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Travel mode preferences among German commuters over the course of COVID-19 pandemic

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ABSTRACT

The COVID-19 pandemic has changed the way how the people live, work and move, and naturally the transport sector became one of the most affected by this global crisis. Beyond the sudden fall of mobility at the beginning of the pandemic, it is important to understand how people are regaining trust in travelling, even if it is still unpredictable if and when the transport sector will recover to the pre-pandemic levels. This study focuses on the analysis of commuting trips and the changes of travel mode preferences over the first eight months of the pandemic in Germany. A survey with an orthogonal design based on sets of cards containing different transport mode alternatives and attributes was conducted in three waves (April, June, and October 2020). The individual characteristics and the preferences of around 4800 commuters were collected through the survey and modelled using a conditional logit approach. The results show that commuters have regained some trust on public transport ticket fares can be the most effective strategy to recover some of the users lost to other modes.

1. Introduction

Following the detection in late 2019 in China of a new coronavirus disease (COVID-19), caused by the virus SARS-Cov-2, strict travel restrictions and lockdowns have been imposed by regional and national governments all over the world. By March 11, 2020, when the disease was officially declared a pandemic by the World Health Organization (WHO, 2020), Europe was already in the eye of the storm, with the first full national lockdowns being declared a few days later. The severe restrictions to the freedom of movement were pushed by the urgency to restrict social contact in face of the lack of knowledge about the transmission mechanisms and the consequences of the new disease. The fear of suffering life-threatening illness or long-term health effects led to the endorsement of the first national lockdowns by the majority of the European population (Manley, 2020). However, the extension and/or intensification of restrictive policies were seen more skeptically (Gollwitzer et al., 2021), as the public acceptance of full lockdowns tended to decrease over the course of the pandemic in favor of targeted local measures (Krauth et al., 2021).

As travel restrictions and social distancing have been a key instrument to contain the spread of COVID-19, the transport sector became one of the most disrupted by the pandemic. Public transport (PuT) ridership suffered a sharp decline in almost every city with community transmission of the virus because of stay-at-home orders, telecommuting, home quarantines, or voluntary self-isolation (Hasselwander et al., 2021; UITP, 2020). The images of major cities with empty streets and of large fleets of parked buses, trains and airplanes are now part of the world’s collective memory. In the early stages of the pandemic, and during the strictest periods of mobility restrictions, transit ridership decreased above 80% in cities such as Budapest (Bucskey, 2020), London (TFL, 2020a), and New York (Teixeira and Lopes, 2020), and between 60 and 80% in Chicago (Hu and Chen, 2021), Manila (Hasselwander et al., 2021), Sydney (Hensher et al., 2021), and Washington D.C. (Hu and Chen, 2021). Different impacts have also been observed within the same city according to the transport mode or the socioeconomic status. For instance, in London and Sydney, the decrease in the number of trips by rail was higher than by bus (TFL, 2020a; Hensher et al., 2021). In Santiago, the decrease in PuT use was more than 30% greater for the highest-income households than for the most unprivileged population (Tirachini and Cats, 2020).

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The unexpected reduction of ridership and the need for new health measures called for immediate actions to adapt PuT services to the new reality. Suddenly, PuT companies had to face an unprecedented fall of ticket revenue accompanied by an increase of expenses in cleaning and safety protocols. Companies were requested to reduce vehicle capacity, and sometimes even to increase frequency to ensure social distancing between users (TfL, 2020; UITP, 2020). Additionally, the more frequent cleaning of hand-touch surfaces and the use of facemasks inside the vehicles and stations became mandatory (TfL 2020; Rab et al., 2020). On the other hand, many companies took actions to contain financial losses and rebalance service supply and demand by reducing frequencies, closing stations, and suspending routes (UITP, 2020). However, this drew some criticism in cities like London and Lisbon, as some lines became overcrowded (UITP, 2020; Severo et al., 2021). Therefore, PuT operators have been walking on thin ice, taking short-term decisions that are many times driven by ad-hoc knowledge (Gkiotsalitis and Cats, 2021).

As the prevention and treatment of COVID-19 has seen remarkable developments over the last year (Betele, 2021; Singh et al., 2020), the disease will sooner or later be declared under control and the pandemic will come to an end. However, the infections will not stop overnight, being expected that some protective measures, such as the use of face-masks or the practice of social distancing, will remain part of everyday life in the foreseeable future, despite the gradual alleviation of restrictions. Moreover, the pandemic has strongly accelerated the digital transformation of the society, stimulating technology innovations that will persist in the post-pandemic future (Brem et al., 2021; Kim, 2020). In other words, a “new normal” is expected to replace at least some of the old habits, given the increased opportunities for remote working, learning, shopping and leisure activities, which will certainly affect the transport sector.

The analysis of the impacts on transport systems over the course of the pandemic allows to get insights about the uptake of active travel and the need for medium-to long-term policies that promote an adaptation to a “new normal” (Mardsen and Docherty, 2021). Most of the previous studies described the early impacts of COVID-19 on travel behavior and preferences, focusing on the period before the summer of 2020 (Abdullah et al., 2020; Dingil and Esztergár-Kiss, 2021; Dong et al., 2021; Eisenmann et al., 2021; Hensher et al., 2021; Kolarova et al., 2021; Shamshiripour et al., 2020; Zhang et al., 2021). The first studies considering the evolution of the pandemic after that period, characterized by new waves of infection, but also by an increasing adaptation of the population and by advances in the knowledge, prevention, and treatment of the disease, are now coming in (Amlöf et al., 2021; Rothengatter et al., 2021).

In this context, this study analyses how the perceived risk of infection may influence the travel modal choice among German commuters and how such influence changed over the course of the COVID-19 pandemic. It follows on the footsteps of the study by Eisenmann et al. (2021), who analyzed transport mode choice during the first lockdown in Germany. Additionally, considering past studies’ findings, the following research hypotheses are tested: (i) PuT lost ground for individual modes, such as car, bicycle, and walking due to the COVID-19 pandemic (Abdullah et al., 2020; Dingil and Esztergár-Kiss, 2021; Eisenmann et al., 2021; Hensher et al., 2021; Mardsen and Docherty, 2021; Rothengatter et al., 2021), (ii) travel time and costs have a high influence on travel mode choices, leading to great changes on mobility preferences (Abdullah et al., 2020; Hensher et al., 2021), and (iii) travelers with access to a private car are more prone to assume car costs and time than members of car-free households (Abdullah et al., 2020; Dingil and Esztergár-Kiss, 2021).

For that, three online surveys were conducted – during the first lockdown (May 2020), immediately after (June 2020), and during a “new normal” period (October 2020) – to collect the respondents’ sociodemographic characteristics, mobility habits, requirements for future mobility solutions, and mode choices. The impacts on the transport mode choice of the remaining variables and of the period to which the survey reports were then estimated using conditional logistic regression. Additionally, to corroborate the three research hypotheses mentioned above, different scenarios were generated by varying the mean value of specific variables to compute the probabilities associated with each transport mode choice.

Research of COVID-19 impact is moving fast, but to the best of the authors’ knowledge, this is the first study that applies this modelling framework to analyze the uptake of commuting trips in a “new normal” context, in which the infection rates are still high but the mobility restrictions are less severe or, at least, more locally targeted. Additionally, compared to revealed preferences (Amlöf et al., 2021), the stated preference survey design implemented in this study aims for an improved knowledge about the commuters’ expectations and requirements regarding social distancing on board the PuT, supporting user-centric policies in the post-pandemic future.

The remainder of this paper is as follows: section 2 describes the survey and modelling methods, section 3 contains the data preparation and description, section 4 presents the modelling results and discussion, focusing on the differences observed between the three survey waves and the prospective scenarios for PuT ridership, and section 5 summarizes the main conclusions and points out the limitations of this study and the directions for future research.

2. Mobility survey

2.1. Design

To test the formulated hypotheses, a longitudinal study was developed to model the perceived utility of private vehicle, PuT, and cycling alternatives over the course of the COVID-19 pandemic. The first step was to design and deploy a stated preference (SP) survey in three specific moments: during the first lockdown (survey wave 1), one month after the lockdown was over (survey wave 2), and at a “new normal” period (survey wave 3). The definition of “new normal” follows the one provided by Nugesro (2020), who states that “the new normal concept is reopening public service activities and the business economy while strictly implementing health protocols, for example keeping physical distance, wearing masks, washing hands, and caring for health”. Survey wave 3 was conducted before the second lockdown in a context of rising infections. The three survey waves are depicted in Fig. 1, together with mobility data from Google LLC (2020) and Apple Inc (2020) to highlight mobility changes along the study period. The procedures for survey design, application, and analysis follow the guidelines provided by Hensher et al. (2005) and are summarized in Fig. 2.

The SP survey is based on a set of cards containing different alternatives regarding the transport modes and corresponding attributes. To define these attributes, a first focus group was set up with private vehicle, PuT, and bicycle users. From this focus group, the alternatives were validated, and a list of attributes and corresponding levels were proposed. To understand the effects of social distancing in PuT, one of the selected attributes was the occupancy of the PuT option. This attribute was defined as categorical and, with the help of a graphic designer, provided as a picture in the choice cards, as depicted in Fig. 3. In a second phase of the design process the number of levels were reduced, and some attributes removed through an iterative process using a second focus group, which lead to the final attributes’ levels, described in Table 1.

An orthogonal design was implemented to generate the choice cards: 64 cards were generated using the orthogonal design tool of the software IBM SPSS, and a blocking variable was defined to decrease the number of cards to be shown to each respondent (Hensher et al., 2005). The questionnaire was built, and after the assessment of a validation group, the number of blocks was set to four, resulting in 16 cards per block, allowing a good balance between number of blocks and questionnaire size.

At the beginning of the SP block survey, each respondent was given a...
brief introduction explaining the different components of the cards and a scenario. The scenario consisted of making the choice for the preferable transport mode to make frequent commuting trips to/from a city, knowing that these trips will usually happen in the morning and afternoon peak hours, thus traffic congestion is a possibility. The trips were described as “you will commute to your place of work or education or any other regular commute in the long term”, inducing the respondent to state her/his preference regarding a long-term commitment to a given transport mode for regular movements. The respondent was informed that the decision should be made without taking COVID-19 mobility restrictions into consideration. Besides the SP questions, the survey also included groups of questions regarding the sociodemographic characteristics of the respondents, the mobility habits, requirements for future mobility solutions, and other questions not pertinent for this study.

The survey was coded using the online platform LimeSurvey, which permits online access to the respondents and a live track of the main response indicators. It also allowed for filtering questions to ensure that the bulk of responses are representative according to defined parameters.

2.2. Data collection and preparation

The field period of the survey was set to one week per wave, beginning on the April 17, 2020 for wave 1, June 2, 2020 for wave 2, and October 12, 2020 for wave 3, as show in Fig. 1. These periods are of interest due to the different status of the COVID-19 pandemic and country measures, being also aligned with other studies (Almlöf et al., 2021; Hensher et al., 2021; Marsden and Docherty, 2021).

To reach a representative sample, the questionnaires were sent out in cooperation with a panel service provider, CINT AB, which carried out the recruitment and target group selection during the data collection process. The response target was set according to available budget to 1600 valid responses per survey wave, with the conversion rate being shown in Table 2. The completed responses were scanned for plausibility during the fieldwork until the sample target was achieved: in average, 1731 responses per survey wave were completed, of which 7.6% were considered not valid, totaling 1600 responses per wave. Assuming that Germany has a population of 83 million inhabitants, the obtained sample size offers a confidence of 95% chance that the true value is within ±2.5% of the measured value (Israel, 1992) and \( p = 0.5 \), which yields the most conservative results.

The final database, after merging the data from the three survey waves and processing each SP card, comprehends a total of 76,752 observations, which correspond to the number of valid responses multiplied by the number of cards shown to each respondent (16 cards). To apply a conditional logit model, a data treatment was conducted to transform some of the survey responses into variables of two types: categorical or continuous. In some cases, different hypotheses were tested to balance the statistical significance and the best representativeness of the variable. The sociodemographic characteristics, mobility habits, and requirements for future mobility solutions represent the respondents’ individual features and are constant across mode choice preferences. Table 3 presents the data description of the variables contained in these three groups as considered in the model. In relation to the sociodemographic characteristics, it was observed that the respondents’ mean age...
tion degree and 68.8% are employed. Please note that the third gender option was considered in addition to these two gender categories. Also, since for citizens who do not identify themselves strictly as female or male, no particular data was obtained through an SP survey, non-employed individuals, including jobseekers, housekeepers and pensioners, were allowed to respond according to their commuting preferences. Regarding the mobility habits, most of the respondents own a car, and 68% use private car as the most frequent transport mode for daily commute, which in average has a duration of 23.4 min, despite 49.1% of the respondents noted that the analysis of the respondents’ features was not the focus of this study, thus it was decided that the individual of reference must correspond to a real respondent. All the transport mode preference scenarios and corresponding probabilities were computed for the individual of reference, also depicted in Table 3, were defined as follows: (i) first, the characteristics of the individual of reference, also depicted in Table 3, were defined as follows: (i) first, the mean age (43) and most representative gender (female) noted that the analysis of the respondents sample. It should be remembered that the three most chosen options are safe, flexible, and user-friendly mobility solutions. The analysis of the transport mode preferences across the three waves was supported by the generation of scenarios, considering the features of one individual of reference. The survey wave was set using a three-level categorical variable. The characteristics of the individual of reference, also depicted in Table 3, were defined as follows: (ii) then, the remaining features were defined as the same of one 43-year-old female randomly selected from the respondents’ sample. It should be noted that the analysis of the respondents’ features was not the focus of this study, thus it was decided that the individual of reference must correspond to a real respondent. All the transport mode preference scenarios and corresponding probabilities were computed for the individual of reference, varying each variable considered relevant for the confirmation of the research hypotheses, ceteris paribus. Besides the survey wave, other variables related to the individual’s car ownership and to the attributes of PuT (travel time, cost, frequency, occupancy, and accessibility) were changed to generate the analyzed scenarios. The SP attributes, also named choice-specific attributes, have already been described in Table 1. Note that for private vehicle attributes, the parking scenario corresponds to three distinct variables: daily parking costs (free of charge, 1 or 2 EUR), the time spent searching for a parking lot (2, 5, 10), and the number of stages to be completed (0, 1, 2). Table 1 Description of the different levels of the SP attributes.

![Fig. 3. Levels of PuT occupancy attribute to represent social distancing: (a) empty, (b) slightly busy, and (c) busy.](image)

| Mode         | Attribute                          | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|--------------|------------------------------------|---------|---------|---------|---------|---------|
| Private vehicle | Trip duration (min)                | 15      | 30      | 45      | –       | –       |
|              | Cost (EUR/month)                   | 30      | 60      | 120     | –       | –       |
|              | Parking scenario (cost (EUR/day), parking time (min), walking time (min)) | Parking lot (2, 5, 10) | Street (1, 10, 5) | Street (1.5, 10, 5) | Street (free, 10, 5) | Company (free, 1) |
| Public transport | Trip duration (% of trip duration by private vehicle) | 50      | 100     | 200     | –       | –       |
|              | Cost (EUR/month)                   | 30      | 60      | 120     | –       | –       |
|              | Number of transfers                 | 0       | 1       | 2       | –       | –       |
|              | Headway (min)                      | 5       | 15      | 30      | –       | –       |
|              | Walking time to the closest station (min) | 5       | 15      | 30      | –       | –       |
|              | Occupancy                          | Empty   | Slightly busy | Busy    | –       | –       |
| Cycling      | Trip duration (min)                | 10      | 30      | 45      | –       | –       |
|              | Existence of bike lane             | No      | Yes     | –       | –       | –       |
|              | Existence of amenities (bike park and shower at work) | Yes | No     | –       | –       | –       |
|              | Terrain                            | Hill    | Flat    | –       | –       | –       |
|              | Weather                            | Rain    | Clear   | –       | –       | –       |

| Survey wave | Partly finished | Completed | Total | Conversion rate |
|-------------|-----------------|-----------|-------|-----------------|
| 1           | 1470            | 1708      | 3178  | 53.7%           |
| 2           | 1361            | 1726      | 3097  | 55.9%           |
| 3           | 1579            | 1758      | 3337  | 52.7%           |

* Parking was shown as a scenario and the scenario characteristics were embedded in the card. The scenarios were created according to three attributes and reduced to four scenarios according to the focus groups feedback.

1 Trip duration levels for PuT were defined in relation to the corresponding trip duration by car, although the actual travel times were shown in the survey.

is approximately 43 years old and the mean monthly income is 2353 EUR. 51.5% of the respondents are female, 31.5% hold a university degree and 68.8% are employed. Please note that the third gender option “diverse”, which has been legally adopted in Germany since 2018 for citizens who do not identify themselves strictly as female or male, was considered in addition to these two gender categories. Also, since the data was obtained through an SP survey, non-employed individuals, including jobseekers, housekeepers and pensioners, were allowed to respond according to their commuting preferences. Regarding the mobility habits, most of the respondents own a car, and 68% use private car as the most frequent transport mode for daily commute, which in average has a duration of 23.4 min, despite 49.1% of the respondents living close to PuT station (less than a 5-min walk). The survey also included a question to which the respondents had to choose up to three options that better represent their requirements in terms of future mobility features, among the following: zero-emission, safe, flexible, fast, free of charge, user-friendly, shared, individual, and functional. While most options are self-explanatory, some deserve to be clarified. A flexible transport means that it can be used for different purposes and/or adapts to the needs and activities of its users. In the context of new mobility services, technologies, and digitalization, user-friendly solutions must be easy to learn, use, understand, or deal with. In turn, a functional mobility solution is designed to fit the purpose of moving a person from A to B without creating unnecessary obstacles or complexity; the function overcomes the aesthetic of the solution. Table 3 shows that the most three chosen options are safe, flexible, and user-friendly mobility solutions.
The conditional logit model was applied considering the three analyzed transport mode choices, i.e., private vehicle, PuT and cycling, as dependent variable, and the choice attributes, survey waves, sociodemographic characteristics, mobility habits, and requirements for future mobility solutions as independent variables. To evaluate the impacts of the variables in common to the three mode choices, i.e., all observed covariates of individuals. In fact, previous studies in different fields of research compared the standard conditional logit model with other more sophisticated models, showing that the impact of not considering the assumption of independence of irrelevant alternatives is limited and hardly justifies the application of more complex models (Marinelli, 2011; Dahlberg and Eklof, 2003; Dow and Endersby, 2004; Haan, 2006; Christiadi and Cushing, 2007). Additionally, Christiadi and Cushing (2007) state that when the number of alternatives is small, the risk of dependence of irrelevant alternatives decreases.

In this sense, the conditional logit model was applied considering the three analyzed transport mode choices simultaneously, i.e., any variable that was statistically significant for all mode choices simultaneously, i.e., any variable that was statistically significant for at least one mode choice was kept in the model. In the end, the

\[ \text{Prob}(Y_i = j) = \frac{\exp(z_{ij}\theta)}{\sum_{k=1}^{J} \exp(z_{ik}\theta)} \]  

where \( Y_i \) is a random variable that indicates the choice made.

The main disadvantage of the conditional logit model is that it assumes the independence of irrelevant alternatives, meaning that the choice between any pair of alternatives must be independent from the remaining ones (Gutiérrez et al., 2019). However, Train (2003) argue that this approach provides suitable estimations of the average preferences of individuals. In fact, previous studies in different fields of research compared the standard conditional logit model with other more sophisticated models, showing that the impact of not considering the assumption of independence of irrelevant alternatives is limited and hardly justifies the application of more complex models (Marinelli, 2011; Dahlberg and Eklof, 2003; Dow and Endersby, 2004; Haan, 2006; Christiadi and Cushing, 2007). Additionally, Christiadi and Cushing (2007) state that when the number of alternatives is small, the risk of dependence of irrelevant alternatives decreases.

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\[ F(e_i) = \exp\left( - \exp(-e_i) \right) \]  

Hence, the probability that the i-th respondent chooses travel mode alternative j is given by:

| Group | Variable | Mean | Standard deviation | Relative frequency (%) | Individual of reference |
|-------|----------|------|--------------------|------------------------|-------------------------|
| Sociodemographic characteristics | Age | 43.3 | 12.6 | - | 43 |
| | Monthly income (EUR) | 2352.9 | 1685.7 | - | 1500 |
| | Gender: Female | - | - | 51.5 | Yes |
| | Gender: Male | - | - | 48.3 | No |
| | Gender: Diverse | - | - | 0.2 | No |
| | University degree | - | - | 31.5 | No |
| | Occupation: Employed | - | - | 68.8 | Yes |
| | Occupation: Not employed | - | - | 21.4 | No |
| | Occupation: Student | - | - | 8.5 | No |
| | Occupation: Other | - | - | 1.3 | No |
| Mobility habits | Commuting time (min) | 23.4 | 17.3 | - | 5 |
| | Own car | - | - | 81.0 | Yes |
| | Own bike | - | - | 68.5 | No |
| | Own e-bike | - | - | 14.2 | No |
| | Frequent use of private car | - | - | 68.0 | Yes |
| | Frequent use of bus or urban rail | - | - | 20.1 | No |
| | Frequent use of suburban rail | - | - | 15.6 | No |
| | Frequent use of regional rail | - | - | 8.5 | No |
| | Frequent use of soft modes | - | - | 72.5 | No |
| | Walk to PuT <5 min | - | - | 49.1 | No |
| | Walk to PuT 5-10 min | - | - | 34.5 | Yes |
| | Walk to PuT 10-15 min | - | - | 10.6 | No |
| | Walk to PuT >15 min | - | - | 5.8 | No |
| Requirements for future mobility solutions | Zero-emission | - | - | 30.6 | No |
| | Safe | - | - | 47.8 | No |
| | Flexible | - | - | 45.6 | No |
| | Fast | - | - | 39.5 | No |
| | Free of charge | - | - | 40.8 | Yes |
| | User-friendly | - | - | 40.9 | Yes |
| | Shared | - | - | 9.3 | No |
| | Individual | - | - | 16.6 | No |
| | Functional | - | - | 11.5 | Yes |

\* Includes tram and U-Bahn (German term for urban metro systems).
\( \text{S-Bahn} \) (German term for suburban rail systems).

spot (0, 5 or 10 min), and the walking time from the parking spot to the destination (1, 5 and 10 min). Regarding the occupancy of PuT (Fig. 3), only the category associated with the “busy” situation was distinguished from the others in the model due to multicollinearity issues. This variable represents the importance for the respondents of social distancing in the pandemic context.

### 3. Conditional logit model

Mode choices were modelled using an unordered choice model which can be motivated by a random utility model (Greene, 2008). Since the survey includes the attributes of the travel mode alternatives in addition to the characteristics of the individuals making the choice, a conditional logit model was applied (McFadden, 1974). For the i-th respondent faced with J choices (in this study, \( J = 3 \)), suppose that the utility of choice j is given by:

\[ U_{ij} = z_{ij}\theta + \epsilon_i \]  

(1)

where \( z_{ij} \) are the attributes of the travel mode alternatives \( x_{ij} \) and the characteristics of the respondents \( w_i \), such that \( z_{ij} = [x_{ij}, w_i] \), \( \theta \) is a vector of estimated parameters, and \( \epsilon_i \) is the disturbance term.

If one respondent makes a particular choice j, then \( U_{ij} \) is maximum among the J utilities. Therefore, the statistical model is driven by the probability that choice j is made, which is \( \text{Prob}(U_{ij} > U_{ik}) \) for all other \( k \neq j \). Assuming that the J disturbances are independent and identically distributed with standard Gumbel (type-I extreme value) distribution, the corresponding cumulative distribution function is:

\[ F(\epsilon_i) = \exp\left( - \exp(-\epsilon_i) \right) \]  

(2)

Hence, the probability that the i-th respondent chooses travel mode alternative j is given by:

\[ \text{Prob}(Y_i = j) = \frac{\exp(z_{ij}\theta)}{\sum_{k=1}^{J} \exp(z_{ik}\theta)} \]  

(3)
model included 49 explanatory variables. The Pearson correlation between most pairs of variables, being smaller than 0.5, is considered to be low (Cohen, 1988). Moderate correlations (between 0.5 and 0.7) are observed only in three cases.

Finally, several scenarios based on changing categories or mean values of specific variables were generated to evaluate (i) the impacts of the pandemic evolution on mode choice, and (ii) the impacts of car ownership, and (iii) different policies regarding travel time and costs on the preference for PuT. In the latter case, the analysis focuses on the PuT monthly cost, trip duration, headway, and walking time to the nearest PuT station, as well as on the PuT occupancy in the pandemic context.

4. Results and discussion

Modelling results are shown in Table 4. The estimated parameters for the sociodemographic variables show that age is statistically significant only for the cycling mode, denoting that the preference for PuT in relation to the car alternative may not be related to the respondent’s age. In contrast, the educational level, represented by the binary variable “university degree”, does not seem to influence the preference for the cycling mode. Male and diverse respondents are more prone to the choice of PuT and cycling compared to female respondents. As expected, higher incomes decrease the probability of choosing PuT or cycling. Curiously, the estimated parameters for students have a negative sign, denoting that students give a lower utility to PuT and cycling alternatives in comparison to the use of private car.

Additionally, the mobility habits of the respondents were found to be associated with their mode choice. Indeed, owning a car decreases the probability of selecting PuT or cycling as the preferred transport mode. This aspect was analyzed by Eisenmann et al. (2021, p. 65), who found that “one third of individuals in car-free households missed owning a car during the lockdown and 6% even considered buying one”. Accordingly, owning a bicycle or an e-bike increases the probability of selecting PuT or cycling. The transport mode frequently used by the respondents is also associated with an increased preference for the corresponding alternative. Users of soft modes are also likely to prefer PuT in relation to the private vehicle, but the reverse is not always the case. The respondents who live too far (more than a 15-min walk) or too near (less than a 5-min walk) from a PuT station give lower utility to this mode than those who live 5–15 min away. The proximity to PuT does not seem determinant for choosing the bicycle over the private car. Higher commuting times increase the probability of stating a preference for PuT. In fact, PuT can be regarded, especially by the commuters who live in the outskirts of a major city, as a more efficient choice to avoid peak hour congestion.

Regarding the requirements for future mobility solutions, the model results suggest that the respondents who consider safe, flexible, fast, and individual features as being relevant for mobility solutions show a lower preference for PuT and cycling compared to the private vehicle. In contrast, the probability of choosing PuT and cycling increases when the respondents identify zero-emission, shared, and functional features as requirements for future mobility. Furthermore, user-friendly mobility is a feature associated with a lower probability of preferring the bicycle over the car. The respondents who advocate for free-of-charge mobility solutions prefer cycling than using the car, but not necessarily prefer using PuT.

Considering the main objectives of understanding the impacts of the pandemic on PuT and addressing the research hypotheses previously mentioned, the specific analyses (one for each research question) are presented in the next two subsections. In this sense, the impacts of relevant variables were assessed by calculating the mode choice probabilities associated with different variable combinations (scenarios), as presented in Table 5, and by comparing these scenarios with a baseline scenario (scenario 0). The baseline scenario was defined by the characteristics of the individual of reference described in Table 3 and by the mode choice attributes presented in Table 6.

4.1. Survey waves and car ownership

The estimated coefficients for the variables that represent the second and third survey waves are all positive, denoting that through the observed pandemic period, the probability of selecting PuT and cycling as preferred travel modes increased in relation to the first lockdown. As demonstrated by Eisenmann et al. (2021) through a survey conducted in the beginning of April 2020, also during the first lockdown, PuT use in Germany highly decreased in comparison to the pre-pandemic levels. This effect resulted from considerable changes on how people performed their daily tasks, mainly oriented to remote activities, such as online shopping and working from home, but also from the shifting to transport modes that avoid physical contact with other people. As Eisenmann et al. (2021, p. 65) mentions, “public transport lost ground in Germany during the particularly restricted period of lockdown while individual modes of transport, especially the private car, became more important”. Despite this conclusion for Germany, as well as for other countries and cities around the world with similar findings (Abdullah et al., 2020; Dingil and Esztergár-Kiss, 2021; Marsden and Docherty, 2021; Rothengatter et al., 2021), our study shows that between April and October 2020, people changed their perceptions about PuT, slowly regaining some trust on PuT modes. Indeed, all the estimated survey wave coefficients for PuT and cycling modes are not only positive, but also increase from survey wave 2 to 3, denoting that the probability of the respondents choosing PuT and, especially, cycling over the private vehicle increased over the course of the pandemic.

This effect is well noticeable in scenarios 2 and 3 (Table 5). Note that both scenarios consider the same characteristics of the individual of reference and mode choice attributes as the baseline scenario. Scenario 2 shows that the probability of this individual selecting the cycling alternative one month after the end of the April–May lockdown increased by 2% in relation to the lockdown (scenario 0), while the preference for PuT remained stable. Then, in October, or five months after the end of the first lockdown (scenario 3), the preference for the use of PuT increased by 0.5%, while for cycling, the preference rose by a further 0.4%. The probability of choosing the private vehicle decreased by 3% since the lockdown. These results show a tendency for the decrease of car use, as people adapt to a “new normal”, even if the rate of infections is still high. The regain of trust by PuT observed in this study is small, but Almlöf et al. (2021) confirmed this trend by showing that ticket validations in Stockholm increased between May and October 2020, after a strong decrease observed in March and April. Remarkably, a past study from Wang (2014) focused on how the fear of the SARS-Cov-1 virus impacted PuT in Taipei in 2003. An immediate daily loss of subway ridership was observed each time new cases were announced, in an effect that is named by the author as “fresh fear”. However, a gradual return of passengers was observed as the infection cases gradually faded away from the news headlines (“residual fear”). As stated by the author “this indicates the return of public confidence in using the underground system as a mean for daily transportation to offices and schools” (Wang, 2014, p. 3).

Furthermore, to analyze the effects of car ownership on travel mode preferences, scenario 1 was compared against scenario 0, which uses as a reference a 43-year-old woman who owns a car. Scenario 1 shows that if this person did not own a car, the probability of preferring PuT or cycling would increase by 4.8 and 11.5%, respectively, which denotes some predisposition to keep using other transport modes besides the car. In scenarios 1, 2, and 3, cycling is the most probable choice due to its short travel time in the baseline scenario, followed by the private vehicle.

4.2. Public transport scenarios

The previous results denote that it may take a long time before PuT ridership returns to the pre-pandemic levels. The recent technology advancements that increase the convenience of remote activities (Brem
| Group                              | Variable                      | Private vehicle<sup>a</sup> | Public transport | Cycling |
|-----------------------------------|-------------------------------|-----------------------------|------------------|---------|
|                                   | Coefficient | Standard error | P-value | Coefficient | Standard error | P-value | Coefficient | Standard error | P-value |
| Intercept                         | 0.7747       | 0.0892          | 0.0000  | 0.9462      | 0.0835          | 0.0000  |             |             |         |
| Longitudinal                      |               |                 |         |             |                 |         |             |                 |         |
|                                   |              |                 |         |             |                 |         |             |                 |         |
| Sociodemographic characteristics  |               |                 |         |             |                 |         |             |                 |         |
|                                   |              |                 |         |             |                 |         |             |                 |         |
| Mobility habits                   |               |                 |         |             |                 |         |             |                 |         |
|                                   |              |                 |         |             |                 |         |             |                 |         |
| Requirements for future mobility solutions |       |                 |         |             |                 |         |             |                 |         |
|                                   |              |                 |         |             |                 |         |             |                 |         |
| Note: Number of observations = 76 752; Log likelihood = −68 934; AIC = 138 023. | | | | | | | | |
| Category of reference for mode choice. | | | | | | | | |
The relevance of social distancing inside PuT vehicles for the respondent this mode has a relatively small decrease to 12.8%. In the same line, if monthly cost, from 120 to 30 EUR, is tested, showing that the preference for PuT. In this scenario, PuT occupancy was set to decreases to 11.9%. Finally, scenario 8 was generated to represent the respondent lives in an area where the walking time to the closest PuT station increases from 5 to 15 min (scenario 7), the preference for PuT decreases to 12.7%, a similar variation to the one obtained in the frequency change scenario (scenario 6). Nevertheless, scenarios 6 and 8 were considered independent, as a smaller frequency does not necessarily yield a higher occupancy, especially in rail modes, which are quite flexible in relation to the number of vehicles that can be coupled in the same train set.

The results from scenarios 4 to 8 denote that reducing the ticket fare may be a more effective way to increase the preference for PuT, even in the pandemic/post-pandemic context, than acting on the side of service supply with measures to expand the network and/or increase frequency, such as infrastructure investments, rolling stock acquisitions, and increasing the labor force.

5. Conclusions

This paper offers a unique view on mobility users’ preference for different alternative modes during the COVID-19 pandemic by designing a longitudinal SP survey. The survey was distributed in Germany during three different periods in time (April, June, and October of 2020), and a total of 1600 responses were obtained at each survey wave, totaling a sample size of 4797 valid responses and 76 752 observations (16 cards per respondent), evenly distributed through the selected periods. With this approach, the utility for private vehicle, PuT and cycling alternatives was modelled considering the attributes of each mode choice, the characteristics of the respondents, and a variable to represent the evolution of COVID-19.

The results showed that the travel mode preferences among German commuters vary, as expected, according to their sociodemographic characteristics, mobility habits, and requirements for future mobility solutions, as well as to the mode choice attributes. However, this study also shows that the significant changes in mobility preferences introduced by the COVID-19 pandemic, mainly at the expense of PuT, as reported by Eisenmann et al. (2021), have not been fully recovered across the study period, in which the uptake of the preferences for PuT has been slow. In this sense, some scenarios were analyzed by manipulating key attributes related with the PuT mode choice. The results from these scenarios show that the reduction of ticket fares during the study period would be more effective to increase the preference for PuT than the reinforcement of service supply to reduce travel time and occupancy.

This study offers the first insights on the travel mode changing preferences over the course of the COVID-19 pandemic in Germany. While the analysis of the results and scenarios is focused on the pandemic evolution and the possible strategies for PuT ridership recovery, further efforts are being made to analyze in more detail the effects of the respondents’ individual features on transport mode preferences, particularly by exploring the development of wave-specific models. Additionally, this work is limited to first eight months of the
pandemic, i.e., until October 2020. Future research is planned with the results of later surveys to keep tracking the regain of trust on PuT and to further support the initial findings of this study. More detailed investigation should be conducted to better understand the impacts of the mode choice attributes on travel mode preferences in a pandemic and post-pandemic context, for instance by analyzing the willingness to pay for social distancing on board PuT and the uptake of PuT ridership after the 2021 mass vaccination campaign. Finally, this study based on stated-preference surveys should be complemented by revealed-preference surveys to reflect the real situation regarding travel mode choice.

Author contributions

Sara Ferreira: Conceptualization, Methodology, Formal Analysis, Data Curation, Writing – Original Draft, Visualization, Project Administration, Funding Acquisition; Marco Amarim: Conceptualization, Methodology, Formal Analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualization; António Lobo: Formal Analysis, Writing – Original Draft, Writing – Review & Editing, Visualization; Mira Kern: Data Curation, Methodology, Visualization; Nora Fanderl: Conceptualization, Resources, Project Administration, Funding Acquisition; António Couto: Conceptualization, Methodology, Formal Analysis, Resources, Writing – Review & Editing, Funding Acquisition.

Declaration of competing interest

None.

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