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# Vehicle-to-grid and car sharing: Willingness for flexibility in reservation times in Switzerland

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ABSTRACT

Combining vehicle-to-grid (V2G) with car sharing can substantially contribute to decarbonization of both energy and transportation sectors. Car-sharing users' booking slot flexibility is crucial for integration yet remains underexplored. We developed an integrated choice and latent variable model to estimate the value of financial incentives needed for shifting slots and how it is affected by socio-demographics, latent attitudes, trip-level characteristics. We conducted a stated preference survey with car sharing users in Switzerland. The value of time in our sample ranged between 22.4 CHF/h and 35.5 CHF/h (23.5 USD/h and 37.2 USD/h). Older adults, lower income groups, individuals in employment and with a university degree had lower time flexibility. Work, leisure, trips involving others, trips taking place during weekdays and morning peaks were harder to alter. This flexibility has the potential to encourage car-sharing operators and users to engage in V2G initiatives, contributing to decarbonization of transportation and energy systems.

## 1. Introduction

An increasing number of countries, cities, and businesses have committed to achieving net-zero emissions by 2050. Despite transportation accounting for a growing portion of global emissions, reducing emissions from this sector has proven to be particularly challenging. Transitioning to electric vehicles (EVs) and increasing the prevalence of car sharing programs are viewed as potential solutions to decarbonize the transport sector. EVs are expected to increase overall electricity demand as well as change the timing and scaling of peaks, requiring higher grid capacity and electricity generation (Das et al., 2020; Habib et al., 2018; Mullan et al., 2011). To minimize negative impacts of EVs on grid stability, smart and flexible charging technologies including vehicle-to-grid (V2G) are put forward as promising solutions for smoothing electricity demand (Guille and Gross, 2009; Kempton and Tomić, 2005). These technologies aim to promote flexibility by enabling consumers to benefit from lower cost off-peak electricity for charging and from the opportunity to sell unused power from car batteries back to the grid during times of peak demand or low renewable generation. Existing policy and research mostly focus on the benefits of EVs on grid capacity and energy price surge avoidance for car owners (Uddin et al., 2018; Huang et al., 2021; Kubli, 2022). Car sharing operators can, in principle, benefit from lower energy prices for charging their fleets and selling unused power back to the grid at peak times. Yet, it is poorly understood how the benefits of smart and flexible charging technologies could be used by car-sharing operators, and what the potential implications on

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user experience would be. The objective of this paper is to make a contribution to the existing literature by addressing this research gap by studying car-sharing user behavior and their degree of time flexibility. Understanding user flexibility and preferences will be crucial for car sharing operators on their decision to engage in V2G initiatives, contributing to the decarbonization of transportation and energy systems.

To benefit from V2G technologies, car sharing operators will require the operational set-up for charging when prices are low, and selling back to the grid at peak times. They will also need to ensure car-sharing users can access EVs when needed at the desired state-of-charge level. Operators can potentially influence users' booking behavior by incentivizing or de-incentivizing certain day-hours to optimize operations. On the user side, this will require flexibility in booking times. In this paper, our goal is to better understand users' willingness to offer temporal flexibility when using car-sharing in return for financial incentives. We first reviewed existing literature as presented in Section 2. We then used a combination of revealed preference (RP) data and stated preference (SP) data to understand the effects of selected determinant factors, including socio-demographics, subjective attitudes, and trip level attributes (Section 3). We estimated an integrated choice and latent variable (ICLV) model (Section 4). Based on the model results, we propose actions that can help encourage user flexibility in car-sharing systems (Section 5). The primary source of data is an SP survey conducted in German- and French-speaking parts of Switzerland undertaken by the authors in collaboration with one of the largest car-sharing companies in the country from October to December 2022.

## 2. Literature review

### 2.1. User behavior in vehicle-to-grid services

There has been extensive research on consumer behavior in the context of EVs focusing mostly on driving range and range anxiety, charging time, price of purchase and driving (Liao et al., 2017) with less focus on V2G capabilities (Noel et al., 2019). The acceptance of V2G technology was found to be influenced by factors such as attributes of the regulatory and operational framework for the market, range anxiety, level of financial incentives, and battery degradation (van Heuveln et al., 2021; Sovacool et al., 2018; Kester et al., 2018; Sovacool et al., 2019). Previous research using choice models for V2G mostly focused on analyzing attributes of contracts between aggregators and car owners. The aggregator acts as an intermediary between EV owners and energy markets for coordinating battery operations for an efficient V2G market. Aggregator contracts will have plug-in time requirements for EV owners in return for financial incentives. Existing work analyzed how different attributes of V2G contracts and technical attributes affect the owners' decision to participate in V2G contracts (Geske and Schumann, 2018; Kubli, 2022; Parsons et al., 2014; Huang et al., 2021). As expected, the amount of financial incentives (i.e. remuneration) had a positive impact on willingness to participate. The presence of fast charging technology was identified as a significant factor in the willingness of electric vehicle owners to engage in V2G contracts (Huang et al., 2021). Users expressed a high concern regarding the guaranteed battery levels (Geske and Schumann, 2018; Parsons et al., 2014) and the number of discharging cycles as they were worried about the potential negative effects on the battery. Plug-in time requirements had a negative and non-linear impact on users' willingness to participate, indicating that as the number of hours the cars needed to be connected to the grid increased, owners became less willing to participate (Parsons et al., 2014). Users had a preference for shorter contract duration (Parsons et al., 2014; Huang et al., 2021). In the context of the present study, car-sharing operators own fleets and have the capacity to participate in V2G markets without relying on third-party aggregators. However, certain findings remain highly pertinent. More specifically, prior research has shown that users place a high value on having the flexibility to drive when and for however long they need to, with minimal limitations or constraints. In this paper, we focus on their willingness to offer flexibility in booking times in return for financial incentives. We would expect less concern about battery degradation as they do not own vehicles. Although it falls outside the scope of the present study, we would expect that guaranteed battery level would also be a significant consideration for users of car-sharing services.

### 2.2. User behavior in car-sharing services

The rise of car-sharing programs attracted attention as a potential solution to the challenges posed by the growing ownership and usage of private vehicles, such as environmental degradation, traffic congestion, and parking space constraints (Shaheen et al., 1998; Shaheen and Cohen, 2013). Several studies, including those conducted by Shaheen et al. (1998), Shaheen and Cohen (2013), Becker et al. (2017a) and S. and Polak (2019), have demonstrated the influence of car-sharing services on both car ownership rates and the total distances traveled by car. Different business models including traditional station-based, one-way station based, and free-floating car sharing systems were considered (Becker et al., 2018, 2017a; Mounce and Nelson, 2019; Le Vine et al., 2014; Becker et al., 2017b). Both mid-term and short-term choice behavior were studied. The mid-term decision of enrolling in car-sharing programs and paying for membership was found to be affected by concerns related to the potential unavailability of vehicles, cost savings, experiences of existing users, and demographics (Kim et al., 2017c; Prieto et al., 2017; Efthymiou et al., 2013; Katzev, 2003; Zhou and Kockelman, 2011; Le Vine et al., 2014). Existing car-sharing programs were found to be mostly used by younger, higher-income, well-educated males who are employed and live in densely populated areas (Prieto et al., 2017; Kawgan-Kagan, 2015). Differences in user groups of car-sharing services were also identified (Ramos et al., 2020; Katzev, 2003; Kim et al., 2017b). Some users did not own a car and used car sharing to meet their occasional need for cars. Meanwhile, others who already owned private vehicles used car-sharing services to gain access to additional cars or specific attributes of available cars, such as the ability to transport large items.

Studies that focused on short-term trip-level mode choice decisions found that convenient access and proximity, travel time, price, availability of parking spaces, and social influence were influential along with trip specific attributes (e.g. carrying heavy or large equipment, traveling for children, and availability of seat facilities) (Kim et al., 2017a,b,c; Carrone et al., 2020; Balac et al., 2017; Ciari and Axhausen, 2012; Le Vine et al., 2014).

A recent literature review on electric vehicle car-sharing systems by Yao et al. (2022) covered studies focusing on both demand and supply side. Similar to traditional car sharing, users behavior were found to be influenced by supply side characteristics (e.g. time to the nearest car, vehicle types, charging time, prices), trip-specific attributes (e.g. weather, time of day, trip purpose), demographic and mobility attributes including car ownership. There are only a limited number of studies that focused on how V2G technology might affect car sharing user preferences (Caggiani et al., 2021; Prencipe et al., 2022). Recently, Gschwendtner and Krauss (2022) studied factors that affect the choice between conventional car sharing, electric vehicle car sharing, and V2G car sharing. In their stated preference design, attribute levels were identical for electric and V2G car sharing, and included remuneration, cost per hour, access and egress time, and scheme type (e.g. free floating vs. round-trip vs station-based). Respondents were asked to choose between alternatives with varying attributes and found that EV ownership and familiarity with V2G technology significantly and positively affected preferences towards V2G car sharing. These studies revealed that the uncertainty of car availability at the desired time is a significant factor in both mid-term and short-term user decisions. Willingness or reluctance of electric car sharing users' to shift desired booking times will, however, be a crucial factor for operators to benefit from V2G markets (Kim et al., 2017b; Shaheen et al., 2016; Ruhrort et al., 2014).

## 3. Car-sharing in Switzerland

Switzerland has a long history of car-sharing and more than 4% of the Swiss resident population with driving licence was a member of a car-sharing organization in 2021. This percentage is higher in urban areas (6%) followed by suburbs (3%), and much lower at 1% in rural areas (FSO and ARE, 2023).

Among the 10% of the Swiss resident population living in the densest neighborhoods, one out of 10 people (9%) was a member of a car-sharing organization in 2015. At the extreme opposite, among the 10% of the people living in the least dense neighborhoods, this rate is only 1%. 13% of people having more than one car of Mobility, the main car-sharing organization in Switzerland, within a 300-meter radius, are car-sharers. If there is no car in this radius, the rate is only 3% (Bubenhofer et al., 2018).

Car sharing represents 0.11% of the average daily distance within Switzerland made by the resident population (33 meters out of 30 kilometers). It corresponds to 0.16% of the distance covered by car (33 meters out of 21 kilometers).[1]

## 4. Data collection

### 4.1. The survey

The data used in this paper was specifically collected to study the effect of price incentives on users' willingness to shift reservation times when using car-sharing services. We partnered with one of the largest car-sharing companies in Switzerland for data collection as the population of interest was active users of car-sharing. While the primary interest in understanding user flexibility is to provide insights for V2G integration when using EVs, the share of EVs in the vehicle fleet was lower than 5% hence many users did not have experience with using EVs for car-sharing. Previous studies suggest that long surveys and a lack of previous experience may lead to unrealistic behavior and biased results (Louviere et al., 2000). Therefore, we designed the stated preference experiment to ask about willingness to shift reservation times given pricing incentives and excluded variables specific to EVs (e.g., guaranteed battery levels). Existing users of car-sharing were ideal for this study since they have experience with choosing booking slots. The survey consisted of six sections (see Supplementary Information for the full list of questions that were included in the survey):

1. The first section focused on collecting some socio-demographic information about respondents (age, gender, level of education) and information on vehicle ownership, travel passes, car-sharing memberships, and frequency of using different travel modes. Participants were also asked to indicate their frequency of car-sharing use for different activity purposes (e.g., commuting, shopping, socializing).
2. The second section aimed at collecting information about the respondents' attitudes and perceptions toward time flexibility and price sensitivity.
3. The third section collected detailed information about respondents' most recent mobility booking (pick-up time and location, drop-off time, activities conducted during booking, number of people traveled with, total price paid, vehicle category, number of km driven, how far in advance of the start time reservation was made).
4. The fourth section collected information about specific constraints that might have affected time flexibility on the specific day of the most recent booking (e.g. restrictions on how early and late respondents could have departed).
5. The fifth section consisted of a stated choice (SC) experiment, pivoted around values in the third section. The SC included two attributes related to the booking: time of reservation and total cost. A more detailed description of the SC experiment is provided in Section 4.2.

[1] Computed using the 2021 data of the Mobility and Transport Microcensus (FSO and ARE, 2023). The sample size is 55'018 persons. The code used for the analysis is available at https://github.com/antonindanalet/use-of-car-sharing-in-Switzerland.

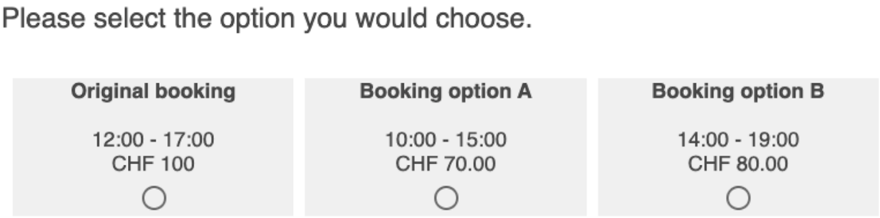


**Fig. 1.** Stated preference choice situation: example screenshot from the survey.

6. The last section asked more detailed questions on demographics including household size, type, income and type of residential location (e.g., city centre, suburbs, rural).

We designed the survey and hosted it online on Qualtrics. The length of the survey was approximately 15–20 min. We collaborated with a car sharing company in Switzerland for recruitment. A random sample of 10,000 active users (defined as having made a booking in the last months) residing in German and French speaking parts of Switzerland were invited to participate via e-mail by the car-sharing company. Taking part in the survey was voluntary and participants were incentivized to participate with the option to be entered into a prize draw to win one of five CHF 100 gift vouchers on completion. No reminders were sent to respondents. From the total number of invitations sent, 10.2% (1020 out of 10,000) have at least entered the online survey, and 7.7% (777 out of 10,000) completed the full survey including the SC experiment. The responses from the 172 customers who have clicked on the link from the invitation e-mail but did not complete the survey were not used in the analysis.

### *4.2. Stated choice experiment*

In the third section of the survey, respondents were asked to complete basic information about their most recent booking. They could use their smart phone app of the car sharing service to retrieve their booking histories including time of the booking and the total amount paid. Based on this information, for the stated-choice experiment part, respondents were presented with a series of five hypothetical choice situations where they were asked to choose between two alternative settings (alternative A and B) for shifting their booking times in return for financial incentives. For each choice situation, they also had the option to stick with their original booking slot. The attribute levels of alternatives A and B were pivoted around the attribute levels of the original booking which is considered as the reference alternative. The duration of their booking was kept the same as their original booking.

The choice attribute levels were as follows: (i) four levels for shifting booking times (by −2, −1, 1, 2 h, i.e., one or two hours earlier or later than its original time), (ii) three levels of financial incentives in the form of percentage reductions in total cost of booking (10%, 20%, 30%). The experimental design was based on a random design where choice tasks are randomly chosen from full factorial design and we also removed choice tasks where one alternative dominated the other (e.g. higher incentive offered for a shorter time shift). An example of choice situation is shown in Fig. 1 .

The final dataset used for model estimations consisted of 777 survey responses completed between 28 October 2022 and 8 December 2022.

### *4.3. Sample characteristics*

Socioeconomic characteristics of our survey sample are presented in Table 1 along with comparisons with the Swiss population (FSO and ARE, 2023). We note that no census information is available specifically for car-sharing users, hence population statistics are used as a proxy for comparison. As expected, car-ownership rates are much lower in the study population, with 79.5% households with no cars compared to the 22% for the Swiss population. Men with higher educational attainment in higher income groups who are in employment are over-represented in our study sample. While this is mostly in line with previous literature (Ramos et al., 2020; Dias et al., 2017; Mouratidis, 2022), Switzerland differs from other countries since older age groups are also likely to be users of car-sharing, potentially due to the long history of car-sharing cooperatives in Switzerland (Shaheen et al., 1998).

## 5. Modeling methods

### *5.1. Integrated choice and latent variable framework*

We used an Integrated Choice and Latent Variable (ICLV) model for incorporating latent behavioral constructs relating to time flexibility within the traditional discrete choice framework used for individual decision making (McFadden, 1986; Train et al., 1987; Ashok et al., 2002; Ben-Akiva et al., 2002). In line with the ICLV framework, there were two components to our model formulation: a multinomial discrete choice model and a latent variable model. The discrete choice component is consistent with the random utility maximization theory; individuals choose the alternative with the largest utility where the utility is defined as a function of observed and latent attributes of alternatives and characteristics of decision makers. The latent attitudes are measured by responses to Likert-scale survey questions and modeled as a function of socio-demographic characteristics. The model is represented by Fig. 2 adapted

**Table 1**
Comparative distribution of socio-demographics and mobility characteristics.

| | Survey sample % | Switzerland % |
|---|---|---|
| Age | | |
| 20–39 years | 30.4 | 32.6 |
| 40–64 years | 57.1 | 43.6 |
| 65–79 years | 12.4 | 17.0 |
| 80 years and older | 0.2 | 6.7 |
| Gender | | |
| Female | 21.9 | 50.4 |
| Male | 78.1 | 49.6 |
| Car ownership | | |
| No cars | 79.5 | 22 |
| With cars | 20.5 | 78 |
| One car | 17.1 | 49 |
| Two cars | 2.6 | 23 |
| Three or more cars | 0.8 | 6 |
| Household size | | |
| 1 person | 24.1 | 36.8 |
| 2 persons | 37.1 | 32.7 |
| 3 persons | 14.7 | 12.8 |
| 4 persons | 16.2 | 12.3 |
| 5 or more persons | 7.9 | 5.4 |

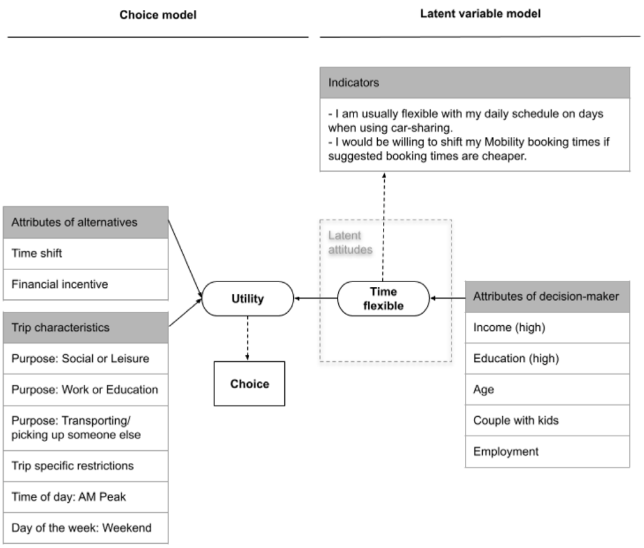


**Fig. 2.** Modeling framework.

from Atasoy et al. (2013). We included a separate set of questions to capture attitudes relating to time flexibility and price sensitivity (Table 2). While the initial factor analysis identified several factors capturing separate latent behavioral constructs, parameters associated with price sensitivity were not found to be significant in the final choice model. Therefore, we used one latent variable to capture time flexibility in the final specification. In Fig. 2, observed variables (i.e. socio-demographic variables, psychometric indicators, and choices) are represented by rectangles and latent variables (i.e. attitudinal variables, utilities) are represented by ovals. In our formulation, socio-demographics has an influence on choice behavior through attitudinal variables only and were not directly included in the utility specification. We estimated all parameters simultaneously using PandasBiogeme (Bierlaire, 2020, 2003). We omitted variables that were insignificant (e.g., sex, residential area type) from the final specification. An alternative formulation could have been including the psychometric indicators directly in the choice model as an explanatory variable without latent variables to explain choice behavior. However, as suggested by Vij and Walker (2016), this approach does not offer insights on models' forecasting ability in practice as we do not have information on measurement indicators; we therefore used the ICLV framework.

**Table 2**
Results of factor analysis using indicators.

| Indicators | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| T1: I am usually flexible with my daily schedule on days when using car-sharing. | | 0.587 | |
| T2: It is very important to me to have a Mobility car available to me exactly when and where I need it. | | | 0.719 |
| T3: I would be willing to shift my Mobility booking times if suggested booking times are cheaper. | | 0.725 | |
| T4: Schedule compliance/punctuality is very important to me when using car-sharing. | | | 0.549 |
| P1: I do not mind booking a car from a station that is further away if it costs less money. | | | |
| P2: I usually choose the cheapest Mobility car available to me. | | | |
| P3: I try to limit kilometers driven when using Mobility to avoid high costs. | 0.668 | | |
| P4: I keep my reservation periods to a minimum so that I pay less. | 0.662 | | |
| P5: I usually book some extra time to avoid penalties for returning the car late. | | | |

### 5.2. Latent variable model

In Section 2 of the online survey, we collected information about respondents' attitudes and perceptions toward time flexibility and price sensitivity. We asked the participants to indicate the degree to which they agreed with a set of statements (Table 2) on a Likert scale ranging from 1 (does not apply at all) to 5 (very much applies), related to their experience by asking "How much do these statements apply to you when you use car-sharing?". As common with psychometric measurements, when gathering indirect measurements for latent concepts, some of these statements were designed to overlap. First, we performed factor analysis on the psychometric indicators using the statsmodels library in Python (Seabold and Perktold, 2010) to calculate the loading coefficient for each factor and each question associated with latent factors. All coefficients that were above 0.5 in absolute value are presented in Table 2. As shown in Table 2, we label the questions with a letter (T for time flexibility questions, P for price sensitivity questions). We initially selected two latent factors (Factor 1 and Factor 2 in Table 2), which we label as *time flexible* as measured by questions T1 and T3 and *price sensitive* as measured by questions P3 and P4. We used the corresponding indicators as inputs to the latent variable model, leaving out T2, T4, P1, and P5. The parameters associated with price sensitivity were found not to be significant in the final ICLV estimations. Therefore, we focus on the latent attitude variable, *time flexible*, for the rest of this paper. The structural equation for the latent attitude variable, *time flexible*, is defined by Eq. (1).

$$\begin{aligned} A_{TF} = {} & \beta_0^{TF} + \beta_{age}^{TF} AGE + \beta_{inc}^{TF} Y_{highinc} + \beta_{edu}^{TF} Y_{highedu} \\ & + \beta_{emp}^{TF} Y_{employed} + \beta_{kids}^{TF} Y_{couplewkids} + \sigma_{TF}\epsilon^{TF} \end{aligned} \tag{1}$$

where $\beta_0^{TF}$ is the constant for the time flexibility attitude to be estimated, $AGE$ represents the age of the respondent. Dummy variables were associated with having a high income, $Y_{highinc}$, (monthly income over CHF 16,000), having a university degree, $Y_{highedu}$, being employed, $Y_{employed}$, and household type being couple with children, $Y_{couplewkids}$. $\epsilon_{TF}$ is a random variable normally distributed with mean 0 and variance 1, and $\sigma_{TF}$ is estimated.

Measurement equations for latent attitudes were built using indicators T1 and T3 for the *time flexible* attitude as presented in Eq. (2). We expected people who are more time flexible to agree with both T1 and T3; we used T1 to define the units and scale of the latent variable $A_{TF}$, and keep the signs in the same direction. The latent variable $A_{TF}$ can therefore be interpreted as time flexibility. Measurements used a Likert scale with 5 levels, the probability of a response on a Likert scale is then modeled using ordered probit.

$$\begin{aligned} I_{T1} &= A_{TF} \\ I_{T3} &= \beta_{0_{T3}}^{TF} + \beta_{T3}^{TF} A_{TF} + \sigma_{T3}\epsilon_{T3} \end{aligned} \tag{2}$$

where $I$ represent psychometric indicators included in the survey, $\beta$ and $\sigma$ are parameters to be estimated, $A_{TF}$ represents latent attitude associated with time flexibility, $\epsilon_{T3}$ is a random variable normally distributed with mean 0 and variance 1.

### 5.3. Discrete choice model

In the stated choice experiment, respondents choose between sticking with their original booking slot (i.e. *status quo* alternative, short SQ) and two additional alternative settings (alternative A and B) for shifting their booking times in return for financial incentives. In line with the random utility theory, the utility function $U$ has a random and deterministic component. The deterministic component $V$ of the utility function associated with the three alternatives ($V_{SQ}, V_A$ and $V_B$) were defined as follows.

$$\begin{aligned} V_{SQ} &= ASC_{SQ} + \beta_{weekend} Y_{weekend} + \beta_{AM\,Peak} Y_{AM\,Peak} + \beta_{restrict} Y_{restrict} \\ &\quad + \beta_{leisure} Y_{leisure} + \beta_{work} Y_{work} + \beta_{someoneelse} Y_{someoneelse} \end{aligned} \tag{3}$$

$$V_A = \beta_{tr} e^{\beta_{TF} A_{TF}} TIMESHIFT_A + \beta_f INCENTIVE_A \tag{4}$$

$$V_B = \beta_{tr} e^{\beta_{TF} A_{TF}} TIMESHIFT_B + \beta_f INCENTIVE_B \tag{5}$$

where trip-specific characteristics including dummies for trip purposes ($Y_{leisure}$, $Y_{work}$, $Y_{someoneelse}$), bookings starting between 6am to 9am ($Y_{AM\,Peak}$) and on the weekend ($Y_{weekend}$), and having reported any time restrictions ($Y_{restrict}$) that affect the utility of the *status quo* alternative ($U_{SQ}$). Latent variables are introduced in the coefficient of the travel time. The behavioral assumption is that the sensitivity to time shifts in booking slots is different depending on attitudes related to *time flexibility*. $A_{TF}$ is included in the utility function via the exponential to ensure the overall sign of the time coefficient does not change. Estimations were carried out simultaneously for the ICLV model using PandasBiogeme (Bierlaire, 2020). We also took the panel effects into account using a mixed logit specification where we included an error component that is individual specific for $U_A$, $U_B$, and $A_{TF}$; however, this did not improve the model fit.

## 6. Results and discussion

### 6.1. Estimation results

Full estimation results are presented in Table 3. For measurement equations, the set of indicators were related to statements T1 and T3 focusing on time flexibility. As expected, we found that the coefficient estimate for $B_{T3}^{TF}$ was positive, in line with our expectations and intuition as the latent variable $A_{TF}$ can be interpreted in terms of time flexibility. The intercept and scale capture measurement errors across different measurement questions.

We found that older individuals are less flexible with their times (negative coefficient estimate for $\beta_{age}^{TF}$). We also found, as expected, that employment and having a university degree were associated with lower time flexibility (negative estimates for $\beta_{emp}^{TF}$ and $\beta_{edu}^{TF}$). Coefficient estimates associated with the dummy variable for *couple with children* and higher income were positive, suggesting higher time flexibility for these individuals.

For the choice model, we find that people tend to stick with their original booking times for leisure or social trips, work trips, as well as trips involving picking up someone else. Interestingly, work or education trips had the smallest effect compared to leisure and social trips. This suggests that people are most reluctant to change booking times when they use car-sharing to participate in activities involving other people. As expected, users are more reluctant to switch booking times on weekdays compared to weekends and when they reported trip-specific constraints in the survey for conducting the activity on another time or day. Specifically, trips that take place during morning peaks (between 6am and 9am) were found to be most difficult for users to switch from their desired times.

The coefficient estimate associated with the financial incentive, $\beta_f$, was positive as expected; decision makers derive a positive utility from financial incentives offered. The reference parameter estimate associated with time shift $\beta_{tr}$ was negative, in line with our expectation as individuals dislike rescheduling their booking times. The negative parameter $\beta_{TF}$ captures the impact of time flexibility with respect to the beta time parameter. Time flexibility reduces the level of dis-utility associated with the rescheduling time so that individuals who are more flexible with their times are less concerned about rescheduling their booking slots. As it is difficult to interpret these values just by looking at the parameter estimates, we also evaluated value of time across the sample population in the next subsection.

### 6.2. Analysis of the value of time

We analyzed the value of time (i.e. the value of flexibility) by looking at the willingness to shift booking times in return for financial incentives. As we included the latent variable in the time coefficient, it influences the value of time. Value of time is the ratio between the derivative of the utility function with respect to time, divided by the derivative of the utility function with respect to the financial incentive. We also multiply this value by 1000 to get the value of time in CHF/h as the financial incentive variable was scaled by 0.001 for estimations. The reference value of time is 33 CHF per hour, i.e. the amount of financial incentive needed to shift booking times by one hour. This value gets smaller for individuals with higher time flexibility since the $\beta_{TF}$ estimate is negative.

We estimated the value of time across the sample population as shown in Fig. 3. In this plot, each dot represents an individual in the sample. For each individual, we calculated the expected attitude of time flexibility from the structural equation (which is on the x-axis). We also computed the value of time (y-coordinate) for each individual, using the following formula:

$$VOT = 1000 \frac{\beta_{tr} * e^{\beta_{TF} * A_{TF}}}{\beta_f} \text{ CHF/h} \tag{6}$$

**Table 3**
Estimation results.

| | Value | SE | | Value | SE |
|---|---|---|---|---|---|
| $ASC_{SQ}$ | −1.380** | 0.148 | $\beta_{age}^{TF}$ | −0.008** | 0.003 |
| $\beta_{AM\,Peak}$ | 0.360** | 0.123 | $\beta_{kids}^{TF}$ | 0.131** | 0.045 |
| $\beta_{leisure}$ | 0.680** | 0.087 | $\beta_{emp}^{TF}$ | −0.219** | 0.074 |
| $\beta_{someoneelse}$ | 1.110** | 0.138 | $\beta_{edu}^{TF}$ | −0.236** | 0.080 |
| $\beta_{work}$ | 0.672** | 0.149 | $\beta_{inc}^{TF}$ | 0.057** | 0.019 |
| $\beta_{restrictions}$ | 1.090** | 0.096 | $\beta_{0}^{TF}$ | 0.875** | 0.338 |
| $\beta_{weekend}$ | −0.244** | 0.078 | $\beta_{0_{T3}}^{TF}$ | 0.021 | 0.062 |
| $\beta_{f}$ | 37.00** | 3.232 | $\beta_{T3}^{TF}$ | 1.440** | 0.462 |
| $\beta_{tr}$ | −1.220** | 0.100 | $\sigma_{TF}$ | 0.713*** | 0.242 |
| $\beta_{TF}$ | −0.446* | 0.195 | $\sigma_{T3}$ | 0 | 0 |
| Number of respondents | | 777 | $\mathcal{LL}_0$ | | −20933 |
| Number of choice observations | | 3885 | $\mathcal{LL}_{\hat{\beta}}$ | | −13929.43 |
| Number of estimated parameters | | 22 | $\rho^2$ | | 0.33 |

*: $p < 0.05$, **: $p < 0.01$, SE: Standard Error.

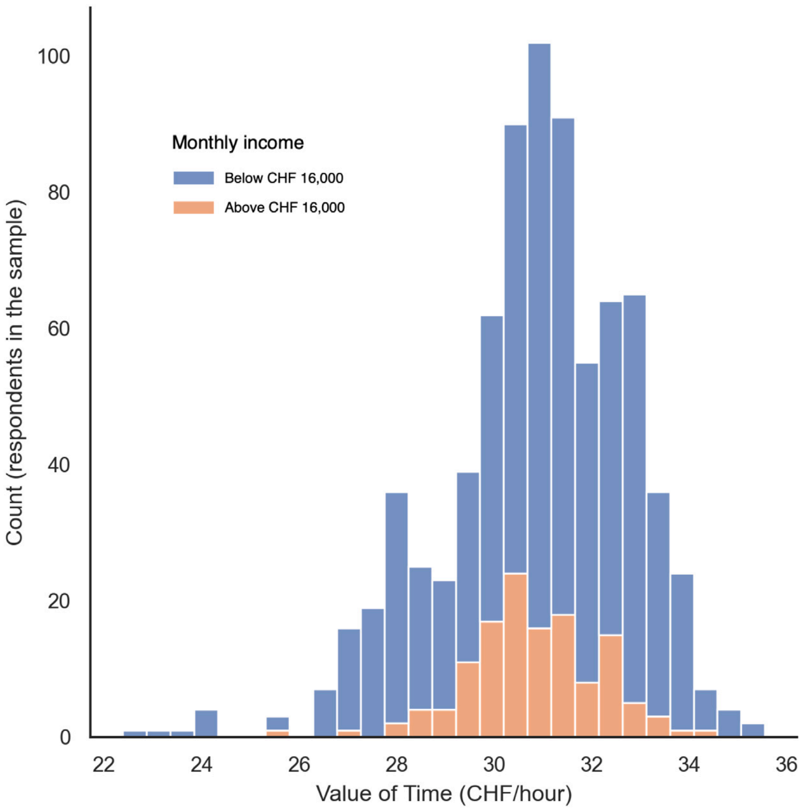


**Fig. 3.** Value of time estimates across the sample population.

As individuals are more time flexible, as measured by their responses to Likert-scale questions T1 and T3 shown in Table 2, the amount of financial incentive needed for the car sharing operators to shift their desired booking times gets reduced. The value of this incentive across the population in our sample ranged between 22.4 CHF per hour to 35.5 CHF per hour (corresponding to 23.5 USD/h and 37.2 USD/h using average exchange rate in 2022). While value of time flexibility has not been measured in the context of shifting car sharing booking times, our estimates are plausible when compared to recent mode-specific values of travel time savings (VTTS) for Switzerland reported by Schmid et al. (2021) as follows: 30.6 CHF/h for car and motorbike, 27.7 CHF/h for carpooling, and 26.7 CHF/h for car sharing.

## 7. Conclusions and future work

This paper presented a stated choice experiment designed to measure car-sharing users' willingness to offer flexibility, which will be a critical aspect when combining car sharing with V2G technologies. As far as we are aware, this study is the first to examine the willingness of car sharing users to offer flexibility in their booking slots in exchange for financial incentives. Our work shed light on user behavior of car sharing users, which received less attention in the literature compared to car owner behavior in the context of V2G technologies. The study was applied to the choice between the status quo option (i.e. not shifting booking slots) and alternative booking slot offers with lower prices. It measured time flexibility as a latent attitude. We showed that the sensitivity to time shifts in booking slots is different depending on attitudes relating to *time flexibility*. Time flexibility was measured based on socio-demographic variables through psychometric measurement questions. Older adults, lower income groups, users in employment, or those with a university degree had lower time flexibility. Trip level characteristics were also influential on choice behavior. Specifically, social and leisure trips, trips involving picking up or dropping off others, and work trips were less flexible. In addition, it was more difficult for users to shift booking times for trips taking place during weekdays and morning peak periods between 6am and 9am, and where they had trip-specific constraints. These insights will be important in making decisions about car sharing operators' decision to engage in V2G initiatives, which are important for efficient integration of car-sharing with V2G markets in the future as they are seen as promising for decarbonizing both energy and transport systems.

During our study, we also identified limitations in empirical applications of discrete choice models in this context. First, experience using EVs in car sharing users' sample was very limited. As a result, it was difficult to measure the effects of EV-specific attributes on choice behavior in a realistic manner. Therefore, our study excluded EV-specific variables and focused on time flexibility, which is assumed to be independent of car sharing vehicle type. In reality, however, we would expect users' decision to be affected by the state-of-charge variable in addition to booking slots. Also, car sharing operators could potentially benefit from V2G technology to varying levels depending on user needs relating to state-of-charge requirements at the start of the booking periods. This aspect, however, might become less relevant as charging technology improves to allow for faster charging cycles as suggested by existing literature reviewed in Section 2. Second, the degree of temporal flexibility will depend on a range of factors not only associated with general attitudes, but also the availability of vehicles and other modes, and trip or day-specific constraints. It is difficult to capture all the different aspects via a survey instrument especially given low response rates as survey lengths increase. Conducting research with real users and actual data is crucial, yet obstacles arise due to limitations on data usage and sharing agreements between commercial operators and researchers. These restrictions make it challenging to carry out studies even on topics that have a significant impact on society, such as the pressing need to reduce carbon emissions. Future work may focus on utilizing larger datasets from car sharing operators and designing field experiments to be conducted in real life settings as drivers get more experienced with EVs.

The analysis of the value of time estimates in our population sample showed that the level of financial incentive needed for users to shift their booking slots ranged between 22.4 CHF per hour and 35.5 CHF per hour. Car sharing operators and cities can utilize these estimates to explore novel service offers and designs, make informed decisions about vehicle-to-grid infrastructure, and tailor promotional campaigns to encourage both car sharing operators and users to adopt the technology. Specifically, car sharing operators can better understand if and under which pricing scenarios they can benefit from participating in electricity markets via V2G services using these values. Cities, on the other hand, can plan for additional incentives (e.g. additional parking provision for car sharing only (Gafafer, 2023)) to make it attractive for car sharing operators and users to contribute to peak shaving to contribute to decarbonization of both energy and transport systems. Finally, the legal framework could potentially differentiate between incentives offered to aggregators of car owners and car sharing operators for participation in energy markets to make car sharing more attractive for both users and operators and discourage private car ownership, allowing for contributions to decarbonizing energy and transport sectors. Subsidies to incentivize EVs could be better designed to encourage car sharing.

## CRediT authorship contribution statement

**Esra Suel:** Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Yanan Xin:** Conceptualization, Writing – review & editing. **Nina Wiedemann:** Conceptualization, Writing – review & editing. **Lorenzo Nespoli:** Conceptualization, Writing – review & editing. **Vasco Medici:** Conceptualization, Writing – review & editing. **Antonin Danalet:** Writing – review & editing. **Martin Raubal:** Conceptualization, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.trd.2023.104014.

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