modes (train, bus, road network, etc.) every day????

Behavioral mechanism design for transportation services: Laboratory experiments and preference elicitation cost

Yusuke Hara, Transportation Research Part B: Methodological, Vol.115, pp.231-245, 2018.

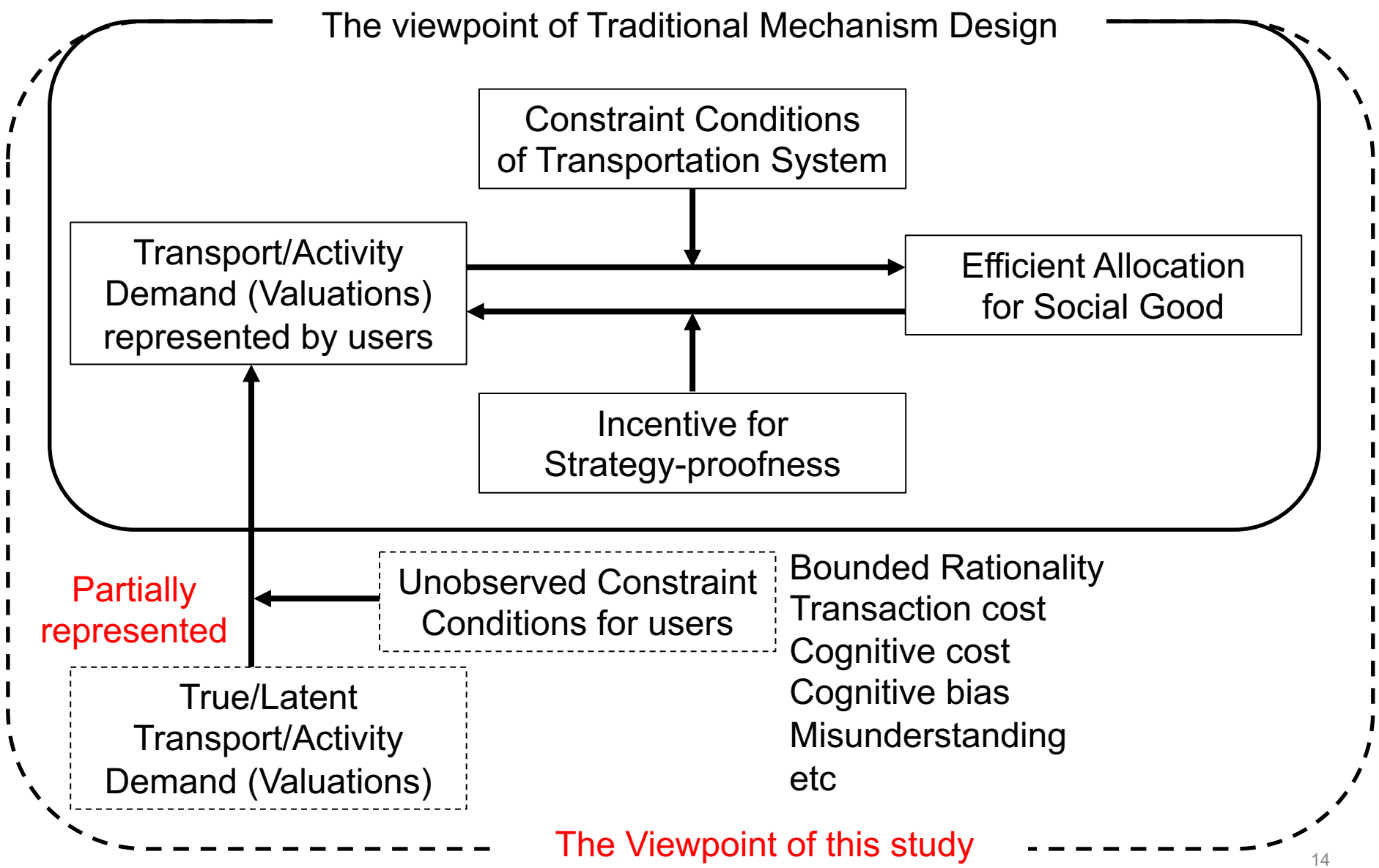
1. Background of my research

- Transportation system such as road network and public transport have a supply capacity.

- For the efficient transport system, it is important to allocate the resource efficiently.
  - One Approach: Tradable permit system/Auction
    - Tradable permit: Akamatsu (2007), Hara and Hato (2018)
    - Tradable credit: Yang and Wang, Wu et al., Nie and Yin

- Auction mechanism such as VCG mechanism can achieve the strategy-proofness and efficient allocation, but in reality, there is cognitive cost for preference elicitation.
  - Hara and Hato (2019) shows there exists the cognitive cost for transportation auction system in bicycle sharing auction empirically.
  - Users don't behave rationally in reality.

The viewpoint of this study



2. The research question and contributions

- The research questions of this study

1. Are there cognitive costs of preference representation in reality?
2. If they do exist, is it possible to design preference elicitation mechanisms that can reduce such cognitive cost for efficient allocation?

- The contributions of this study
  1. We designed and executed experiments to analyze differences in elicitation mechanisms.
  2. Based on the experiment, we empirically showed that valuations and the number of representations vary depending on a preference representation system.
  3. The differences in the number of representations resulted in a thin market. A thin market means a market with a low number of transactions. As a result, the differences in the number of representations reduce the efficiency of the auction results.
  4. We showed that we can significantly improve the efficiency of auction via increasing the number of preference representations using the preference-prediction mechanism.

3. Experimental Design

- The objective of our experiment
  1. The differences of elicitation mechanisms have effect on the quality of participants' representation such as the number of representation which the subject represents the positive WTP and the value of WTP.
  2. As a result, the quality of participants' representations affects the allocation result and efficiency of auctions.

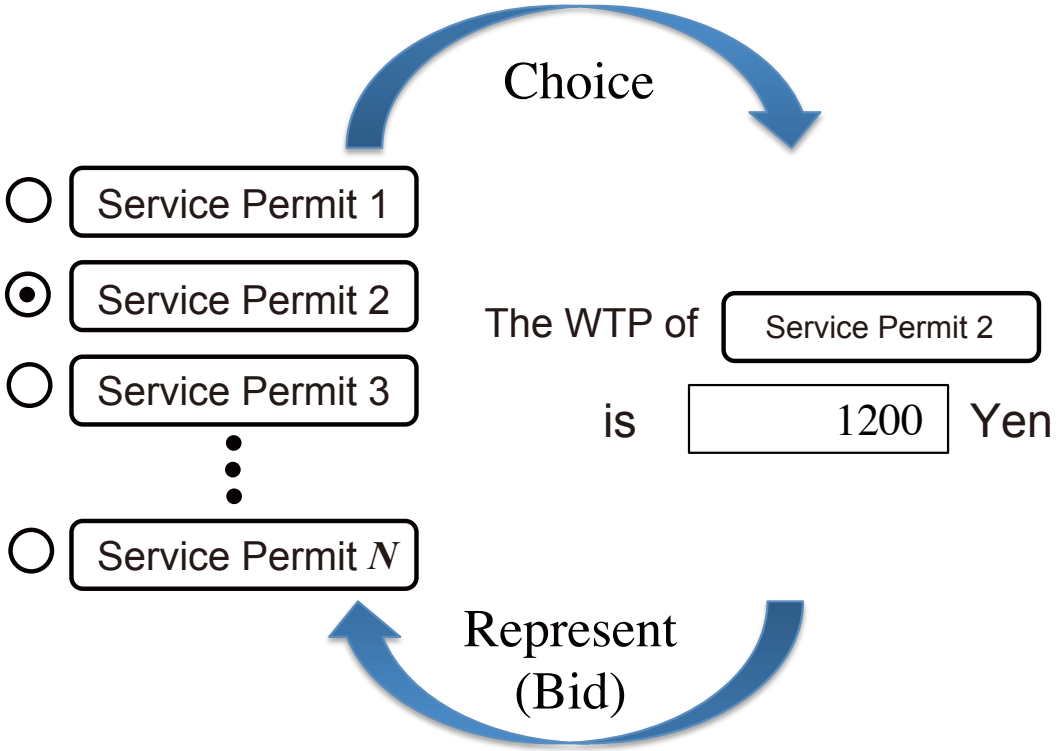
- The overview of this experiment
  - We collected 1647 participants who were 20-59 years old in the Tokyo metropolitan area.
  - Our experimental design is Randomized Controlled Trial (RCT). And we assigned participants to three groups (n = 550, n = 547, and n = 550) randomly.
  - Each participant represents the Willingness to Pay (WTP) for transportation service in three situations.

3-1. Three situations

- Situation 1: The reserved seat for rush hour commuter train in Tokyo metropolitan area
  - WTPs for reserved seat of rush hour commuter train.
  - The frequency of the train is every 15 minutes.
  - The time you start working is 9am.
- Situation 2: The flight from Tokyo to Fukuoka on business trip
  - WTPs for the flight from Tokyo to Fukuoka.
  - The frequency of flights is every 30 minutes.
  - The meeting begins at 1pm.
  - Your company pays all the travel fee.
- Situation 3: The flight from Tokyo to Okinawa for leisure trip
  - WTPs for the flight from Tokyo to Okinawa.
  - The frequency of flights is ever 1 hour.
  - You need to pay for your own round-trip flight.

3-2. Three preference representation mechanisms

1. step-by-step representation



(a) step-by-step representation

Choice and representation of WTP
Many page transitions occur.

3-2. Three preference representation mechanisms

2. all-in-one representation

The WTP of Service Permit 1 is 300 Yen

The WTP of Service Permit 2 is 1200 Yen

The WTP of Service Permit 3 is 500 Yen

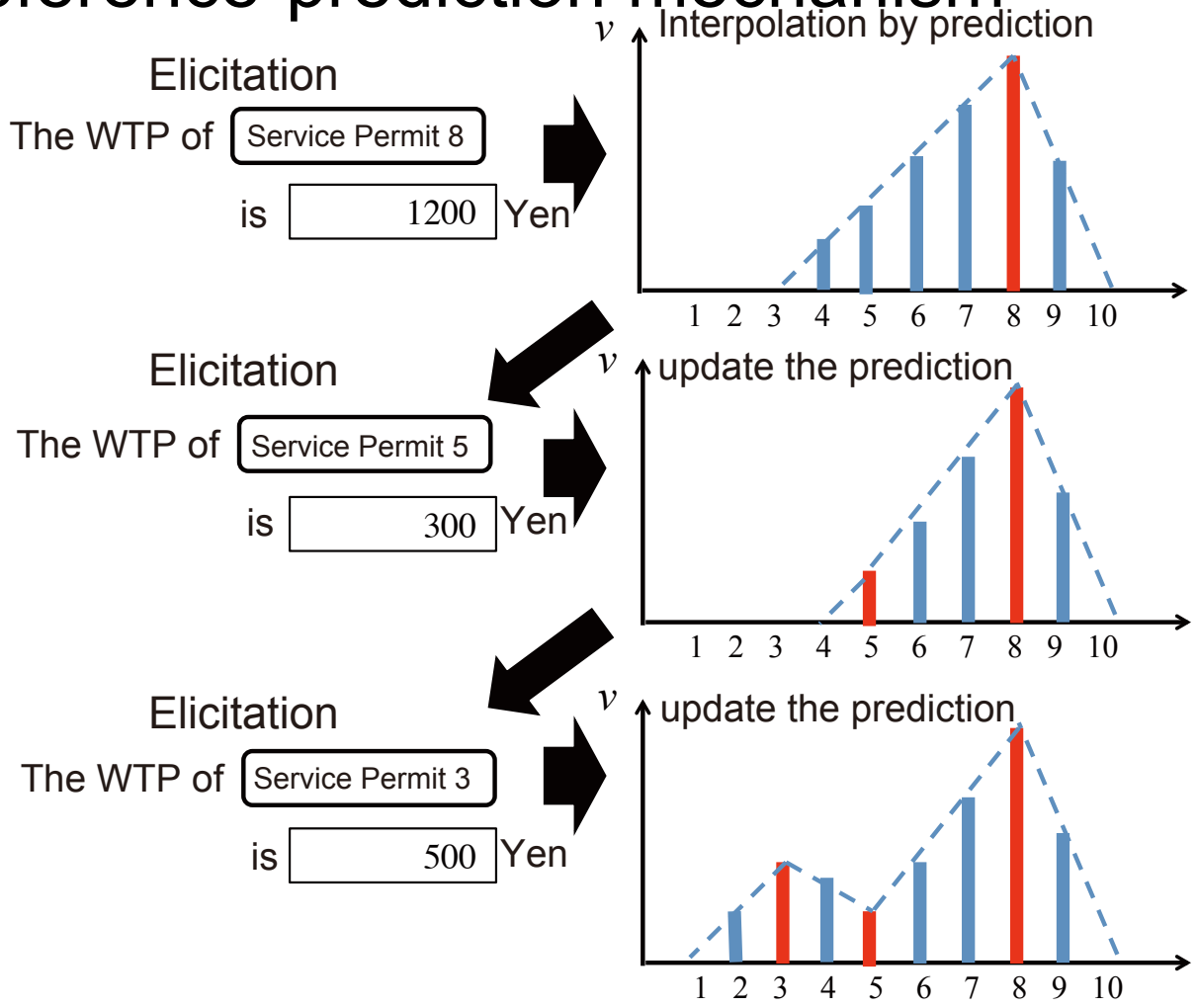
•
•
•

The WTP of Service Permit N is 0 Yen

All usage permits are presented in the table.
But you need to fill in the valuations for all usage permits.
(The default value is 0.)

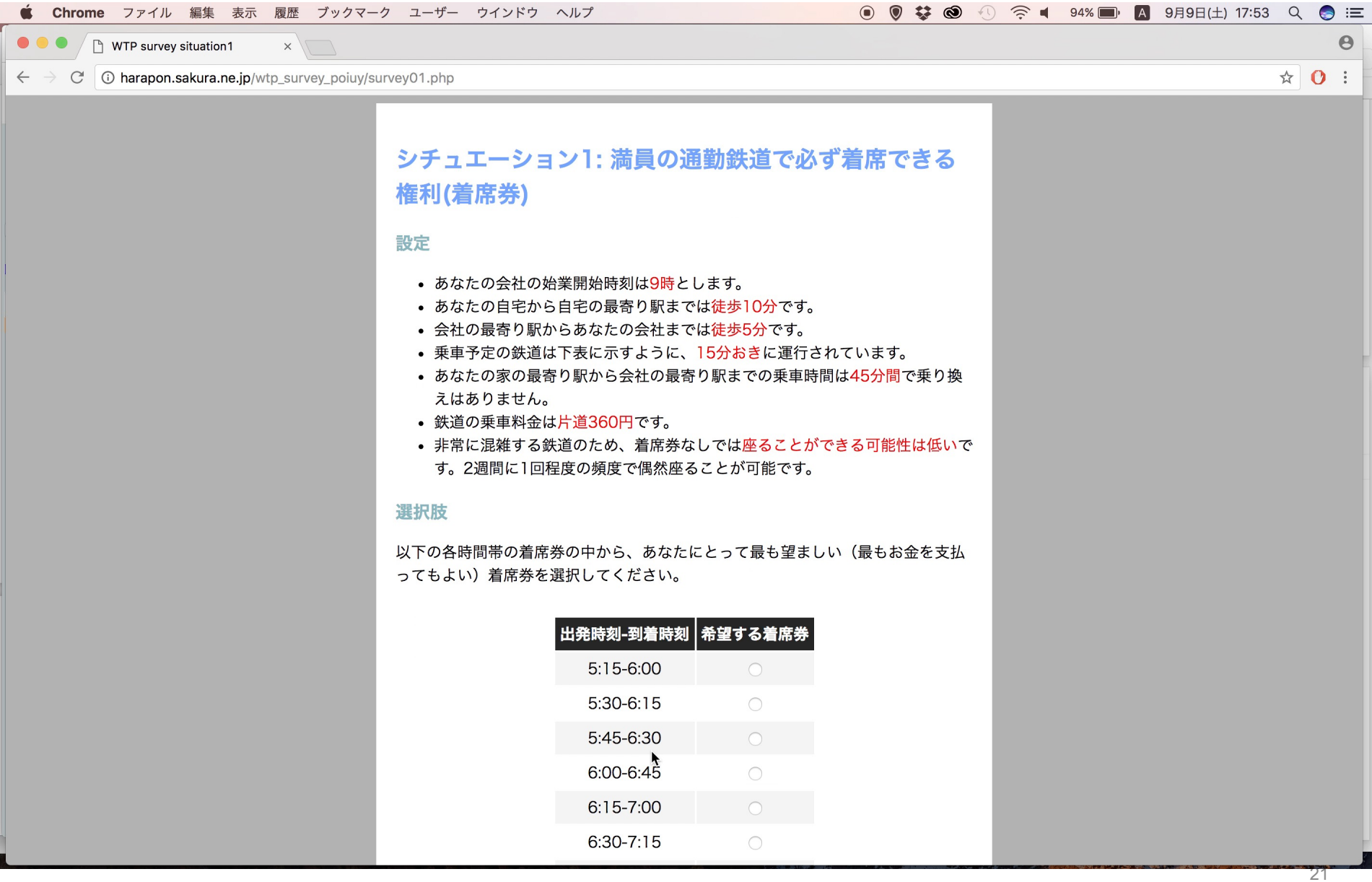
3-2. Three preference representation mechanisms

3. preference-prediction mechanism

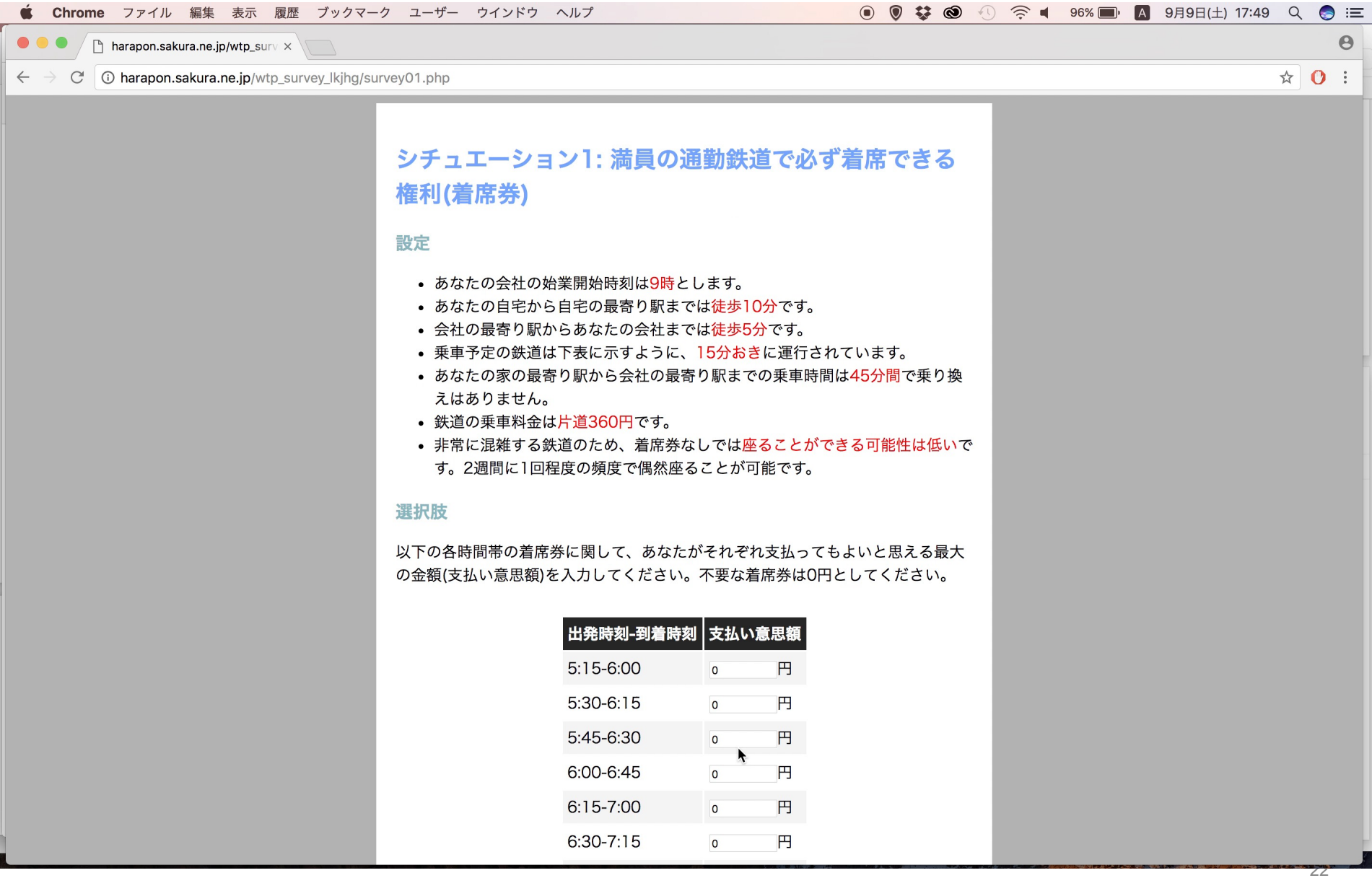


If you represent a valuation, the system predict the valuations of other time slot.
And you can modify the valuations which are predicted by the system.

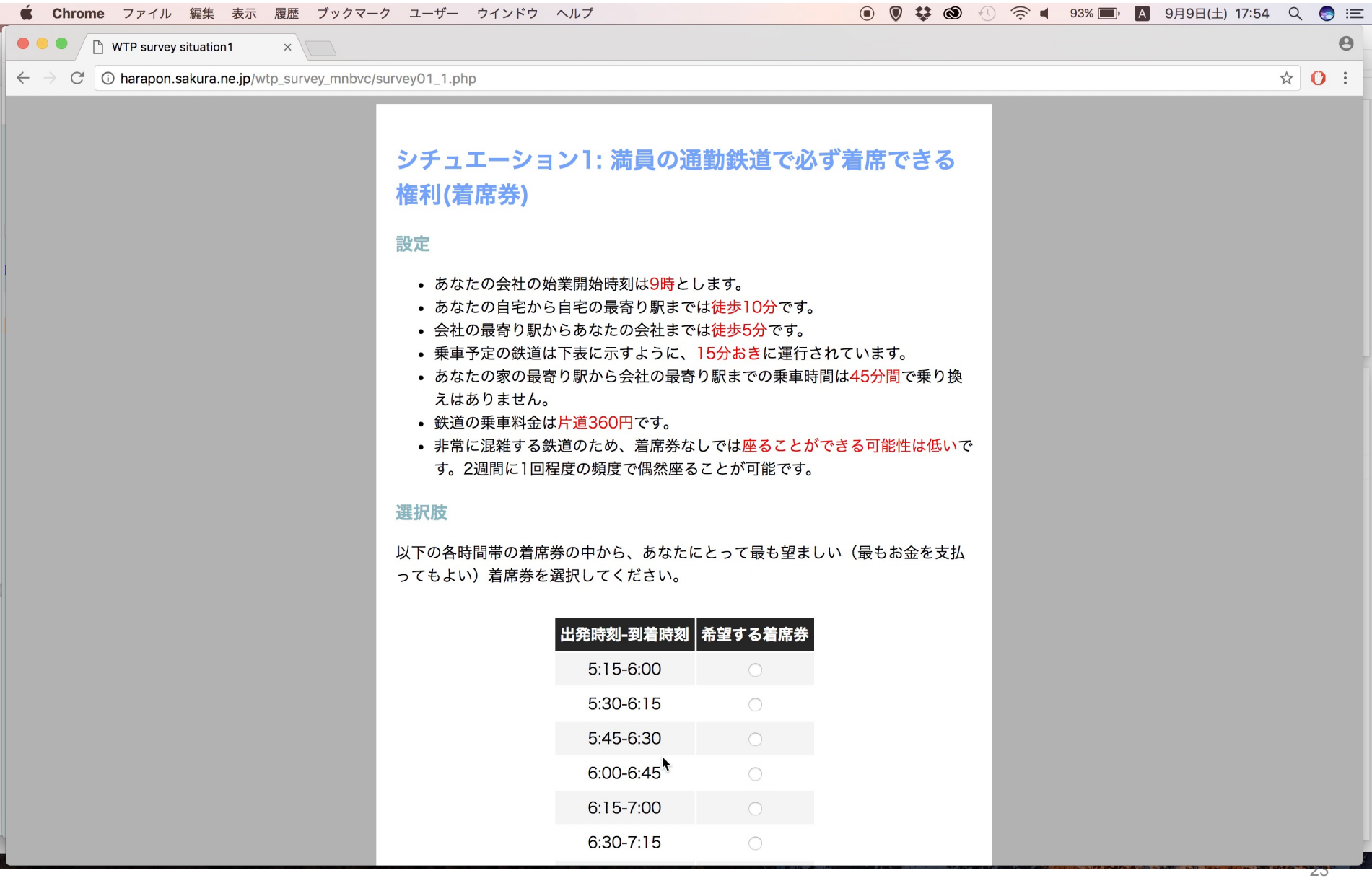
1. The example of step-by-step



2. The example of all-in-one

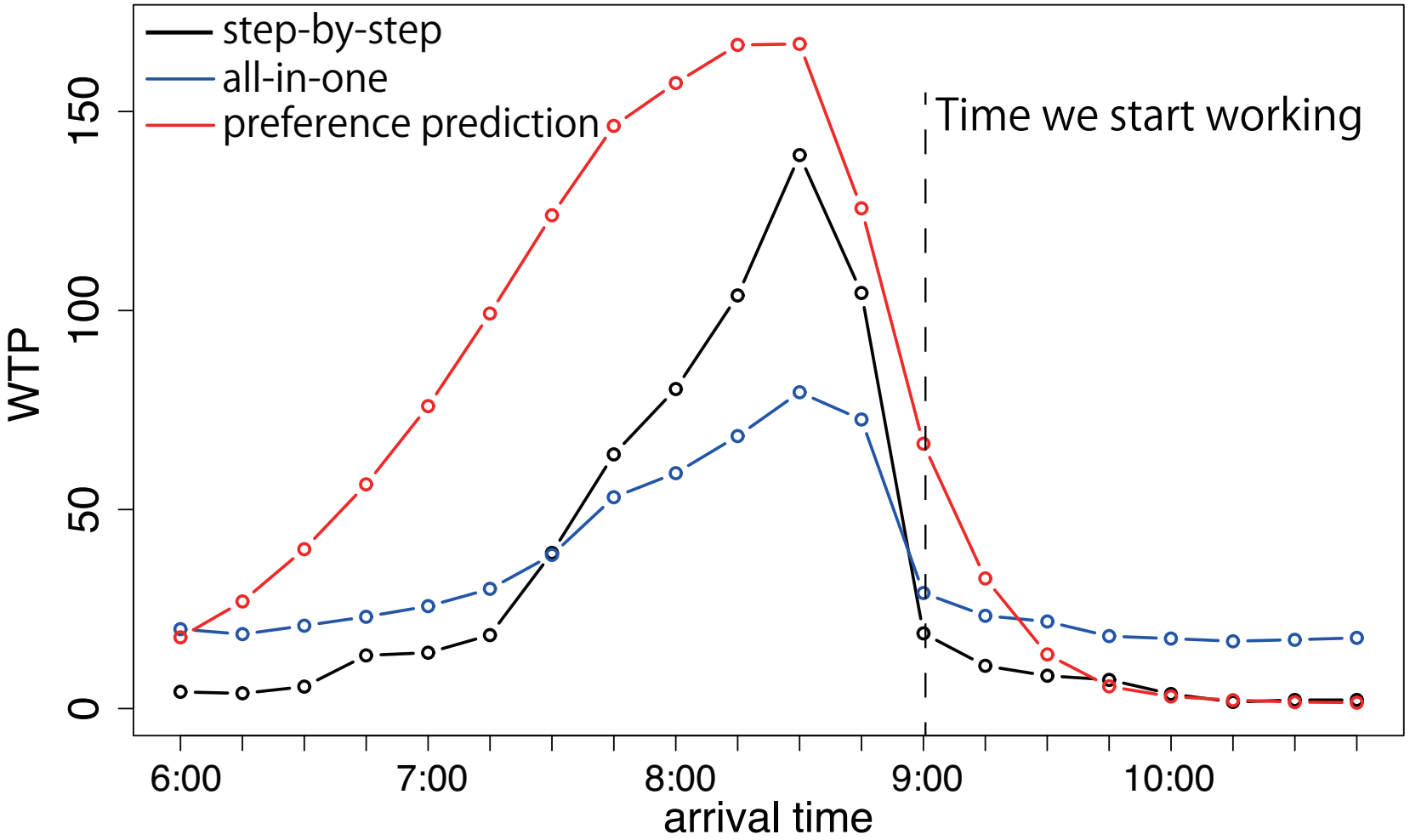


3. The example of preference-prediction



4. Results

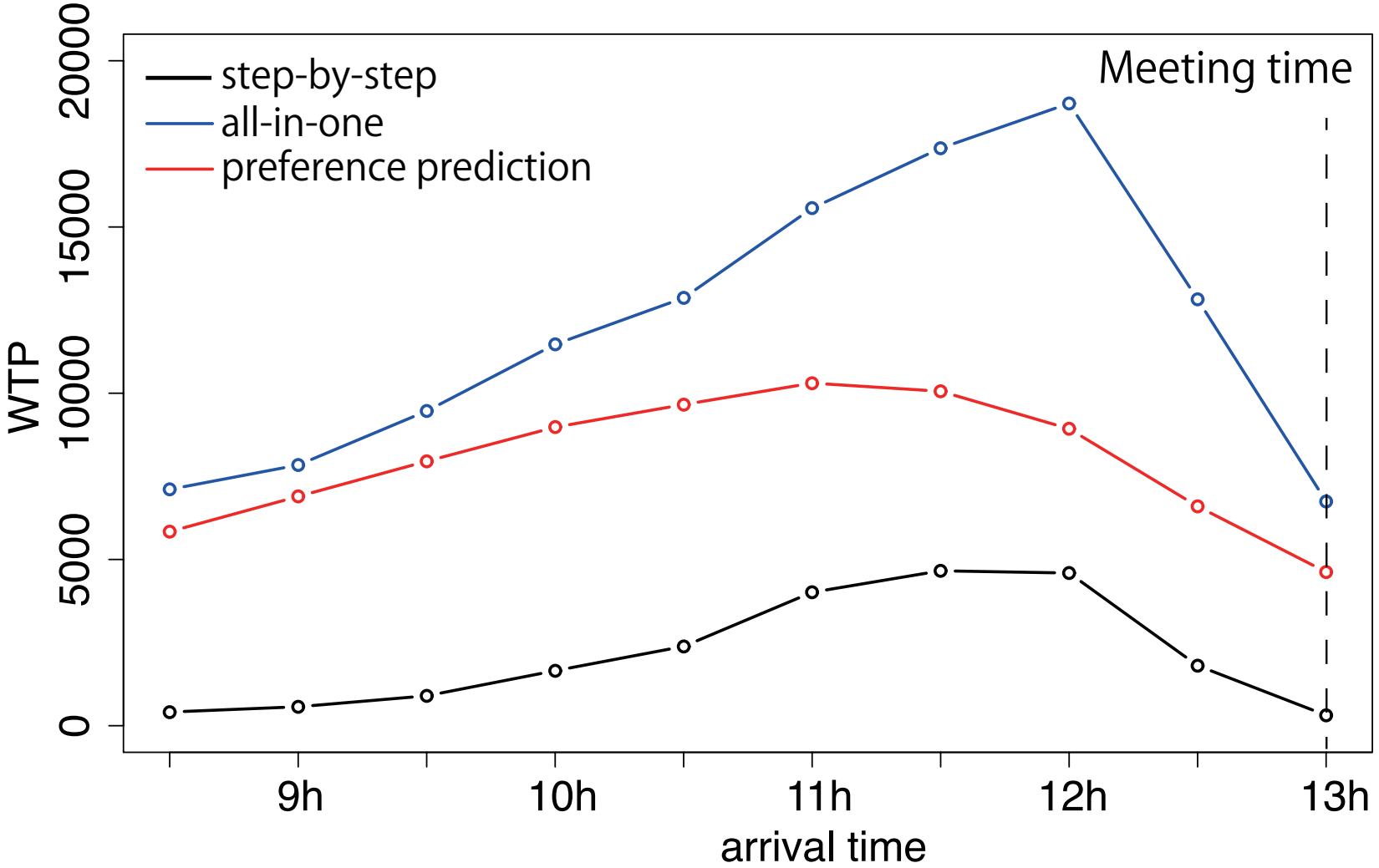
The average WTP of each time slot in situation 1



The arrival time of the most highest WTP is 8:30am in all elicitation mechanism.

4. Results

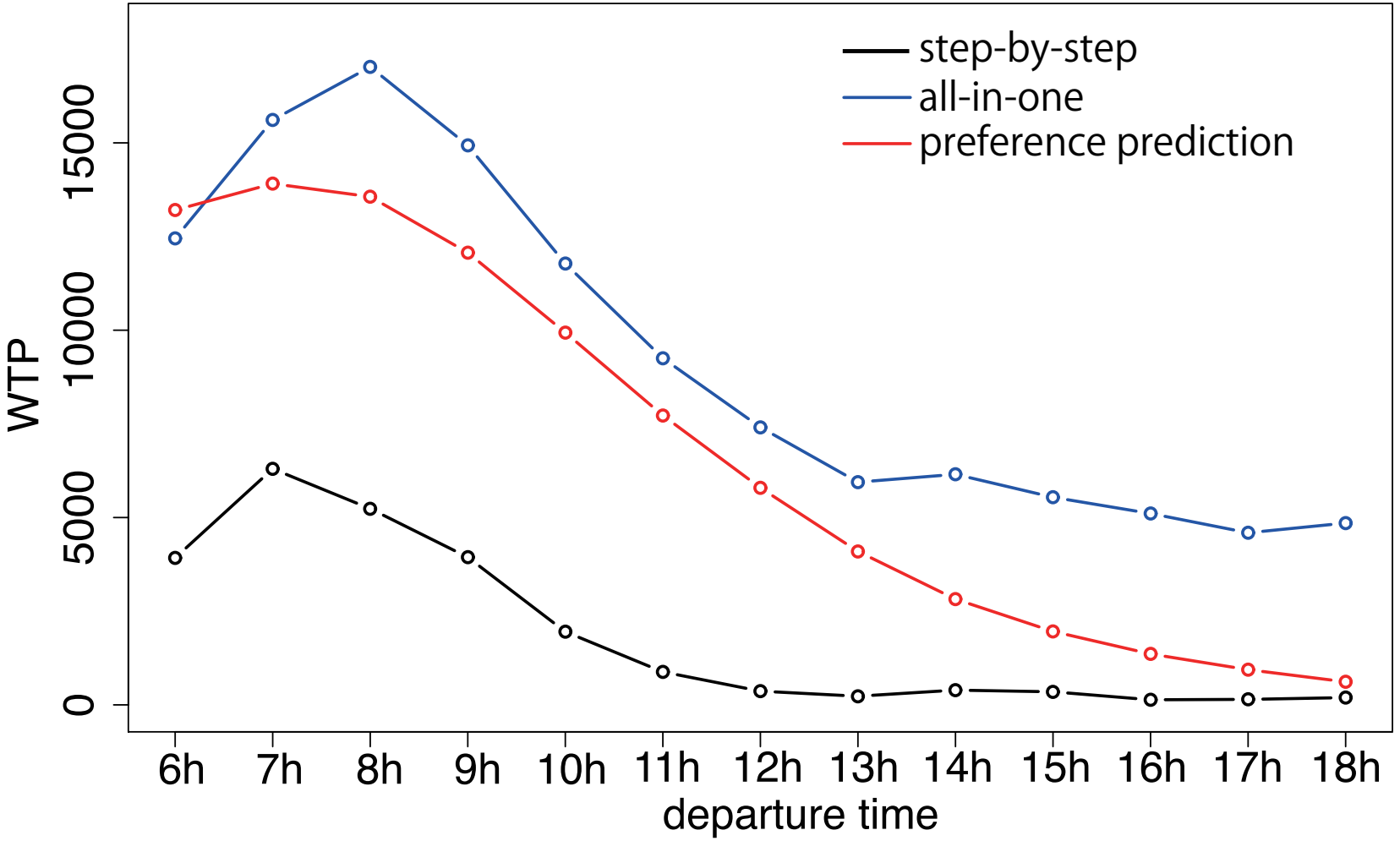
The average WTP of each time slot in situation 2



The desired arrival time is from 11am to 12am.
The WTP of all-in-one elicitation is higher than other mechanisms.

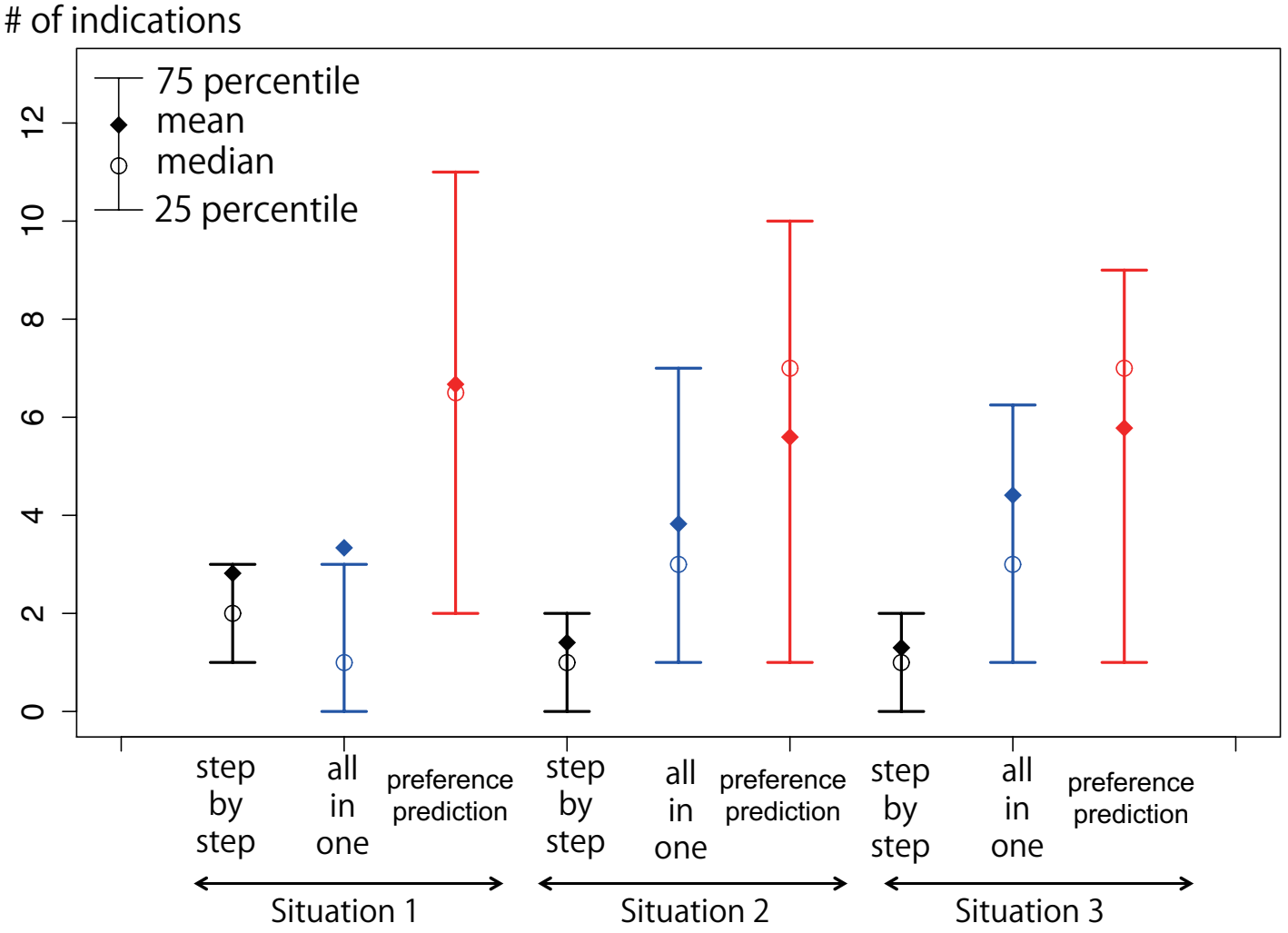
4. Results

The average WTP of each time slot in situation 3



The desired departure time is 7am or 8am.
The WTP of all-in-one elicitation is higher than other mechanism.

The number of representations of each participants in each elicitation mechanism



step-by-step: 2-3, all-in-one: 4-5, preference-prediction: 6-7

→Under the same situation and RCT, the preference elicitation mechanism has the impact on the number of representations.

5. The effect on the auction efficiency

- The preference elicitation mechanism has the impact on the number of representation.
  - A naïve elicitation mechanism results in thin market.
- The formulation of tradable permit auction

$$W(\boldsymbol{v}) = \max_{\boldsymbol{x}} \sum_{t \in T} \sum_{iinI} v^i(t) \cdot x^i(t)$$

$$\text{subject to}$$

$$\sum_{t \in T} x^i(t) \leq 1 \qquad \forall i \in I \qquad \text{single unit demand}$$

$$\sum_{i \in I} x^i(t) \leq \mu \qquad \forall t \in T \qquad \text{capacity limit}$$

$$x^i(t) \in \{0, 1\} \qquad \forall i \in I,\ \forall t \in T$$

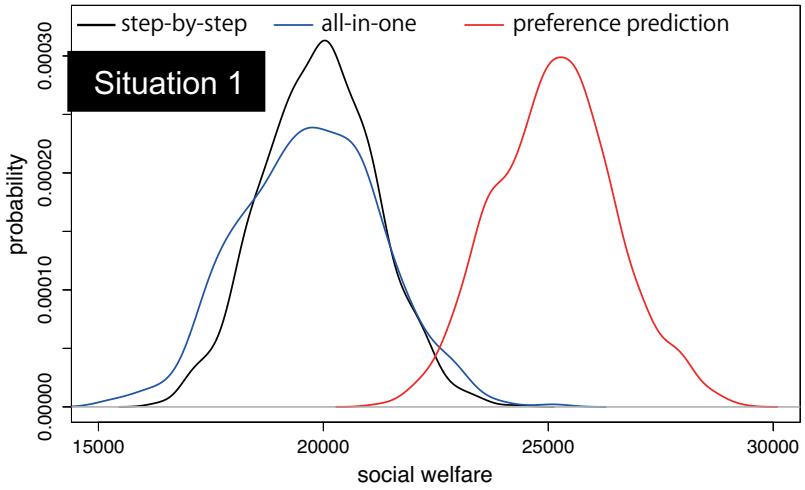
$\boldsymbol{v}^i = (v^i(1), \ldots, v^i(t), \ldots, v^i(|T|))$: Valuation vector of user i

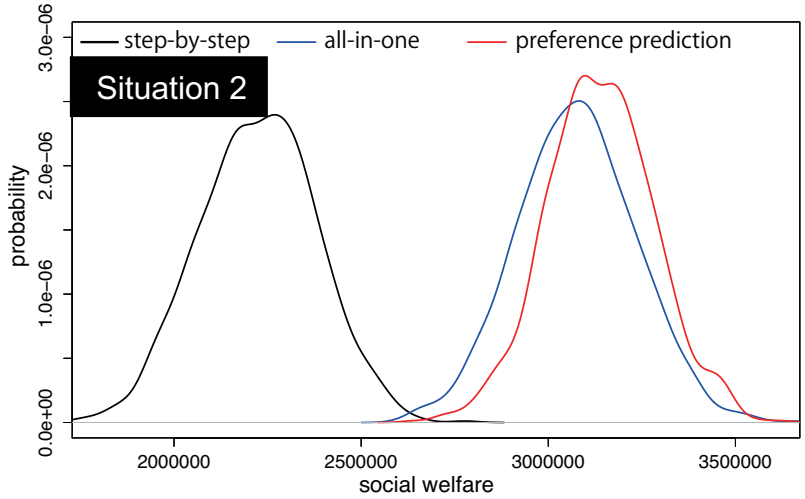
$x^i(t) \in \{0, 1\}$: Allocation variable of user i at time slot t

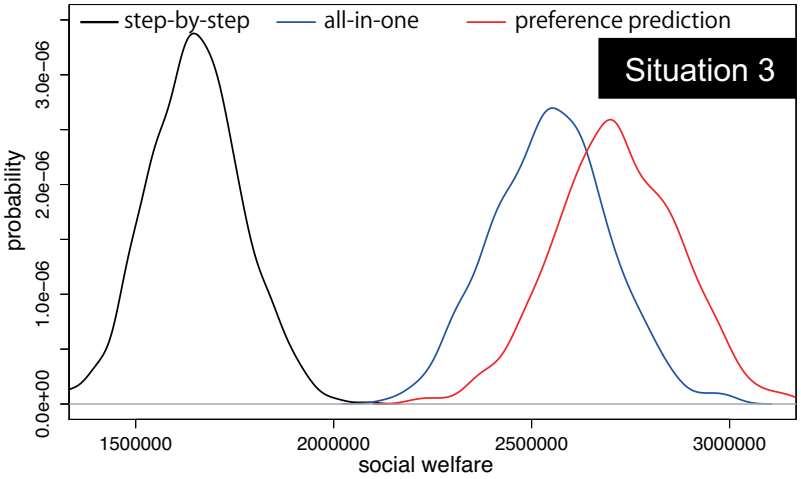
- From the participants set, we resampled 200 participants 1000 times.
- The capacity limit at all time slot is 100.

5-1. The difference of the efficiency

- The distribution of social welfare of each elicitation mechanism
  - The number of resampling: 1000







Under the all situations,
The preference prediction mechanism can achieve the efficient allocation.

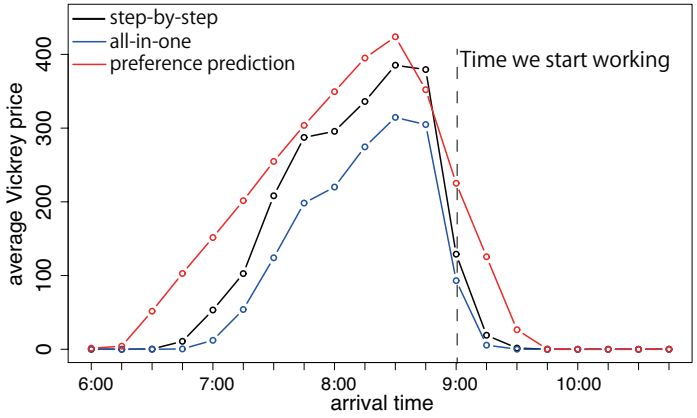
5-2. The difference of permit price

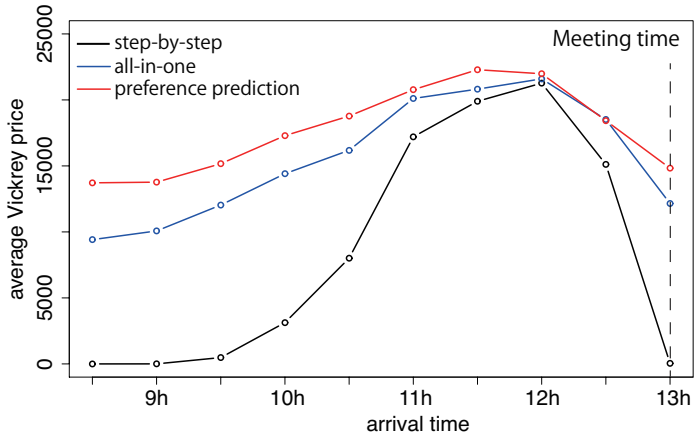
- The permit price (VCG payment) of each time slot
  - The payment of user i

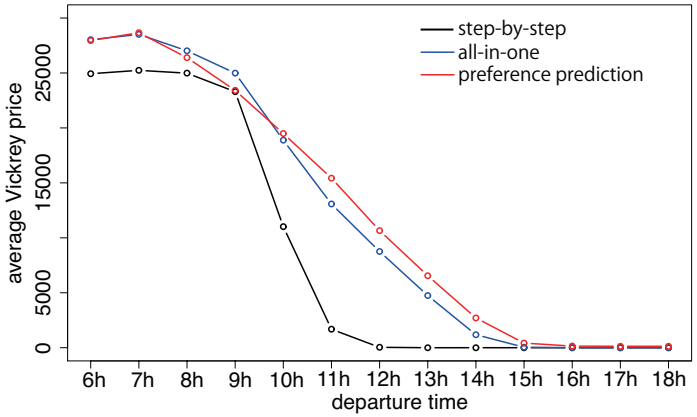
$$P^i(\boldsymbol{v}) = W\left(0, \boldsymbol{v}^{-i}\right) - W^{-i}(\boldsymbol{v})$$

Maximum Social Welfare without i in the bidders set

Maximum Social Welfare except i's value







The time slot of the most highest price is similar in all elicitation mechanism.

The preference prediction mechanism improves the price of time slots whose demand is low.

6. Conclusion

- The contributions of this study
  1. Design the experiments to analyze differences in elicitation mechanisms.
  2. Based on the experiment, we empirically showed that valuations and the number of representations vary depending on a preference elicitation mechanism.
  3. The differences in the number of representations resulted in a thin market. As a result, the differences in the number of representations reduce the efficiency of the auction results.
  4. We showed that we can significantly improve the efficiency of auction via increasing the number of preference representations using the preference-prediction mechanism.

- For future work
  - In repeated situations, we can improve the preference-prediction mechanism using historical data of each user.
  - If there are similar characteristics between items such as OD and timeslot, we may use the approach of collaborate filtering.

Thank you!

References

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