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Exploring the impact of COVID-19 on individual’s travel mode choice in China

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\textbf{A B S T R A C T}

Travel activities and travel behaviors have been greatly affected by the outbreak of Covid-19. Facing the change of individuals’ travel choices, policymakers have to make an appropriate response to mitigate negative consequences. This paper aims to explore how the COVID-19 would impact travel mode choice and the intention of car purchase. The data was collected from a large-scale survey conducted in June 2020 after the highest point. Random utility maximization (RUM), random regret minimization (RRM) and generalized regret minimization (GRRM) are employed to examine the effects of various factors on mode choice behaviors. The estimation results reveal that regret aversion psychology doesn’t have a dominant proportion of decision choices, even if the congested condition of the mass mobility plays a significant role in the consideration of decision-making. Combined with the statistical results from the official departments, we concluded that public transport displacement plays a great propensity on the long trip, and meanwhile, the industry of ride-hailing services has shocked sharply. In terms of the intention of traffic tool purchase, carless people prefer to buy electric two-wheel vehicles rather than automobiles. The research findings and the contribution to policy implications give assistance to authority in understanding citizens’ travel mode preferences under the impact of COVID-19.

\section{1. Introduction}

Since the first outbreak of the coronavirus disease 2019 (COVID-19) in late 2019 in Wuhan, Hubei, China (Zhang et al., 2020; Chen et al., 2020), this highly contagious respiratory syndrome had spread quickly to become the most serious issue to public health globally (Zhou et al.). As of March 16, 2021, the WHO reported that more than 119.9 billion cases have been confirmed worldwide and more than 2.65 million people died (2020a). The authorities of every country have already implemented response measures to keep citizens healthy such as broader and city lockdown, building the cabin hospitals, bans on some social and economic activities, stopping gastronomical events, international travel restrictions, a herd immunity, and so on (Oumand Wang, 2020). Some of these strict and effective actions taken have controlled the disease in some countries like China, South Korea, Japan and Singapore. On the contrary, America and some European countries have not combatted COVID-19 and still keep the increasing trend.

The outbreak of COVID-19 and the widespread transmission of this disease affect the lives and work of people deeply and the development of the economy as well. People are fully aware that close contact is the predominant way to spread the virus, and keeping social distancing, avoiding crowded places, washing hands and wearing face masks are essential preventive measures to come into effect by person ((CDC), 2020), which greatly impacts individuals’ mobility behaviors. It is worth exploring the preferences and changes of travel choice in the post-COVID-19 era to instruct future policy-making.

Our paper hopes to contribute to the transport policy implications after suffering COVID-19 from three aspects in the long run. First, we take China as an empirical example and analyze the psychological changes under the impact of the COVID-19 pandemic. Second, exploring the influencing factors of mode choice and revealing the mode preferences of individuals. Third, we will predict the choice probability of public, shared and private transit, and traffic status according to the survey of the intention of car purchase.

Prior to examining the impact of COVID-19 on travel mode choice, we predicted several possible results, and then we will confirm the truth and validity of our predictions via our research. Predictions can be written as follows:

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https://doi.org/10.1016/j.tranpol.2021.04.011
Received 17 March 2021; Accepted 10 April 2021
Available online 14 April 2021
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Since the willingness to travel and the usage of mass transit have remarkable declined (Barbieri et al., 2020; Beck and Hensher, 2020b; Labonte-LeMoyn et al., 2005; Fenichel et al., 2013; Kim et al., 2017). However, these lessons very well. The empirical results indicate that the viral outbreaks and_Hensher_2020aBeck and Hensher (2020a) and the public transit are guaranteed, the individuals would like to travel again (bib_Beck_ and_Hensher_2020aBeck and Hensher (2020a)) and the public transit would rebound to use as well (Przybylowskiet al., 2021). However, the intention is still far from the pre-COVID-19 era.

Overall, the existing studies offered valuable insights into travel behavior impacted by public health concerns. Different countries have their special stages of the evolvement of the COVID-19, and learning lessons from different regions and contexts are also based on various socio-economic characteristics. Our study takes China as an example and the study time is selected during the pandemic under controlled nationally. The contribution of our paper may offer an empirical lesson for the post-COVID-19 world.

As for mobility behavior, it is always a hot research spot in the area of transportation science. Many efforts have been made to explain mode choices and decision rules from various perspectives. The existing studies on mode choice are roughly classified into four groups. Firstly, a large number of literatures are from the perspective of specific travel modes with unique and unsubstitutable characteristics. As one of the examples in this group, the emergence of car-sharing mode ramifies several industries such as traditional and online ride-hailing services (Anderson, 2014). Tang et al. examined how app-based ride-hailing impact individuals’ mode choice via a large-scale survey in China and concluded that this shared mobility service more attracted the point-to-point trip around 10–30min, for passengers pursued fast pattern compared with public transit and evaded the difficulty of parking compared with private cars (Tang et al., 2020). Secondly, researches on travel mode preference with area distinguishing features receive much attention. For instance, developed countries or areas vary from developing countries or areas concerning economy, population density, culture and so on. Hatamzadeh et al. focused on the walking behaviors in the city of Rasht, Iran, and gave the reasons to explain the gap with developed countries (Hatamzadehet al., 2020). Thirdly, a large number of literatures has examined travel mode choices determined by different socio-demographic factors (gender, age, income, education et al.). Extensive researches showed that average male historically

| Study | Study timeline | Region | Key findings |
|-------|---------------|--------|--------------|
| Shakibaeiet al. (2021) | Before and during the early stages of the pandemic | Istanbul, Turkey | 1 Decline of the use of public transport modes. In contrast, the trend to use car increase. 2 Urban travel and behavioral changes were in a stage of flux. |
| Beck and Hensher (2020b) | March and April 2020 | Australia | 1 Significant drop in public transport and car use 2 Highest drop for outdoor recreational activities |
| Beck and Hensher (2020a) | 23 May, 15 June 2020 | Australia | 1 50% of the respondents would like to use mass mobility since easing the restrictions. 2 Car use and bicycle use also increase. 3 The use of public transport is not back to the pre-COVID-19 days. 4 90% of respondents limited use the public transport 5 75% of respondents plan to reuse public transport when the pandemic situation has stabilized. |
| Przybylowskiet al. (2021) | Before and during the COVID-19 | Gdańsk, Poland | 1 Multiple shocks to the transport sectors 2 The outputs of all transport sectors severely decrease. 3 In densely populated cities, non-motorized activities declined 48%. 4 In less densely populated cities, walking and bike activities significantly increased. |
| Cui et al. (2021) | The first quarter of 2020 | China | 1 In densely populated cities, non-motorized activities declined 48%. 2 In less densely populated cities, walking and bike activities significantly increased. |
| Zhang and Fricker (2021) | Before and after the outbreak of COVID-19 | The United States | 1 Removable mode transfer from mass mobility. 2 Potentially increasing car dependence. |
| Zhang et al. (2021) | The end of April and late May 2020 | All over the world (expert survey) | 1 In densely populated cities, non-motorized activities declined 48%. 2 In less densely populated cities, walking and bike activities significantly increased. |

1. Due to the high degree of intensity and trepidation with infection, individuals will have regret aversion psychology to choose travel mode.
2. Public transport will face great shocks when travelers consider the risk of infection, especially the physical social distancing.
3. The private car will become a dominant travel way and could result in heavy traffic congestion in the long run. Avoiding the crowd in public transit mode will excite the strong desire of carless people to buy automobiles.
4. The taxi services and app-based ride-hailing services will relatively develop, for not everyone has the ability to buy a private car, but they would be less likely to choose public transport.

The remainder of the paper is organized as follows. The second section gives an overview of related literature. The third section addresses the main decision models we used to estimate results. In section 4, we present the survey and data collection on mode choice. In section 5, we describe the estimation results and discuss our policy suggestions according to our analysis. The last section concludes with the main findings and illustrates the limitations and future directions of our paper.

2. Literature review

The COVID-19 pandemic has a disruptive influence on the entire world and people’s lifestyle, the way of work, mobility behaviors et al. have to be changed a lot. The underlying literature regarding the interaction between viral outbreaks and travel behavior is limited. The earlier viral outbreaks like SARS, HIN1 and MERS pandemic affords us lessons very well. The empirical results indicate that the viral outbreaks have greatly affected people’s traveling and inclination to travel (Wen et al., 2005; Fenichel et al., 2013; Kim et al., 2017). However, these studies seem to lack the exploration of long-run impacts and lack the combination of the current social, economy et al.

The COVID-19 pandemic is also a contagious respiratory disease, but the impact is more widely and durable. Table 1 presents some significant findings on the travel behavior in the post-COVID-19 era. Summarizing the recent researches, we found that a growing number of publications on the effects of the disease on individuals’ mobility behavior reveal that the willingness to travel and the usage of mass transit have remarkable declined (Barbieri et al., 2020; Beck and Hensher, 2020b; Labonte-LeMoyne et al., 2020; Cui et al., 2021; Zhang and Fricker, 2021). Since the major crisis of public transport is physical social distancing, some of the travelers who usually take public transport to work or recreational activities shift the mode to motor vehicles (Shakibaeiet al., 2021; Labonte-LeMoyne et al., 2020; Campisi et al., 2020) or micromobility (Teixeira and Lopes, 2020; Bergantino et al., 2021; Zhang and Fricker, 2021). Some researches also show that if the development of pandemic is stable gradually, and the safety and hygiene of the mass mobility can be guaranteed, the individuals would like to travel again (bib_Beck_ and_Hensher_2020aBeck and Hensher (2020a)) and the public transit would rebound to use as well (Przybylowskiet al., 2021). However, the intention is still far from the pre-COVID-19 era.

As for mobility behavior, it is always a hot research spot in the area of transportation science. Many efforts have been made to explain mode choices and decision rules from various perspectives. The existing studies on mode choice are roughly classified into four groups. Firstly, a large number of literatures are from the perspective of specific travel modes with unique and unsubstitutable characteristics. As one of the examples in this group, the emergence of car-sharing mode ramifies several industries such as traditional and online ride-hailing services (Anderson, 2014). Tang et al. examined how app-based ride-hailing impact individuals’ mode choice via a large-scale survey in China and concluded that this shared mobility service more attracted the point-to-point trip around 10–30min, for passengers pursued fast pattern compared with public transit and evaded the difficulty of parking compared with private cars (Tang et al., 2020). Secondly, researches on travel mode preference with area distinguishing features receive much attention. For instance, developed countries or areas vary from developing countries or areas concerning economy, population density, culture and so on. Hatamzadeh et al. focused on the walking behaviors in the city of Rasht, Iran, and gave the reasons to explain the gap with developed countries (Hatamzadehet al., 2020). Thirdly, a large number of literatures has examined travel mode choices determined by different socio-demographic factors (gender, age, income, education et al.). Extensive researches showed that average male historically
commutes longer and further than his female partner, and travel demand and behavior indeed evolved as the changes in female employment and independence (Boarnetand Hsu, 2015; Crane and Takahashi, 2009; Kuhnminhof et al., 2012; Scheiner, 2014). Lastly, personal traits, habits, and preferences influence choice decisions as well. A significant portion of the literature showed that habitual behavior as a cognitive process trigger impulses to repeat some actions and has the potential to overpower intentional behavior (Gardner et al., 2020; Allom et al., 2016; Cooper and Salliclce, 2006; de Bruijn et al., 2009).

For quite a long time, discrete choice modeling based on random utility maximization (RUM) is a stream of research derived from McFadden, Daganzo and Sheffi (McFadden, 1976; Daganzo and Sheffi, 1977). The utility decision rule assumes that decision-makers attempt to determine the alternatives with the highest utility of every attribute, and it is widely used in transportation and urban planning (Arentzenand Timmermans, 2007; Hess et al., 2008; Zhu and Timmermans, 2010). Since the introduction of the regret-based model for discrete choice analysis (Bell, 1982), the regret theory also becomes a novel perspective on choice modeling, that is, the substantial decision rule is to avoid negative emotion and pursue regret minimum (Chorus et al., 2008). It has been acknowledged that random regret minimization (RRM) model highlights to get a better choice associated with the attribute comparison and alternative comparison. Later, RRM in logarithmical specifica

\[ RR_i = R_i + \epsilon_i = \sum_{m=1}^{M} \ln \left( 1 + \exp \left( \beta_m \cdot (x_m - x_m^*) \right) \right) + \epsilon_i \]  

Where \( RR_i \) is the regret value of alternative \( i \), \( R_i \) denotes the observed regret and \( \epsilon_i \) presents the unobserved part. \( (x_m - x_m^*) \) is the attribute m comparison process between alternative i and alternative j. In order to provide a flexible account of choice behavior, a Generalized RRM model (GRRM) is put forward by Chorus in 2014 (Chorus, 2014) and the formulation is written as follows:

\[ RR_i = R_i + \epsilon_i = \sum_{m=1}^{M} \ln \left( \gamma_m + \exp \left( \beta_m \cdot (x_m - x_m^*) \right) \right) + \epsilon_i \]  

In Equation (3), regret-weight \( \gamma_m \in [0,1] \) replaces “1” in Equation (2), which is determined by the socio-demographic variable \( \delta_m \). From the estimation of parameter \( \delta_m \) can provide an explanation associated with the determinants of regret minimization versus utility maximization for the attributes. The weight- \( \gamma_m \) can be calculated as follows:

\[ \gamma_m = \exp (\delta_m)/(1 + \exp (\delta_m)) \]

In the regret-based model, the unobserved part is distributed i.i.d Extreme Value Type I, which presents the heterogeneity of individuals. The choice probability of alternative \( i \) can be written as Equation (5).

\[ P_i = \exp \left( - R_i \right)/ \sum_{j=1}^{J} \exp \left( - R_j \right) \]

The maximum likelihood of data to estimate the parameters is written as follows:

\[ LL(\beta) = \ln \left( \prod_{i=1}^{n} P_i(i|\beta)^{y_i} \right) \]

where \( \delta_m = 1 \) means alternative i is chosen by decision-maker n, and zero otherwise.

In our study, the linear-in-parameters random utility model (RUM) can be written as:

\[ V_{B_{RES}} = \beta_{C} \times TRAVEL\_TIME_{B_{RES}} + \beta_{G} \times TRAVEL\_COST_{B_{RES}} \]

\[ + \beta_{d} \times CONGESTION\_DEGREE_{B_{RES}} + \beta_{x} \times WAIT\_TIME_{B_{RES}} \]

\[ V_{M_{METRO}} = \beta_{C} \times TRAVEL\_TIME_{M_{METRO}} + \beta_{G} \times TRAVEL\_COST_{M_{METRO}} \]

\[ + \beta_{d} \times CONGESTION\_DEGREE_{M_{METRO}} + \beta_{x} \times WAIT\_TIME_{M_{METRO}} \]

\[ V_{C_{CAR}} = \beta_{C} \times TRAVEL\_TIME_{C_{CAR}} + \beta_{G} \times TRAVEL\_COST_{C_{CAR}} \]

\[ + \beta_{d} \times CONGESTION\_DEGREE_{C_{CAR}} + \beta_{x} \times WAIT\_TIME_{C_{CAR}} \]

\[ V_{SHARED} = \beta_{C} \times TRAVEL\_TIME_{SHARED} + \beta_{G} \times TRAVEL\_COST_{SHARED} \]

\[ + \beta_{d} \times CONGESTION\_DEGREE_{SHARED} + \beta_{x} \times WAIT\_TIME_{SHARED} \]

The regret function of the bus mode can be written as shown in Equation (11)-(15).

\[ R_{B_{RES}} = R_{\	ext{TRAVEL\_TIME}_{B_{RES}}} + R_{\	ext{TRAVEL\_COST}_{B_{RES}}} + R_{\	ext{CONGESTION\_DEGREE}_{B_{RES}}} + R_{\	ext{WAIT\_TIME}_{B_{RES}}} \]

\[ R_{\	ext{TRAVEL\_TIME}} = \ln \left( \gamma_m + \exp \left( \beta_m \times (TRAVEL\_TIME_{M_{METRO}} - TRAVEL\_TIME_{B_{RES}}) \right) \right) \]

\[ + \ln \left( \gamma_m + \exp \left( \beta_m \times (TRAVEL\_TIME_{C_{CAR}} - TRAVEL\_TIME_{B_{RES}}) \right) \right) \]

\[ + \ln \left( \gamma_m + \exp \left( \beta_m \times (TRAVEL\_TIME_{SHARED} - TRAVEL\_TIME_{B_{RES}}) \right) \right) \]

\[ R_{\	ext{TRAVEL\_COST}} = \ln \left( \gamma_m + \exp \left( \beta_m \times (TRAVEL\_COST_{M_{METRO}} - TRAVEL\_COST_{B_{RES}}) \right) \right) \]
be expressed distinctly due to different values of \( \rho \)
to various considerations with different trip distances, 3 typical factors with the highest proportions were selected as attributes in Fig. 1, individuals to choose from. Further, according to the previous investigated private car and ride-hailing or taxi presented as alternatives for in the commuter journey. There are four modes including bus, metro, usually used to collect data. Please note that the mode choice is just for available to private car, the Stated Preference (SP) survey method is count and the intention of car purchase. As not all respondents are preference for commuters, the major influencing factors taken into ac

\[
R_{CONGESTION_{BUS}} = \ln(f_{cd} + \exp(\beta_{cd} \times (CONGESTION_{DEGREE_{METRO}} - CONGESTION_{DEGREE_{BUS}}))) \\
+ \ln(f_{ct} + \exp(\beta_{ct} \times (CONGESTION_{DEGREE_{CAR}} - CONGESTION_{DEGREE_{BUS}}))) \\
+ \ln(f_{cs} + \exp(\beta_{cs} \times (CONGESTION_{DEGREE_{SHARED}} - CONGESTION_{DEGREE_{BUS}})))
\]

\[
R_{WAIT_{BUS}} = \ln(f_{wt} + \exp(\beta_{wt} \times (WAIT_{TIME_{METRO}} - WAIT_{TIME_{BUS}}))) \\
+ \ln(f_{wr} + \exp(\beta_{wr} \times (WAIT_{TIME_{CAR}} - WAIT_{TIME_{BUS}}))) \\
+ \ln(f_{ws} + \exp(\beta_{ws} \times (WAIT_{TIME_{SHARED}} - WAIT_{TIME_{BUS}})))
\]

(15)

It should be pointed that the above regret-based formulation would be expressed distinctly due to different values of \( f_{in} \).

4. Survey and data description

To explore the diversifications of individual’s mode choice decisions about travel behaviors after suffering COVID-19, we designed related willingness questionnaires targeted various cohorts and conducted from June 1st, 2020 to June 20th, 2020 in China. It is meaningful to take China as the empirical context, as the time of our investigation is the period after the highest outbreak of the COVID-19 and people have gone back to work and school. The main data source employed in our study is a web-based survey called ‘Investigation of Residents’ Travel Mode and Behavior after the New Crown Pneumonia Epidemic’. This questionnaire contained two parts: a basic survey regarding socio-demographic information and a travel behavior survey under different scenarios. 566 valid responses were retrieved and 428 responses from 4 main cities of China were elicited for our analysis.

The main motivation of our survey is to learn the present travel mode preference for commuters, the major influencing factors taken into account and the intention of car purchase. As not all respondents are available to private car, the Stated Preference (SP) survey method is usually used to collect data. Please note that the mode choice is just for the commuter journey. There are four modes including bus, metro, private car and ride-hailing or taxi presented as alternatives for individuals to choose from. Further, according to the previous investigated results of the possible factors for mode choices, top four influencing factors with the highest proportions were selected as attributes in Fig. 1, i.e., travel time, travel cost, the degree of congestion and wait time. Due to various considerations with different trip distances, 3 typical scenarios designed for each respondent are the distances of less than 6 km (Scenario I), between 6 km and 12 km (Scenario II), and more than 12 km (Scenario III, respectively. Four attributes separately contain low, medium and high levels, which were determined according to specific scenarios. For instance, in the Scenario I, the low, medium, high level of travel time for bus matches 30, 35, 40 min, respectively, and in the Scenario II, the low, medium, high level of travel time for bus is 40, 45, 50 min. The final plans were generated by an optimal orthogonal test design. Lastly, 1284 choice observations were obtained for our analysis. Table 2 presents descriptive statistics of the socio-demographic information for respondents. As can be seen in Table 2, 46.65% were male and 53.35% were female. 57.93% of participants were between 26 and 40 years old, 17.07% were between 18 and 25 years old, 12.5% were between 41 and 55 years old, and less than 15% were older than 56. Most respondents had higher education experience. Respondents with a monthly income over 5000 RMB accounted for 51.22%, which means

Table 2

| Variables               | Proportion |
|------------------------|------------|
| Gender                 |            |
| Male                   | 46.65      |
| Female                 | 53.35      |
| Age                    |            |
| 18-25                  | 17.07      |
| 26-40                  | 57.93      |
| 41-55                  | 12.5       |
| >55                    | 12.5       |
| Education              |            |
| Level is high school or below high school. | 18.9 |
| Level is college.      | 15.55      |
| Level is an undergraduate. | 35.67    |
| Have received higher education. | 29.88   |
| Income per month       |            |
| Less than ¥3000        | 20.73      |
| ¥3001-5000             | 28.05      |
| ¥5001-7000             | 19.21      |
| More than ¥7000        | 32.01      |
| Car ownership          |            |
| Yes                    | 57.93      |
| No                     | 42.07      |

Fig. 1. Survey for the possible factors for mode choice.
that half of them are high-income and middle-income people. Moreover, the cohort of car made up 57.93% of all the participants.

5. Result and discussion

5.1. Model results

In this section, the results calculated from different models are compared to find the best model to explain travel mode choice after suffering COVID-19. The explanatory variables are tested in the estimation process.

In this study, the RUM and four regret-based models are given a symbol including the basic regret model RRM, the generated regret models GRRM(\(\gamma = 0\)), GRRM(\(\delta\)) and GRRM(\(\delta_m\)). GRRM(\(\delta\)) model is a generated regret model with generic (across attributes) values for \(\delta\), and GRRM(\(\delta_m\)) is a generated regret-based model with attribute specific values \(\delta_m\). All of these models are estimated by PandasBiogeme (Bierlaire, 2003, 2020bib_Bierlaire_2003bib_Bierlaire_2020), and the estimation results of these models for Scenario I (distance < 6 km), II (distance 6–12 km), and III (distance > 12 km) are separately shown in Tables 3–5.

According to the results of three scenarios, all of GRRM (\(\gamma = 0\)) models have the same log-likelihood and t-values as the corresponding RUM models, for the formulation of GRRM (\(\gamma = 0\)) is a variant of RUM. However, due to the Logsum (Chorus, 2012), parameters from utility-based models are approximately four-times smaller than GRRM (\(\gamma = 0\)) models rather than three times (Chorus, 2014; An et al., 2015) in our study. The estimation results (parameters and t-values) of GRRM(\(\delta\)) and GRRM(\(\delta_m\)) models for Scenario I, II, and III are similar as well. This is due to the similar value of regret-weight \(\gamma\) after re-estimation as shown in Table 6. In terms of log-likelihoods of GRRM(\(\delta_m\)) and GRRM(\(\delta\)), generated regret-based models with attribute specific values \(\delta_m\) outperforms slightly generated regret models with generic (across attributes) values.

For Scenario I (distance < 6 km), the log-likelihoods of the five individual components show RUM model performs slightly better than regret-based models, which is different from the results obtained by Chorus (Chorus, 2014), An et al. (2015), Wang et al. (2018) and Anowar et al. (2019). However, in line with the results reported in previous studies, the treatment of log-likelihoods and parameters for RRM and GRRM model is preferred to the pure RUM treatment suggesting that regret-based models fit the database of Scenario II and III better than linear-in-parameters RUM models and the difference is small. Since every attribute’s \(\delta_m\) is close to 0, GRRM model emphasizes less regret element than basic RRM model, which is proved by the final loglikelihoods in Tables 3–5 Hence, in the subsequent section, we use the results from the model with the best final log-likelihood for analysis.

In our study, we don’t focus on which rule or model (i.e., regret minimization or utility maximization) is better to explain the attributes. It is important to discuss the characteristics of each attribute. In the GRRM(\(\delta_m\)) model, attributes are decided by the socio-demographic variables \(\delta_m\) which reflects the utility or regret tendency. When \(\delta_m\) is a large positive value, it means passengers have regret psychology on certain attributes, and vice versa. As shown in Tables 3–5, all of the values of \(\delta_m\) in Scenario I, II, III are negative, which is against our exception. It seems that individuals still prefer to pursue utility maximization on travel time, travel cost, congestion degree and wait time after suffering COVID-19. The values of regret-weight in the GRRM model equals close to 0.5, which indicates that travelers’ regret aversion psychology is not relatively strong.

As can be seen, all estimated parameters are statistically significant at the 95% level. There is also the accordant relation among attributes, which indicates the reliability of all models we used is very high. For the trip distance less than 6 km, travelers emphasize travel time that is followed by the degree of congestion. When travel distance is between 6 km and 12 km, the degree of congestion is the most important factor for mode choice. Individuals are more likely to consider travel cost first, the degree of congestion second for the commuter journey above 12 km. The results indicate that passengers more easily ignore to consider waiting time among four attributes when they make decisions for travel mode.

5.2. Discussion

5.2.1. Overview of our results

In the first section, we made a prediction regarding the travel psychological changes brought by COVID-19 on travel mode choice. However, the above evidence suggests that the impact of this epidemic on commute mode choice is not as great as expected in the long run and the degree of trepidation for the risk of infection gradually began to fade. Life returned to regular as people do hopefully start to work, meet friends, eat out, entertain, and go shopping in China. The willingness to travel and the usage of mass transit have the tendency to rebound. Yet, one cannot neglect that people still concern about social distancing, which is demonstrated by the estimation results of the degree of congestion.

The key findings from the above SP survey not only include the analysis of influencing factors of decisions, but also the prediction of mode choice in the future. As can be seen from the probability of mode choice in Fig. 2, respondents have a preference for driving motor vehicles for work at short and medium distances. The reasonable interpretation is that short-range and medium-range trips by car are lower risk of infection, and short travel time, particularly the travel cost within a certain tolerance. On the contrary, long commute trips are less likely to be undertaken by car. The high commute costs for ride-hailing services and private transit are likely to make people attempt to choose public transport. Very often, the metro is considered a lower-cost and higher-speed alternative to the bus. Therefore, our prediction regarding the coming great challenge of public transport, in the long run, was rejected.

Table 3

|                      | RUM       | RRM       | GRRM(\(\gamma = 0\)) | GRRM(\(\delta\)) | GRRM(\(\delta_m\)) |
|----------------------|-----------|-----------|-----------------------|------------------|------------------|
| TRAVEL_TIME          | -0.020 (-0.04) | -0.010 (-0.17) | -0.005 (-0.04) | -0.007 (-0.11) | -0.007 (-0.11) |
| TRAVEL_COST          | -0.069 (-0.10) | -0.031 (-0.08) | -0.010 (-0.12) | -0.017 (-0.10) | -0.025 (-0.10) |
| CONGESTION_DEGREE    | -0.023 (-1.14) | -0.010 (-1.24) | -0.006 (-1.14) | -0.008 (-1.18) | -0.008 (-1.18) |
| WAIT_TIME            | -0.073 (-8.27) | -0.035 (-7.59) | -0.018 (-8.27) | -0.027 (-7.88) | -0.027 (-7.88) |
| \(\delta\) (generic) |            |           |                      |                  |                  |
| (travel time)        |            |           |                      |                  |                  |
| (travel cost)        |            |           |                      |                  |                  |
| (congestion degree)  |            |           |                      |                  |                  |
| (wait time)          |            |           |                      |                  |                  |
| Number of choices    | 1968       | 1968      | 1968                  | 1968             | 1968             |
| Null log likelihood  | -2728.227 | -2728.227 | -2728.227             | -2728.227        | -2728.227        |
| Final log likelihood | -2521.327 | -2523.497 | -2521.327             | -2522.407        | -2522.407        |
due to a lack of evidence. Despite the impact of COVID-19, the obvious advantages of sustainable transportation cannot be replaced by private transportation.

Since the survey data were based on the access of private car, the results about the car mode choice for short and medium trips cannot jump to the conclusions that the car will be in a dominant way and will lead to the consequential heavier traffic jam. We also investigated the intention of buying a car further and the result is shown in Fig. 3. In the beginning, we expected that the desire for automobiles will come sooner and stronger because of the viral pandemic, while 71.01% of carless

### Table 4
Estimation results for Scenario II (distance 6–12 km).

|                  | RUM     | RRM     | $GRRM(\gamma = 0)$ | $GRRM(\delta)$ | $GRRM(\delta_m)$ |
|------------------|---------|---------|--------------------|----------------|------------------|
| **TRAVEL_TIME**  | -0.049  | -0.023  | -0.012            | -0.018         | -0.018           |
| **TRAVEL_COST**  | -0.102  | -0.048  | -0.025            | -0.037         | -0.037           |
| **CONGESTION_DEGREE** | -0.022  | -0.010  | -0.005            | -0.008         | -0.008           |
| **WAIT_TIME**    | -0.103  | -0.051  | -0.026            | -0.038         | -0.038           |
| $\gamma$ (generic) | -       | -       | -                 | -0.016        | -                |
| $\gamma$ (travel time) | -       | -       | -                 |              | 0                |
| $\gamma$ (travel cost) | -       | -       | -                 |              | 0                |
| $\gamma$ (congestion degree) | -       | -       | -                 |              | -0.016          |
| $\gamma$ (wait time) | -       | -       | -                 |              | 0                |
| **Number of choices** | 1968   | 1968   | 1968              | 1968          | 1968             |
| **Final log likelihood** | -2224.973 | -2219.462 | -2224.973      | -2221.689     | -2221.668        |

### Table 5
Estimation results for Scenario III (distance >12 km).

|                  | RUM     | RRM     | $GRRM(\gamma = 0)$ | $GRRM(\delta)$ | $GRRM(\delta_m)$ |
|------------------|---------|---------|--------------------|----------------|------------------|
| **TRAVEL_TIME**  | -0.030  | -0.016  | -0.008            | -0.012         | -0.012           |
| **TRAVEL_COST**  | -0.020  | -0.009  | -0.005            | -0.007         | -0.007           |
| **CONGESTION_DEGREE** | -0.024  | -0.011  | -0.006            | -0.009         | -0.009           |
| **WAIT_TIME**    | -0.172  | -0.085  | -0.043            | -0.064         | -0.064           |
| $\gamma$ (generic) | -       | -       | -                 | -0.016        | -                |
| $\gamma$ (travel time) | -       | -       | -                 |              | 0                |
| $\gamma$ (travel cost) | -       | -       | -                 |              | 0                |
| $\gamma$ (congestion degree) | -       | -       | -                 |              | -0.016          |
| $\gamma$ (wait time) | -       | -       | -                 |              | 0                |
| **Number of choices** | 1968   | 1968   | 1968              | 1968          | 1968             |
| **Final log likelihood** | -2414.536 | -2410.085 | -2414.536      | -2412.220     | -2412.193        |

### Table 6
Regret-weight $\gamma$ after re-estimation for Scenario I, II, and III.

|                      | Scenario I | Scenario II | Scenario III |
|----------------------|------------|-------------|--------------|
| $\gamma_{genetic}$  | 0.495775   | 0.49605     | 0.495975     |
| $\gamma_t$          | 0.5        | 0.5         | 0.49545      |
| $\gamma_c$          | 0.4942     | 0.5         | 0.5          |
| $\gamma_d$          | 0.496125   | 0.496125    | 0.49595      |
| $\gamma_w$          | 0.5        | 0.5         | 0.5          |

![Fig. 2. The probability of mode choice.](image-url)
respondents have no intention of car purchase in line with the previous studies from J.D. Power (Power, 2020). The fact that the retail sales of automobiles fell 8.2% year-on-year by the statistics results of the Chinese National Bureau of Statistics also reflected individuals’ intentions.

Interestingly, the market data shows that the sales of Electric Two-wheelers (E2W) have soared sharply including electric motorcycles, scooters, and bicycles. The accumulated main business income of electric bicycle companies increased by 8.2% year-on-year, and profits increased by 20.8% year-on-year from January to May. In our study, we also counted the main traffic modes of carless people for work, entertainment and shopping. The respondents without motor vehicles presented their daily travel modes in Fig. 4. This figure and our survey indicate that people live in fear of future COVID-19 pandemic to some extent and take notice of social distancing and the condition of public hygiene during the trip. Due to the severe recessions and the rising jobless rate, people would be likely to buy the less expensive E2W than the private car in order to reduce the risk of infection as far as possible. Moreover, another reason for not buying a car is vehicle maintenance, insurance, parking, tolls and other later costs are too high to afford.

5.2.2. Policy implications and suggestions

In the nascent stage of the outbreak of the COVID-19, the government and transport authority took drastic measures like lockdown, halting the mass transit operations, self-restriction orders et al. to control the viral spread. In order to quickly contain the spike of new cases, Chinese governments implemented centralized isolation for the confirmed cases rather than the household quarantine (Zhu et al., 2020). Maybe other mitigation measures would have a positive effect on the anti-epidemic process, however, China with the largest population of around 1.4 billion could not provide enough medical resources and available medical care for the huge number of patients. Due to the large population base, the spread of contagion and the incidence is several times than the other countries. Hence, the target of the authority is not to “flatten the curve”, but to clear all the confirmed cases of the pandemic as quickly as we can. The facts have verified a series of actions such as building cabin hospitals, travel ban for individuals, wearing-makes orders et al. successfully suppress the spread of the virus and the Chinese government spent three months to decline all native cases of the COVID-19 to zero.

In the short term, some policy implications for different travel modes are suggested below. In terms of mass transit, the public health concern as the most significant factor is still taken into account by the passengers. The public health concern as the most significant factor is still taken into account by the passengers. In the early stages of the outbreak of COVID-19, most of the bus lanes were out of action at the government’s request for fewer trips and better insulation at home. Later, with the success of combat the spread of COVID-19, the government took action by controlling the maximum passenger capacity to prevent recurrent attacks. At present, since stores reopen and people go back to work, the operations of bus and metro have basically returned to normal as well. Still, there was no winking in the matter for the health and safety of public transportation. Firstly, increasing the number of buses and shorten the waiting time of passengers during peak hours will be essential for splitting the public transport crowding. Secondly, deep-cleaning and regular disinfection carrying over into public hygiene will banish passengers’ fear and anxiety effectively. In addition, it would be beneficial to set hand sanitizer near the bus or subway doors. For personal biosecurity, wearing...
face masks is also a necessary order for public places. Lastly, authorities will likely need to advocate vigorously cashless trading and WeChat or Alipay payment online, which have already started to do so. Once there is a confirmed case, this move is better to follow the track of patients and find close contacts to accept medical observation focus and test for COVID-19.

The above analysis and results provided evidence that the number of E2W would noticeably increase in the short term, since the intention to buy E2W is strong. Furthermore, the bike-sharing service is taken more notice by lower-income individuals and it has become a great substitute for the short-distance trip.

The development of micromobility protect the environment by reducing pollution and improving air quality. On the other hand, this phenomenon and trend will also cause traffic chaos. Chronic traffic problems are easier to be ignored and they accelerate the congested condition of the urban city. The key reason is the seriously insufficient corresponding infrastructures and lack of management regulation. Building non-motor carriageways, charge stations and public parking lots in the proper scale for non-motorized vehicles as the infrastructure investment may be beneficial to road order and safety.

In light of reinvigorating the economy of the automobile industry, the government should appropriately call for residents to buy autos, particularly in the cities with automobile purchase restriction policy. Although the less willing to travel and flexible working arrangement may relieve the traffic congestion to some extent currently, the quota of car purchase should be determined by the urban land-use, traffic capacity and regional planning. The car purchase index is based on households, with priority given to car-free households. Besides, it is possible that the intention of vehicle purchase is motivated through the development and application of smart parking technology and Electronic Toll Collection (ETC). Smart parking refers to the use of cloud computing, GPS positioning technology, GIS technology, networking and et al. to collect and integrate real-time parking information to solve the problem of parking difficulties (Ogus et al., 2020). The popularization of ETC greatly improves the traffic capacity of highways and reduces contact with toll station staff.

Looking at the change of perceptions for ride-hailing services, how to reduce the alertness of passengers seems to be extremely significant. From the hardware perspective, the drivers of the ride-hailing car need to launch several necessary temporary measures to screen off the passengers, such as installing a plastic isolation film. It is worth considering how to design a long-lasting antibacterial interior system or a fundamental air self-cleaning or disinfection system to show passengers a tangible sense of biosecurity. From the software perception, if individuals could acknowledge the health condition of drivers on the ride-hailing app, these intuitive measures can dispel people’s doubts.

In addition, the following suggestions for the industry of app-based ride-hailing services can be regarded as a reference for related companies. Based on the statistical data from the Office of the Central Cyberspace Affairs Commission, there is no denying that the industry of ridesharing has so giant user group (about 362 million) with huge market potential in China. Currently, app-based ride-hailing services allow full-time and part-time drivers to adjust their work plans according to their own free time, which rises fiercer competition between them. Based on the statistic analysis results by the Chinese National Bureau of Statistics, in the second quarter of 2020, although the impact of the epidemic has weakened, the monthly surveyed unemployment rates in urban areas were 6.0%, 5.9%, and 5.7% for April, May, and June respectively. Compared with the unemployment rate staying between 5.0% and 5.3% in the same period of 2019, the current unemployment rate is still high. The third-party shared transit service platform does not require high professional skills for employees except driving, and can better leverage social employment. Besides, innovative thinking may also need to occur, perhaps the online car-hailing open platform can distribute more orders to full-time drivers or drivers with less income based on their reported personal income tax to judge.

As for the post-COVID-19 era, a large number of scholars would like to research the look of “new world” and “new normal” in the long run. Long-term changes in society such as online meetings, teleworking, online shopping instead of the conventional ways may become the new mainstream (Zhang et al., 2021). Meanwhile, many politicians and citizens pinned their hopes on the vaccine. Indeed, the vaccine seems to be the only way to end the devastating disaster. However, the immature vaccine may cloud the positive emotion, as it could not catch the evolution of the COVID-19 mutants at present (Sumathi et al., 2021). We may not have full confidence for the fight victory in the short term, if we only depend on the vaccines. The world is still in the midst of the pandemic, but the epidemic condition is beginning to stabilize in China. The major cases in China are from the residents abroad. Therefore, the severe entry policy requests that individuals with the negative results of the PCR- and IgM Antibody Blood tests are compelled to centralized quarantine for two weeks (2020c). Needless to say, these measures are necessary to guarantee domestic safety situations, which enormously relieve the individuals’ psychological panic and anxiety. However, whatever the vaccine or strict orders, it is probably inevitable to emerge the new cases again, even a small-scale breakout of the pandemic. Faced
with this condition, Chinese authorities would like to conduct the nucleic acid test on all citizens in certain cities or regions where confirmed new cases within three days and it has already accomplished in Dalian (Xinhua, 2020), Qingdao (2020b), Mending (2020e) et al. The large-scale investigation of latent patients could also provide individuals the strong faith for work, leisure, shopping or other social activities.

In our opinion, apart from the investment of vaccines, the long-term policy implications are divided into two perspectives. In the view of the authority, cutting down all the possible sources of infections is still the first step to wrestle with the COVID-19. In addition, once the new case is confirmed, a quick viral check system must be organized and conducted immediately. The big safe underground provides ameliorating assists to solve many issues smoothly such as the economy, employment, the willingness to travel, the usage of mass transport and so on. From the perspective of the individual, keeping hygiene habits may be the only thing we can do and it is the best way to assist society in a healthier environment.

6. Conclusion

This study takes China's an empirical context and presents the preliminary findings from the travel mode survey conducted in June 2020 after the controlled status of COVID-19 in China. The conclusions addressed here may provide a useful reference position and may be applied in other countries as well.

COVID-19 as a 'supernova' in human history has created disruption to normal economy and activities, and changed individuals' behaviors from multiple perspectives. With the objective of enhancing the understanding of travel mode choice influenced by the COVID-19 pandemic, we divided the survey into short, medium and long-distance scenarios and collected 1284 choice observations in the four main cities in China. In light of avoiding further losses, the estimated results are obtained by the best good-of-fit model among RUM, RM and GRRM models. Preference and attitudinal analysis provides some broad insight into policy implications and verified our predictions in section 1 are not true. The conclusions show that:

1. After the outbreak of COVID-19, although people have regret aversion psychology to choose the mode and trepidation for the risk of the infection to some degree, this tendency began to weaken and individuals prefer to pursue utility maximization when facing travel mode choices.

2. In our survey, keeping social distancing directly reflects on the consideration of the attribute of the congestion degree. However, public transport as the most difficult tool to keep biosecurity distance makes great sense on the long trip, even if respondents have access to automobiles.

3. The statistics results of the survey of intention to buy a private car show that the desire for civilian vehicles won't come sooner and stronger in the short term. Instead of purchasing cars, people would be likely to buy the less expensive E2W. The current traffic situation is relatively stable.

4. The ride-hailing services have been shocked a lot due to less travel and the avoidance to contact the drivers of ridesharing. A large number of careless people would likely choose this mode for shopping and other recreational activities.

To sum up, we urge policymakers to perceive the citizens’ psychological changes and preferences of travel behavior exposed by our study and highlights the infection risk of every mode. Infrastructure investment, software services and policy promotion should be carefully considered. In terms of public transport, the measures regarding the distribution of commuter crowd, deep-cleaning and personal precaution should be taken in the long run. The E2W management also faces a great challenge, which requests to strengthen the construction of infrastructures like non-motor carriageways, public parking lots and charging station et al. In order to satisfy the demand of car purchase in the household unit and the strategy of reinvigorating the economy of the automobile industry, the government needs to broader the car purchase index in some metropolis motivating the customers, and, meanwhile, develop intelligent transportation technologies such as ETC and smart parking to relieve the traffic stress. In addition, even if the ride-hailing services have been shocked a lot, it still has so giant market potential. From the hardware and software perspective, it is worth discussing how to dispel people’s travel doubts. In the long run, apart from the vaccines, strict anti-epidemic measures like centralized isolation, all citizen tests, entry quarantine policies are suggested to take in case of a large-scale relapse. It would be a significant precondition to guarantee domestic safety and promote the positiveness for travel.

Future waves of the research will seek to explore the preference characteristics of the specific target population in different scale cities, for every mode occupies distinct proportions in diverse cities. Moreover, there is a scope to investigate more respondents in a longer period to explore their psychological changes, in particular prior to the emergence of COVID-19. Hence, the lack of the compared reference may lead to missing significant findings. Finally, we didn’t consider the micro-mobility alternatives in our SP survey. For the next step, we will add walk, bike/bike-sharing as alternatives for the short- and medium-trip scenario and explore the latent factors for mobility choice.

Availability of data and materials

The data that support the findings of this study are available from Jilin University but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Jilin University.

Author’s contribution

Siliang Luan: Conceptualization; Methodology; Roles/Writing – original draft.

Qingfang Yang: Supervision; Project administration; Writing – review & editing.

Zhontai Jiang: Data curation; Validation; Writing – review & editing.

Wei Wang: Supervision; Investigation.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgment

We acknowledge gratefully the research grant support of the China Scholarship Council (Grant No.201906170189).

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