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Smartphone-based services, perceived accessibility, and transport inequity during the COVID-19 pandemic: A cross-lagged panel study

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ABSTRACT

Individuals have experienced various degrees of accessibility loss during the COVID-19 pandemic, which may consequently influence transport equity. However, conventional measurements of accessibility cannot capture individual experiences and perceptions of accessibility. Moreover, since many daily necessities and services can only be acquired online during the pandemic, the ease of using smartphone-based services play an essential role in people's everyday lives.

Therefore, this paper investigates the relationship between the ease of using smartphone-based services, perceived accessibility, and perceived transport equity during the pandemic. Based on 186 family interviews, a panel survey with 569 respondents was conducted monthly from February to October 2020 in Kunming, China, and a three-wave cross-lagged panel model was developed to understand the causal relationship between the three constructs. The results indicate that the ease of using smartphone-based services dominantly influence transport equity in the early phase of the pandemic, but its effect faded after the lifting of travel restrictions. Perceived accessibility to services appears a sound indicator for transport equity in the new normal, but perceived accessibility and transport equity are not strongly associated when staying at home is perceived as desirable. Moreover, we found that contemporary practices of smartphone-based new mobility services only favour those who already have convenient access to services and have further excluded and marginalised disadvantaged populations, which urgently require policy interventions.

1. Introduction

For the past twenty years, there has been a growing focus on the transport equity issue among academics and policymakers in Western societies. More specifically, the discussion and empirical evidence on transport equity issues can be roughly categorised into four groups: transport poverty, transport disadvantage, accessibility, and transport-related social exclusion (e.g., Levine, 2020; Lucas, 2012; Lucas, 2019; Mattioli et al., 2017). A great deal of research on transport equity focuses on measuring the spatial distribution of

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accessibility to activities and opportunities (e.g., Chang et al., 2019; Liu et al., 2018; Rietveld, 2000); however, a previous study discussing elderly mobility during the COVID-19 pandemic in China revealed that vulnerable groups who suffered from food deprivation, loneliness, and depression due to containment measures had to travel for activities whilst better-off groups stayed at home because they could acquire daily necessities and fulfil the demand for social interactions via smartphone-based services (Liu et al., 2021). Measured objectively, activities were accessible to disadvantaged groups who were actually more excluded and marginalised by the containment measures because they suffered the risks of infection, extensive social pressure, and various other burdens while walking outdoors. Curl (2018) argued that perceptions should be considered if equity is a concern because spatial accessibility cannot accurately reflect the lived experience of different populations; whilst the aforementioned phenomenon further brings into question whether spatial accessibility should be regarded as a useful indicator for transport equity.

The ongoing COVID-19 pandemic, first identified in December 2019 in Wuhan, China, has struck 192 countries and territories, causing more than 105 million confirmed cases with more than 2.28 million deaths worldwide by the end of January 2021 (CSSE, 2021). Beyond the numbers are people, families and societies that have been inconceivably influenced. This global public health crisis, and probably other derivative crises such as economic chaos and entrenched social divisions (e.g., Cerami et al., 2020; Fairchild et al., 2020), put governments and societies to the test. To contain the outbreak of COVID-19, various interventions, such as isolation, social distancing, school closures, and lockdown measures, have been imposed in countries in the East and West. Despite the widely applauded effects of containing the spread of COVID-19 (e.g., Gatto et al., 2020), their social consequences are yet to be explored.

Although containment measures influence almost every citizen, disadvantaged populations, such as elder people and the low-income groups, are more vulnerable to the pandemic in terms of COVID-19 susceptibility and usage of online services, which was crucial to maintain daily life because of pandemic control policies. Hence, it is vitally important to investigate whether the containment interventions are equitable and can ensure all population groups have opportunities to live a satisfactory life during and after the pandemic. Accessibility to daily necessities and services fulfilling basic social needs is, therefore, essential. However, it has recently been criticised that accessibility is only objectively measured in most cases, and the conventional accessibility measurements cannot capture how different individuals perceived their accessibility (e.g., Lättman et al., 2020; Lättman et al., 2016b, 2018). Van der Vlugt et al. (2019) indicated that the perception of accessibility is usually different from the measured accessibility. Considering that equity is a perception, perceived accessibility should be a more appropriate way to understand transport equity than objectively measured accessibility. Even so, the notion of perceived accessibility in the transport arena is still limited to “perceived possibilities and ease to live the life one wants with the help of the transport system” (Lättman et al., 2018). With the increasing use of smartphone-based services, it is no longer necessary for some people to access certain services by conducting trips by themselves. It is noticeable that wealthier or more technology-savvy people had a very high level of accessibility to services without leaving their home whilst disadvantaged groups had to travel to access such services in the first few weeks of the COVID-19 outbreak (Liu et al., 2021). Similar results were found without the impact of the pandemic. Vitman-Schorr, Ayalon and Khalaila (2019) demonstrated that perceived accessibility to services is also influenced by non-transport factors, such as social participation and perceived safety. Ignoring these factors may cause some to misunderstand what is perceived as accessible to the public. Therefore, the generalised notion of perceived accessibility—the ease with which daily necessities and services that are essential to living a satisfactory life can be reached—is used throughout this paper.

To fill the gap of the underexplored impacts of perceptions of accessibility and smartphone-based services on how equitable the transport system is deemed, this paper investigates the relationship between the use of smartphone-based services, perceived accessibility, and perceived transport equity during the pandemic and the work resumption process. It also examines how the ease of using a smartphone, perceived accessibility, and perceived transport had changed over time. Furthermore, it investigates whether perceived accessibility and transport equity during the pandemic can influence the extent to which people consider how equitably they are treated in the new normal.

In so doing, this paper contributes to the literature in four aspects: (a) it reveals how the use of smartphone-based services influence perceived accessibility to services, which may further challenge the conventional accessibility measurements; (b) it contributes to a more robust understanding of the role perceived accessibility plays in shaping people’s perceived transport equity; (c) it employs a mixed-method approach, combining family interview data to develop and interpret the survey with quantitative panel data to test hypotheses; and (d) it uses a cross-lagged panel model to evaluate the lagged effects of the ease of using a smartphone, perceived accessibility, and perceived transport equity, which can offer valuable policy implications for considering the possible long-term consequences of containment policies.

China, as the country where the first confirmed case was discovered, can serve as an ideal case to investigate how accessibility loss caused by containment policies have influenced transport equity. Further, it helps us examine how the lifting of such policy interventions has affected how people perceive transport equity. After the severity of the unknown SARS-like virus became apparent in late January 2020, a few days before the Chinese Lunar New Year, drastic actions aimed at controlling the spread of COVID-19 were taken nationwide, including quarantining entire cities, imposing strict travel restrictions, curfew laws, cutting off villages, community lockdowns, public transport shutdowns, school closure, and the introductions of a smartphone-based health QR code system[1] (e.g., Song et al., 2020; Wu et al., 2020). Due to the containment effects of the aforementioned policies, work resumption gradually took place across China since late February, which allows us to observe scenarios increasingly similar to a post-pandemic world.

[1] China’s Government has employed a colour-based automatically generated quick response code to contain the spread of COVID-19. These codes have been used to indicate the health status of individuals and to give permission to enter public spaces and travel. A green code means free to go, whilst people having amber or red codes are barred from entry.

The remainder of the paper proceeds as follows. Section 2 reviews three bodies of literature: transport equity, accessibility, and perceived accessibility and negative impacts of smartphone use. In Section 3, we discuss the conceptual framework underpinning the study. Section 4 introduces the data variables used in this study. Section 5 presents the empirical results, including descriptive results, results of cross-lagged effects, within-wave effects, and the effects of socio-demographic variables. In Section 6, we discuss the research findings and future research directions.

2. Literature review

2.1. Transport equity

Since social equity has been regarded as the third pillar of public administration since the ’60s (see Frederickson, 2015), equity implications of transport policies have increasingly focused on researchers and policymakers in Western contexts. Although the conceptualisation and theorisation of transport equity is still under debate (e.g., Hananel and Berechman, 2016; Lucas et al., 2016b; Martens, 2012; Pereira et al., 2017), a large body of empirical evidence and related discussions on transport equity and justice has *de facto* crystallised four different, albeit overlapping, dimensions of transport equity: (a) transport poverty (see Lucas et al., 2016a for a review), including transport affordability (e.g., Litman, 2015), fuel poverty (e.g., Walker and Day, 2012), mobility poverty (e.g., Salon and Gulyani, 2010), accessibility poverty (e.g., Velaga et al., 2012), and exposure to transport externalities, transport disadvantage, accessibility, and transport-related social exclusion (e.g., Barter, 1999); (b) transport disadvantage, which focuses on social disadvantages related to the transport system, such as the outcome of a lack of access to essential resources, activities, and opportunities (e.g., Schwanen et al., 2015); (c) accessibility which concerns with the opportunity available to people at a location to take part in activities (see Geurs and van Wee, 2004 for a review); and (d) transport-related social exclusion (see Lucas, 2006, 2012, 2019), which contains seven categories of exclusion: physical, geographical, economic, time-based, fear-based, space exclusion and exclusion from facilities (Church et al., 2000). However, since the conceptualisations of transport equity are mostly Western context-based, these dimensions may not properly reflect transport equity issues or subjects to very different interpretations in other contexts (Liu et al., 2019b). For example, in the Chinese context, institutional factors such as the *hukou*[2] system can influence an individual’s capability of using opportunities, even if the opportunity is spatially accessible (see Zhang et al., 2018; Zhao and Howden-Chapman, 2010; Zhao and Li, 2016). Therefore, although we used Western context-based theories to formulate the questions asked in interviews, what the interviewees perceived as transport-related social (in)equity was adopted to reflect transport equity in this study.

2.2. Accessibility and perceived accessibility

Planning researchers have advocated for the idea of accessibility-oriented development in the past decades (e.g., Deboosere et al., 2018; Levine, 2020; McCahill et al., 2020; Zhang et al., 2020b). However, according to Handy (2020), the accessibility-oriented approach has yet to be widely practiced because this seemingly simple idea is more difficult to measure than mobility. Therefore, accessibility measurement has increasingly become emphasised in the accessibility literature (e.g., Geurs et al., 2010; van Eldijk et al., 2020). Although many accessibility studies have not directly discussed the equity implications of accessibility, progress in accessibility research has been regarded as extremely important to our understanding of transport equity (see Hu et al., 2020). For research addressing accessibility-induced inequity issues, simple measures of accessibility are usually preferred to examine whether the urban environment provides equitable opportunities to its residents (e.g., Cheng et al., 2019), perhaps because more sophisticated measures are usually difficult to calculate in practice and less straightforward for lay-citizens to understand (Handy, 2020). The promised advantage of “accessibility” over “mobility” is that accessibility is more people-centred, concerning “the potential of opportunities for interaction” (Hansen, 1959) or the ease with which something is reached (Dalvi and Martin, 1976), whilst mobility is about “the ability to move”. However, in practice, accessibility is dominantly measured by the separation of people from origins or destinations whilst people’s experiences, feelings, and perceptions have been overlooked (Curl et al., 2011).

Efforts have been made recently to discuss individual perceptions of accessibility, whose impacts on travel behaviour are probably more decisive than objectively measured spatial accessibility (Morris et al., 1979), and thereafter how equitably the transport system will be perceived (Curl et al., 2011). Based on early-stage discussions on perceived accessibility (e.g., Budd and Mumford, 2006; Lotfi and Koohsari, 2009), Lättman et al. (2016b) developed the Perceived Accessibility Scale (PAC), which covers four key aspects, namely the perceived ease of reaching activities, perceived opportunities to travel, perceived opportunities to travel to intended activities, and perceived outcomes of accessibility. Other researchers have later adopted PAC to evaluate perceived accessibility. For example, Van der Vlugt, Curl and Wittowsky (2019) provided evidence on the relationship between self-reported accessibility measured by a Likert-type scale and physical accessibility calculated by an individual walkscore. They discussed how and why perceived accessibility differs from objectively measured accessibility. In a more recent study comparing perceived and objective accessibility levels of 2711 residents of Malmö, Sweden, by Lättman, Olsson, and Friman (2018), perceived accessibility was found consistently different from objectively measured accessibility. More interestingly, conflicting with objective accessibility studies, bike users perceived their accessibility significantly more satisfactory than car or public transport users. Lättman et al. (2019) suggested that perceived accessibility has broader impacts on subjective wellbeing by investigating the relationship between perceived accessibility, satisfaction with

[2] This is a system of household registration used in mainland China. It officially identifies a person as a permanent resident of an area. It is connected to social programs provided by the government, which assigns benefits based on rural and urban residency status.

daily travel, and life satisfaction among elderly people. This study revealed that the elderly could hardly be treated as a homogeneous group—in-home activities become increasingly important for life satisfaction of the very old group (80+). This implies that the perceived ease of reaching activities may vary across different population groups, and perceived accessibility may play quite different roles in overall life satisfaction. Lättman, Friman, and Olsson (2020) compared perceived accessibility before and after a fictive car use restriction in Sweden to understand how different car travellers perceive accessibility when moving the current transport system toward sustainability.

Perceived accessibility has received academic attention in recent studies (see Cheng and Chen, 2015; Cole et al., 2019; Friman et al., 2020; Márquez et al., 2019; Ryan et al., 2016; Scheepers et al., 2016; Yasumoto et al., 2020). Previous studies on perceived accessibility still focus on measuring perceptions of spatial accessibility—"the ease of living a satisfactory life using the transport system" (Lättman et al., 2016a). However, perceived accessibility to services is also influenced by many non-transport factors (e.g., Vitman-Schorr et al., 2019). Daily necessities and services are not merely accessible with the help of transport systems nowadays due to fast-developing online shopping and various web-based services that can fulfil demands for social interaction, participation, and entertainment. It has been particularly noticeable that online services, especially smartphone-based ones, played a critical role during the early phase of the COVID-19 pandemic. According to our qualitative exploration (Liu et al., 2021), perceived accessibility to daily necessities and services was strongly connected with the smartphone. Food was acquired, friends were reached, activities were participated in, and leisure time was enjoyed. Therefore, the notion of perceived accessibility is not limited to transport accessibility but the outcome of what is actually satisfying in this study.

2.3. *Impacts of smartphone-based services*

New mobility services, many of which are smartphone-based, have been a hotspot for academics, policymakers, and practitioners in the transport field. There is a palpable enthusiasm in studying (and, in many cases, advocating) the adoption of these new services, such as dockless bike-sharing, car-sharing and Mobility-as-a-Service (MaaS) (e.g., Alonso-González et al., 2020; Link et al., 2020), probably due to a presumption that such services could effectively shift demand away from private cars. However, the potential social

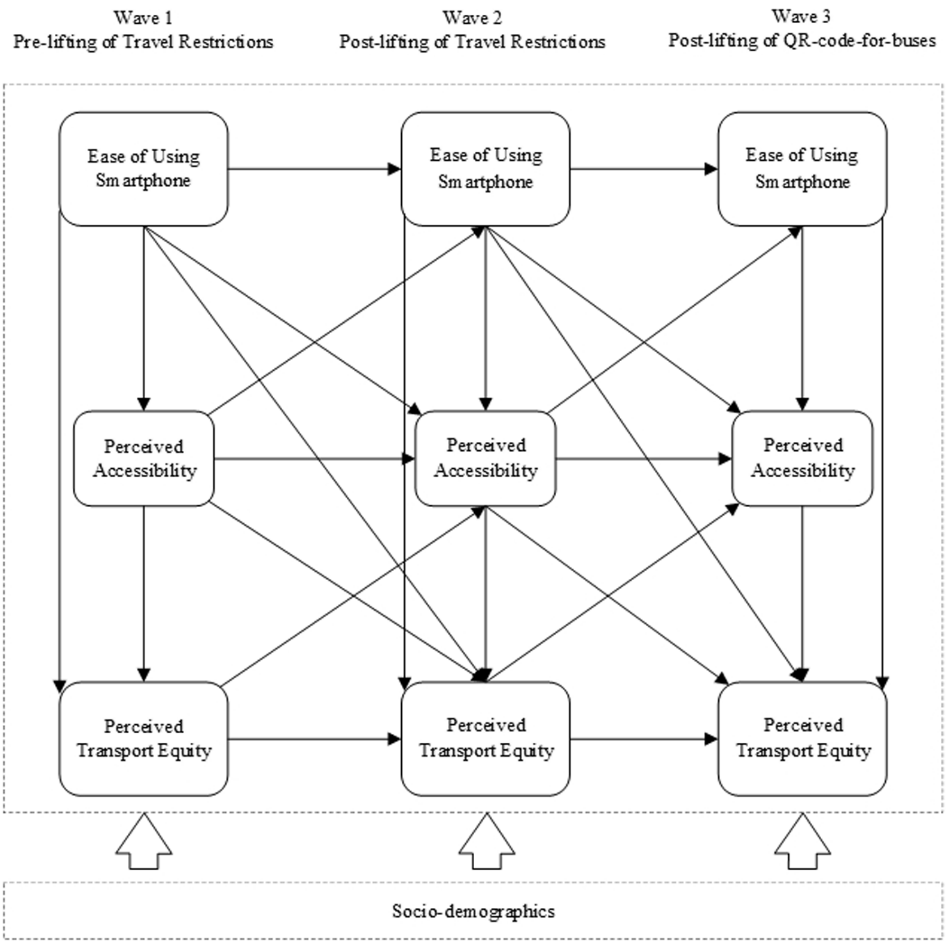

Fig. 1. Conceptual Framework.

consequences, such as equity implications, are underexplored. Mackett and Thoreau (2015) indicated that travel information provided electronically via mobile devices might not be accessible by low-income residents, the elderly and some disabled people. Fitt (2018) suggested that the levels of familiarity with technology may influence the extent to which individuals can effectively access opportunities. Elderly people were reported not comfortable with using smartphone-based services, such as taxi-hailing apps (Shirgaokar, 2020). However, the technological competence that people need to possess has been changing because of how mobility services deliver changes. Pangbourne et al. (2020) argued there is a potential for a "technological gentrification" of transport, which might further exclude disadvantaged groups, such as the elderly. Therefore, we also study how the ease of using smartphone-based services may influence perceived accessibility and transport equity during the COVID-19 pandemic.

3. Conceptual framework

Smartphone-related accessibility and transport equity issues emerged from the analysis of 186 family interviews, which included 519 residents in total. Obviously, the sample is small, but it was selected to enable the social impacts of COVID-19 containment measures to be explored. The full process of recruiting, grouping, and analysing family interviews is presented in another paper (Liu et al., 2021), and here we report on a summary of the key issues that informed the design of a questionnaire that followed.

From the in-depth qualitative analysis, eight themes were identified as being potentially relevant to perceived transport equity: familiarity with online shopping, familiarity with new mobility services, attitude toward technological advances, perceived accessibility to daily necessities, physical accessibility to daily necessities, perceived accessibility of leisure activities, physical accessibility of leisure activities, needs for social interactions, and relative disadvantages. A conceptual framework was developed based on findings from the qualitative study (shown in Fig. 1). The rationale of the conceptual framework and the hypotheses for testing are elaborated below.

3.1. The relationship between perceived accessibility and transport equity

Although a large body of literature extensively discussed the association between accessibility and transport equity issues (e.g., Bills and Walker, 2017; Cui et al., 2019; Deboosere and El-Geneidy, 2018; Guzman et al., 2017; Lucas et al., 2016b; Martens and Golub, 2018; Slovic et al., 2019), the objectively measured physical accessibility of facilities can hardly be seen as an indicator of transport equity during the early phase of the COVID-19 pandemic—better-off populations mostly stayed at home, whilst disadvantaged groups, such as the elderly, had to access groceries and convenience stores to acquire daily necessities physically. Also, they had to go out to fulfil their social needs because they were incapable of sufficiently interacting with others at home. Of these, 257 out of 276 older and poorer interviewees routinely performed outdoor physical activities, whilst only 4 of 243 better-off interviewees regularly went out in the first month of the nationwide outbreak. This result is in line with a study using smartphone location data (Fraiberger et al., 2020). The transport system, especially some specific containment measures, was therefore perceived as unfair by the disadvantaged populations.

It is because the better-off populations could, still with some difficulties, acquire daily necessities via various smartphone-based online shopping and social network apps. However, disadvantaged groups either lacked the experience of using smartphones or could not afford these expensive foods. Therefore, they have no choice but to physically access groceries and convenience stores and expose themselves to risky environments to acquire daily necessities.

As discussed in our foregoing paper (Liu et al., 2021), the role mobility played in many disadvantaged people's lives during the pandemic was not merely a facilitator of other activities. It also served the needs for interacting with non-family members, which was perceived as fundamentally important for their subjective wellbeing because walking and other facilities, such as chess or card rooms, offered them the only opportunity to maintain a social life. By contrast, the better-off populations did not face this problem. Their social and emotional needs were substantially fulfilled using various smartphone apps, such as social apps and mobile games. Many young interviewees even said they were happier staying at home during the pandemic than normal days.

As Liu et al. (2019b) revealed, the notion of transport equity is subject to an egalitarian interpretation. Therefore, in this paper, transport equity is defined and measured by people's perception of whether other people's daily lives were influenced in the same way as theirs by the containment measures.

Some researchers have acknowledged (e.g., Curl et al., 2015; Dixit and Sivakumar, 2020; Martens and Golub, 2012) that accessibility depends on the individual's perceptions. Therefore, as Lättman et al. (2016a) argued, perceived accessibility should be used to understand transport equity issues since conventional accessibility measures cannot capture individuals' abilities, needs, and opportunities (see also Cheng and Chen, 2015; Lättman et al., 2020; Lättman et al., 2016b, 2018; van der Vlugt et al., 2019). As mentioned in the introduction section, the definition of perceived accessibility for this paper is the ease with which daily necessities and services that are essential to living a satisfactory life can be reached. In this study, we begin by hypothesising that the extent to which an individual perceived the ease to live life before and after the lifting of travel restrictions is a significant determinant of their perceived transport equity pre- and post-lifting of restrictions, respectively. The previous qualitative exploration revealed that the better-off populations no longer felt accessibility loss caused by the pandemic soon after lifting travel restrictions, whilst disadvantaged groups could not effectively restore their mobility because many of them could not scan the health QR code compulsory to use public transport. Hence, we considered the second juncture of time, after which the QR code was not required to take buses.

3.2. The relationship between ease of using smartphones and perceived accessibility

In terms of the relationship between the ease of using smartphones and perceived accessibility, Wang and Jia (2021) argued the health QR code system might increase disadvantaged groups' risk of social exclusion. Based on previous qualitative explorations, we assume that the ease of using smartphones is a significant determinant of perceived accessibility for all three key junctures of time. As the qualitative analysis showed, some people ascribed their low level of perceived accessibility to unfamiliarity with smartphone-based online shopping and mobility services. Since perceived usefulness is a key determinant of technology acceptance (e.g., Marangunić and Granić, 2015), those who experienced difficulties in living a satisfactory life using the transport system during the pandemic may be compelled to use smartphone-based services more frequently. Therefore, we hypothesise cross-lagged effects from pre-lifting perceived accessibility (wave 1) to post-lifting ease of using smartphones (wave 2) and from compulsory QR-for-buses perceived accessibility (wave 2) to post-QR-for-buses ease of using smartphones (wave 3).

3.3. The relationship between ease of using smartphones and transport equity

Regarding the relationship between the ease of using smartphones and perceived transport equity, equity implications of the access to new mobility services, which are mostly smartphone-based, has recently prompted discussions about its social consequences (see Groth, 2019; Pangbourne et al., 2020; Varghese and Jana, 2019; Zhang et al., 2020a). We, therefore, assume that the ease of using smartphones significantly influences their perceived transport equity for the three junctures of time. One may argue that perceived transport equity can also influence the ease of using smartphones because low levels of perceived transport equity may urge less technology-savvy people to develop online shopping habits. Since it is out of this study's scope, to reduce the complexity of the model, we do not consider the reverse direction of influence in this study.

3.4. Hypotheses

This study tested the following hypotheses concerning the relationships between smartphone-based services, perceived accessibility, and transport equity.

H1. The perception of accessibility to daily necessities and services has lagged influence on transport equity, and vice versa.

H2. The ease of using smartphones has lagged influence on perceived accessibility to daily necessities and services, and vice versa.

H3. The ease of using smartphones has lagged influence on transport equity.

We also tested hypotheses concerning within-wave relationships between the ease of using smartphones, perceived accessibility, and perceived transport equity. As previous studies have reported associations between socio-demographic variations and perceived accessibility and transport equity (e.g., Curl, 2018), we consider socio-demographic variables as control variables.

4. Data and variables

4.1. Survey data

To investigate the impact of COVID-19 containment measures and attitudinal and behavioural change during work resumption, we

Table 1
Socio-demographic Characteristics of the Sample.

		Frequency	Percentage
Age (mean = 49.68, SD = 18.66)	18–30	87	15.3
	31–45	181	31.8
	46–60	143	25.1
	Above 60	158	27.8
Gender	Male	276	48.5
	Female	293	51.5
Monthly household disposable income (CNY)	<6000	167	29.3
	6000–9999	171	30.0
	10,000–19,999	166	29.2
	>20,000	65	11.4
Employment status	Employed	357	62.7
	Unemployed	52	9.1
	Retired	160	28.1
Residential Area	Within 1st ring road	128	22.5
	Between 1st and 2nd ring road	194	34.1
	Between 2nd and 3rd ring road	183	32.2
	Outside 3rd ring road	64	11.2
Car Ownership	Car Owner	249	43.8
	Non-car owner	320	56.2

conducted a monthly survey to collect panel data from February to October 2020 in Kunming, China. Kunming is a representative big city, which shares similar economic, social and spatial characteristics with other Chinese cities. Also, the seriousness of COVID-19 and the corresponding containment interventions of Kunming are similar to most Chinese cities. The participants of family interviews (for detailed information about the recruiting process of the participants see Liu et al., 2021) conducted in February were asked to take either a face-to-face or online survey and share the link with their acquaintances. A snowball sampling technique was then used to recruit other participants. Since the aim of conducting this survey is to explore how participants' attitudes and behaviour changed over time, the participants were informed that they would receive an increasing value of vouchers if they kept on doing the survey. We collected the first wave of data from February 24–28. A total of 1572 individuals participated in this survey in the first wave. We contacted all the individuals who participated in the first wave of the survey via social apps or other means to participate in the follow-up surveys. Since the process of data collection lasted nine months, many participants did not participate in every wave of the survey. Finally, only 569 individuals (retention rate of 36.2%) completed all three waves of data. Since the time-interval of observation may lead to different parameter estimates, uniformed time-intervals between observations are preferred to avoid biased results (e.g., Kuiper and Ryan, 2018). In this study, we used data collected in February (pre-lifting of travel restrictions), May (post-lifting of travel restrictions and pre-lifting of compulsory QR-code-for-buses) and August (post-lifting of QR-code-for-buses). The socio-demographic characteristics of these respondents are presented in Table 1.

4.2. Variables

Based on a review of existing literature on transport equity, (perceived) accessibility and smartphone-related technology divide, as well as the family interviews, a survey with 67 attitudinal items was designed to investigate how lay-citizens respond to COVID-19 and its containment policies. Three to four quotes from family interview participants were initially selected for each potentially relevant construct (113 statements in total). A 6-point Likert scale was adopted to record the attitudinal items, where 1 = strongly disagree, 2 = moderately disagree, 3 = slightly disagree, 4 = slightly agree, 5 = moderately agree, 6 = strongly agree. An even-number scale was used because it can force respondents to express a certain inclination and 6-point scales have higher reliability than 5-point ones (see Liu et al., 2019a). The final survey statements were refined through a pilot survey with 28 family interview participants and 44 experts with different background, such as psychology and sociology. The internal consistency was tested by calculating the Cronbach's α values of each construct. Items were eliminated if Cronbach's α values were lower than 0.7 (Tavakol and Dennick, 2011). Another three items were also eliminated because of their ambiguousness.

Since the main objective of this study is to investigate the association between the ease of using smartphones, perceived accessibility, and perceived transport equity, only 10 related items were used in this study (shown in Table 2).

5. Empirical analysis

5.1. Descriptive results

As shown in Table 2, in general, the ease of using smartphones, perceived accessibility and perceived transport equity increased over time. The elderly and the low-income population are deemed more vulnerable than other populations, both in terms of coronavirus susceptibility and the mental health consequences of containment policy interventions, such as social distancing (see Armitage and Nellums, 2020).

As shown in Fig. 2, the elderly's perceived ease of using smartphones was significantly lower than the other population groups. The elderly perceived smartphone-related services as extremely difficult to access at the beginning of the COVID-19 outbreak. Although

Table 2
Constructs and Items.

Construct	Item	Wave 1			Wave 2			Wave 3		
		Mean	S.D.	α	Mean	S.D.	α	Mean	S.D.	α
Ease of using smartphones	ES1 - It is convenient for me to acquire food online	2.51	1.647	0.937	2.77	1.587	0.960	3.10	1.633	0.941
	ES2 - It is convenient for me to use dockless bike-sharing	2.18	1.592		2.37	1.505		2.59	1.524	
	ES3 - It is convenient for me to use Didi	2.13	1.063		2.70	1.164		3.45	1.383	
	ES4 - I find no problem scanning QR code for public transport	2.82	1.986		3.50	1.768		4.35	1.514	
Perceived accessibility	PA1 - It is easy to get food I want	2.15	0.999	0.716	3.60	1.103	0.941	4.74	0.638	0.609
	PA2 - I can participate in leisure activity easily	1.74	0.592		3.24	1.403		4.59	0.605	
	PA3 - I can interact with friends easily	2.94	1.662		3.86	1.331		5.19	0.538	
Perceived transport equity	PE1 - Compared to other people, I am more convenient to travel	2.68	1.635	0.961	3.26	0.919	0.889	4.12	0.938	0.849
	PE2 - Others are influenced by travel restrictions more than me	2.65	1.570		2.81	1.069		4.01	0.881	
	PE3 - In general, containment policies are fair to me	3.15	1.439		3.28	1.041		4.42	0.745	

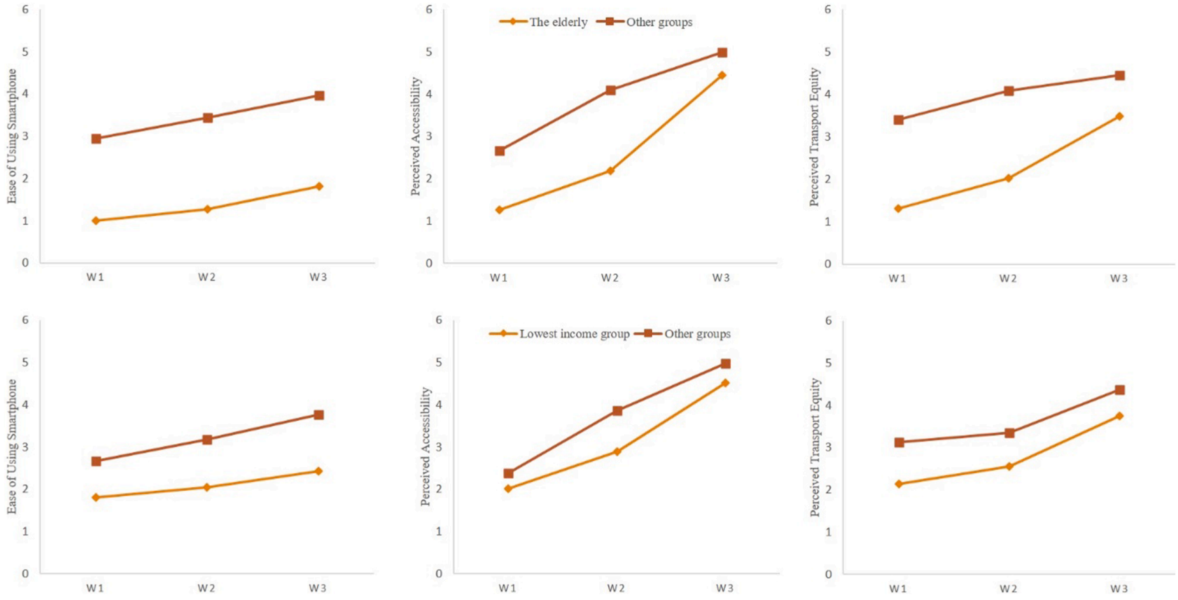

Fig. 2. Changes in The Three Key Constructs.

their perceived ease of using smartphones marginally increased after lifting travel restrictions and compulsory QR-code-for-buses, 97.5% of the elderly respondents still considered themselves unfamiliar with smartphone-based services by the end of August. Their perceived accessibility was significantly lower than the others initially and remained at a moderately low level two months after travel restrictions were lifted, in which other populations' perceived accessibility had been considerably improved. The elderly's perceived accessibility was rapidly restored to a level that was only slightly lower than the other groups after QR codes were not required to take buses. The perceived transport equity of older people was significantly lower than the others during Wave 1 and increased after lifting travel restrictions. The percentage of elderly respondents who expressed an increase in perceived transport equity due to the lifting of travel restrictions was similar to that of other populations. Their perceived transport equity increased substantially after the lifting of compulsory QR-code-for-buses but, still, the elderly perceived relative policies were inequitable to the elderly. This result is in accordance with the qualitative exploration (Liu et al., 2021), indicating that the lifting of travel restrictions had limited effects on elderly people, whilst the lifting of compulsory QR-code-for-buses could effectively restore their mobility because elderly mobility predominantly relies upon public transport in the Chinese context.

Likewise, the lowest income group's ease of using smartphone-based services and perceived transport equity were significantly lower than the better-off populations with a similar increasing trend. The perceived accessibility of the poor was similar to that of other population groups during Wave 1, but other groups more effectively restored accessibility after the lifting of travel restrictions.

5.2. Modelling results

To provide more insights into the relationships between the ease of using smartphones, perceived accessibility, and perceived transport equity, a three-wave cross-lagged panel model was developed to test the potential causal relationships we hypothesised in the conceptual framework (see Fig. 1). Cross-lagged panel models, also known as cross-lagged path models, are a type of structural equations model (SEM) to estimate the directional influence variables have on each other over time (see Kearney, 2017; Kenny, 2014). Despite the criticism on its underlying assumptions, such as synchronicity and stationarity (e.g., Hamaker et al., 2015; Mund and Nestler, 2019), cross-lagged panel models are commonly believed to be a sound tool to identify causal relationships from panel data in social science (e.g., Berry and Willoughby, 2017; Roos and Hahn, 2017).

As suggested by SEM experts (Golob, 2003; Koufteros, 1999), the testing of the structural model should be done after the measurement model is tested by both exploratory and confirmatory techniques. The exploratory study served as a stepping stone for the confirmatory study, aiming at exploring latent variables underlying the observed items. Exploratory techniques used in this study were corrected item-total correlation tests, a within-block factor analysis, an exploratory factor analysis (EFA) of the entire set of variables, and Cronbach's alpha reliability tests. The results of corrected item-total correlation tests indicated that there is no "garbage" items and each block have a common core as the corrected item-total correlations ranged from 0.361 to 0.898 (the bound of acceptable value—see Beck et al., 1996; Kriston et al., 2010). The results of within-block factor analysis (ranged from 0.775 to 0.978) showed sufficient evidence of unidimensionality (Schlegel et al., 2012). Principal axis factoring (PAF) with an oblique rotation method (Osborne et al., 2008) was selected for the EFA (Kline, 2015) because an oblique rotation is preferred if the factor analysis is conducted to obtain theoretically meaningful factors. The exploratory results identified nine latent factors which explained 81% of the variance. After eliminating item PA2 in Wave 3, the lowest factor loading of observed items on the latent variable was 0.597, which confirmed that all the items are appropriate indicators for their corresponding constructs (Worthington and Whittaker, 2006) and no item needed to be removed because of high cross-loadings (Yoo and Donthu, 2001).

Confirmatory analyses were conducted after the EFA. Convergence validity was assessed using t-values, which represent the parameter estimate divided by its standard error. All items exceeded the critical ratio at the 0.05 level of significance. The squared correlations ranged from 0.506 to 0.917, indicating acceptable item reliability (Bollen, 1989). A structural model was then employed to specify the causal relationship between ease of using smartphones, perceived accessibility, and perceived transport equity. We used maximum likelihood (ML) in the AMOS 25 package to estimate the model. Multiple goodness-of-fit measures were used to assess the fit of the structural model to the observed data (Hooper et al., 2008), including normed Chi-square (χ^2), the ratio of χ^2 over degrees of freedom (χ^2/df), the Goodness-of-Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Normed Fit Index (NFI), Comparative Fit Index (CFI), Standardised Root Mean Residual (SRMR), and Root Mean Square Error of Approximation (RMSEA). Our model has a 955.510 Chi-square value with 369 degrees of freedom. Goodness-of-fit indicators imply the hypothesised model fits the observed data well: $\chi^2/df = 2.589$, GFI = 0.921, AGFI = 0.896, NFI = 0.903, CFI = 0.919, SRMR = 0.045, RMSEA = 0.056. Evidence of discriminant validity is provided by tests showing all of the squared correlations between constructs are lower than the average variance extracted (AVEs). The detailed model results are presented and explained in the following subsections.

5.2.1. *Cross-lagged effects*

Table 3 presents the results of cross-lagged effects (the effects of Wave 1 variables on Wave 2 variables and the effects of Wave 2 variables on Wave 3 variables). The hypothesised impact of perceived accessibility on perceived transport equity was supported by the modelling results, and the impact may have a time lag. Those who had a higher level of perceived accessibility before lifting travel restrictions would perceive containment measures as more equitable. The easier access to necessities and social needs the respondents had before the lifting of compulsory QR-code-for-buses, the higher level of transport equity they perceived after the QR code was not required for taking buses. It is noteworthy that, although perceived accessibility has aroused attention when addressing various social equity issues, especially environmental equity (e.g., Yasumoto et al., 2020), the relationship between perceived accessibility to services and transport equity is still underexplored in the literature. Our results suggest that perceived accessibility significantly influences how people rate the transport system as an equitable one. Hypothesis 1 was supported.

Our second hypothesis concerns the relationship between a person's subjective ease of using smartphone services and perceived accessibility during the COVID-19 pandemic. As shown in Table 3, the lagged effect of ease of using smartphones on perceived accessibility was partially supported—the Wave 1 ease of using smartphones did not significantly influence the Wave 2 perceived accessibility. It is probably because the use of smartphones had an instantaneous effect on the ease to live a satisfactory life during the pandemic (see Banskota et al., 2020; David and Roberts, 2021). This result can also be elaborated by within-wave results shown in Section 5.2.2. Hypothesis 2 was partially supported.

We predicted in hypothesis 3 that perceived accessibility would have a lagged effect on the ease of using smartphones. According to many less technology-savvy interviewees, they started using smartphone-based services after the outbreak of COVID-19 because they had no other options. Also, a lower level of perceived accessibility suggested more difficulty to live a satisfactory life. Therefore, those who had experienced low levels of accessibility were more likely to use easily accessible means, such as smartphones, to seek emotional relief (e.g., Kardefelt-Winther, 2014). Elhai et al. (2020) found that people were more reliant on smartphones in the first few weeks of the COVID-19 pandemic. However, after the lifting of travel restrictions, the effect of perceived accessibility faded and had a weak, negative correlation with the ease of using smartphones. Part of the reason could be that although smartphone-based services were accepted (with resistance) by some less technology-savvy people during the first few weeks of the pandemic, they never found these services easy to use. After the lifting of travel restrictions and later the compulsory QR-code-for-buses, they set aside their unwillingly picked-up smartphones and performed daily activities as usual. This result is consistent with studies on the adoption of smartphones (e.g., Groß, 2015). Hypothesis 3 was partially supported.

Table 3
Cross-lagged Effects (Wave 1 on Wave 2 and Wave 2 on Wave 3).

Variables		Estimates	Variables		Estimates
Wave 1	Wave 2		Wave 2	Wave 3	
ES	ES	1.130	ES	ES	0.998
	PA	0.566		PA	.153[a]
	PE	.399[b]		PE	.355[b]
PA	ES	.660[a]	PA	ES	-.060[b]
	PA	.739[c]		PA	.432[a]
	PE	.718[b]		PE	.532[a]
PE	PA	-.894[c]	PE	PA	-.958[a]
	PE	-0.319		PE	-.463[a]

[a] Significantly different from 0 at $p < 0.01$.

[b] Significantly different from 0 at $p < 0.05$.

[c] Significantly different from 0 at $p < 0.10$.

Hypothesis 4 predicted that individuals would perceive containment measures inequitable when they could not easily access smartphone-based services during the pandemic. We found that perceived ease of using smartphones before each wave of surveys had a positive correlation with perceived transport equity at both junctures of time. This finding suggests that barriers to using smartphone-based services, such as online shopping apps and new mobility services, may cause transport inequities during the COVID-19 pandemic. This result is in accordance with previous studies arguing that disadvantaged individuals without smartphones may be further socially excluded (e.g., Seifert et al., 2018, Tsetsi and Rains, 2017), especially during disasters (Wong et al., 2020). Hypothesis 4 was supported.

5.2.2. *Within-wave effects between the ease of using smartphones, perceived accessibility, perceived transport equity*

Table 4 shows the within-wave relationship between the ease of using smartphones, perceived accessibility, and perceived transport equity. As shown in Table 4, the ease of using smartphones has significant effects on perceived accessibility in the first two waves, suggesting that people who found it less convenient to use smartphone-based services would consider daily necessities less accessible, and their social needs were less likely to be fulfilled before the lifting of compulsory QR-code-for-buses. The effect of the ease of using smartphones on perceived accessibility is statistically insignificant, which implies that barriers to using smartphone-based services no longer influenced people's perceived accessibility when people had access to buses without using smartphones. These results are within our expectations. Most of the respondents who had problems with smartphone-based services were the elderly and the poorest group. As the qualitative exploration revealed, the lifting of travel restrictions could not effectively restore their mobility because they were highly dependent on public transport. These results from this very special case corroborate previous argumentation on the role of public transport in vulnerable groups' accessibility (e.g., Ricciardi et al., 2015; Ryan et al., 2015). Further, these results confirm that the health QR code system had significantly influenced disadvantaged groups' accessibility during the pandemic (Wang and Jia, 2021).

In terms of the effects of the ease of using smartphones on perceived transport equity, a significant effect was found in each wave, indicating the use of smartphone-based mobile shopping and new mobility services significantly influenced whether people perceived travel restrictions and the health QR code system as equitable measures. Compared to the effect of perceived accessibility on perceived transport equity, the perceived ease of using smartphones was much more important in shaping perceived transport equity before the lifting of travel restrictions. This result is unexpected since perceived accessibility was anticipated to influence perceived transport equity directly whilst the effect of the ease of using smartphones was anticipated to be indirect. It is probably because the Chinese notion of equity focuses on relatively egalitarian outcomes of the policy intervention (Liu et al., 2019b)—the feeling of being unfairly treated was considerably exaggerated by those who suffered from a lack of daily necessities and social interactions when they believed others could acquire cheap and high-quality food and convenient services via smartphone apps. These results also enrich the current debate on whether new mobility services and technologies can deliver equity (see Dill and McNeil, 2020; Fleming, 2018; Jiao and Wang, 2020). Since most of the new mobility services are smartphone-based, our results suggest that the current practices of so-called shared mobility in China only favour those who already have convenient access to transport and further exclude disadvantaged individuals and neighbourhoods, which may perpetuate existing social inequities.

The results also show that perceived accessibility is a reasonable indicator of perceived transport equity. In wave 3, which could be considered the new normal after the COVID-19 pandemic, perceived accessibility dominantly influences perceived transport equity.

5.2.3. *Effects of socio-demographic variables*

As shown in Table 4, some socio-demographic variables were found to impact perceived accessibility and perceived transport equity significantly. Respondents older than 60 were more likely to suffer from a low level of perceived accessibility and transport equity during the pandemic. The deprivation of daily necessities and social interactions for the elderly was especially serious before lifting travel restrictions. This finding is consistent with evidence from other countries (e.g., Armitage and Nellums, 2020; Rout, 2020).

Table 4
Within-wave Effects (Wave 1, Wave 2, and Wave 3).

	Wave 1		Wave 2		Wave 3	
	PA	PE	PA	PE	PA	PE
ES	.848[a]	.725[a]	.447[a]	.472[a]	0.088	.126[b]
PA		.214[a]		.577[a]		.834[a]
Age	.367[a]	.206[a]	.253[a]	.229[a]	.117[b]	.088[c]
Gender	0.093	0.074	0.058	-0.021	0.016	-0.037
Income	.108[a]	.093[a]	.186[a]	.195[a]	0.031	-0.018
Employment	-0.004	0.015	0.009	-0.027	0.003	-0.011
Residential Area	-.135[b]	-0.057	-0.078	-0.101	-0.029	-0.042
Car Ownership	.044[c]	0.032	.150[a]	.176[a]	-0.006	0.020

[a] Significantly different from 0 at $p < 0.01$.

[b] Significantly different from 0 at $p < 0.05$.

[c] Significantly different from 0 at $p < 0.10$.

As expected, income also significantly influence perceived accessibility and perceived transport equity in the first two waves, but its effects on both latent constructs are insignificant in Wave 3, suggesting that lower-income people had effectively restored their accessibility after the QR code was not required to take buses and had become more supportive towards containment measures. The effects of a residential area on perceived accessibility and perceived equity are limited—the only significant effect found is that people who resided close to the city centre had higher perceived accessibility in Wave 1. It is probably because convenient shops and community grocery shops are much higher in the old town where the land-use mixture is relatively high. According to the qualitative exploration, community grocery shops were the only option for many population groups, such as the elderly, in the first few weeks of the COVID-19 outbreak. However, after lifting travel restrictions, it had been increasingly convenient to travel longer distances for shopping and leisure activities. Hence, their perceived accessibility and transport equity was not significantly influenced by where they live. It implies that, despite the extensively discussed impacts of the built environment on spatial accessibility (e.g., Bivina et al., 2019; Ermagun and Tilahun, 2020), the built environment may have a limited impact on perceived accessibility and transport equity. Car ownership was found to have significant effects on perceived accessibility and transport equity in Wave 2. This result may be partly because the health QR code system was implemented for public transport, which restricted many non-car owners from long-distance travel. This policy was, therefore, perceived as inequitable to non-car owners.

6. Discussion and concluding remarks

Accessibility has long been deemed an important indicator and dimension of transport equity (see Handy, 2020). Perceived accessibility has been increasingly adopted to understand how easy it is to live a satisfactory life, as conventional objectively measured accessibility cannot capture individual characteristics that may considerably influence individuals' experience and perceptions (e.g., Curl et al., 2011; Lättman et al., 2016b). Previous studies on perceived accessibility highlighted that individual experience and perceptions of accessibility could be quite different from objectively measured accessibility (e.g., Lättman et al., 2018; Van der Vlugt et al., 2019) because of different individual characteristics and needs (see Lättman et al., 2019). According to our previous qualitative exploration (Liu et al., 2021), we hypothesised that the use of smartphone-based services also affected perceived accessibility to services, as well as perceived transport equity, during the COVID-19 pandemic. Therefore, this study investigates the relationship between the ease of using smartphone-based services, perceived accessibility to services, and perceived transport equity.

The most important takeaway of this study is that, due to travel restrictions imposed in the early phase of the pandemic, the familiarity with smartphone-based services dominantly influenced perceived accessibility and transport equity and the experience of lacking access to smartphone-based services during the pandemic. Similarly, familiarity and perceptions also influenced people's perceived accessibility and transport equity after lifting travel restrictions. The effect of the ease of using smartphones on transport equity, although still statistically significant, had become much less observable after the lifting of compulsory QR-code-for-buses, as perceived accessibility was not necessarily associated with the smartphone. The results indicate that the ease of using smartphone-based services influences experiences and perceptions of accessibility and perceived transport equity—daily necessities and services were perceived less accessible by those who had difficulties with smartphone-based shopping and mobility services and, therefore, they perceived the transport system and COVID-19 containment measures as less equitable. As smartphones and other digital platforms play an increasingly important role in accessing mobility and other public services, even apart from COVID-19, many services can be virtually accessed without physical mobility. Therefore, although conventional accessibility measures are still helpful to understand how distributional effects influence human life, it is questionable to use objectively measured accessibility as an indicator for transport-related social equity because the better-off populations are more capable of using virtually accessible services.

The results of analysis for in-depth interviews show that not having in-person accessibility in the early phase of the pandemic may limit younger and richer people to virtual accessibility. This may cause internet addiction and negatively impacts their mental health. Conversely, the lack of virtual accessibility may force older and poorer people to travel and thus be exposed to health risks of the Covid-19 pandemic. In this sense, it is imperative to explore how the lack/dependency of virtual accessibility may impact the mental health of different population groups in longer-term. Particularly, attentions should be paid to the heterogeneity of the elderly population because very different profiles coexist within this group and 65–70-year-olds could virtually participate in social activities much more effectively than over 80-year-olds.

This research suggests that perceived accessibility is a sound indicator for transport equity in normal days but cannot fully capture it as satisfactory in some particular cases when staying at home was considered more desirable. This result calls back a much less-mentioned definition of accessibility that may, in this case, more accurately interpret the real-world situation during the COVID-19 pandemic: "the freedom of individuals to decide whether or not to participate in different activities" (Burns, 1979). Our results indicate that the disadvantaged population groups, such as the elderly, low-income people and other less technology-savvy people, had very restricted freedom of making accessibility choices—compelled to go outside for necessities and social needs when fearing the coronavirus infection and stranded in their communities when better-off populations could freely access anywhere with a mask. Therefore, the freedom of making accessibility decisions, although apparently more difficult to measure, can better conceptualise accessibility compared to the more frequently used definitions—"the potential of opportunities for interaction" (Hansen, 1959), which are impeded by spatial separation, "the ease with which any land-use activity can be reached from a location using a particular transport system" (Dalvi and Martin, 1976) and "the benefits provided by a transportation/land-use system" (Ben-Akiva and Lerman, 1977).

As for the social consequences of new mobility services, not to mention the rhetoric of promised advantages that probably cannot be delivered (see, for example, Pangbourne et al., 2020; Wadud, 2017; Wadud et al., 2016), our results suggest that the contemporary practice of new mobility services has further excluded and marginalised disadvantaged population groups. In the early phase of the pandemic, these mobility services only favoured those who already had relatively convenient access to services, which has exacerbated the resentment between different population groups and undermined trust in the government (Liu et al., 2021). After the lifting of travel restrictions, some disadvantaged groups were still excluded from using the public transport system that they relied on due to the health QR code system. Policymakers should make proper efforts to guarantee that disadvantaged groups are not further technologically disadvantaged by direct policy interventions, such as pushing smartphone makers to design affordable, elderly-friendly smartphones.

This study has several limitations and suggests several directions for future studies. Firstly, the sample is mostly distributed in the urban area of Kunming, but people living in the periphery area may perceive accessibility and transport equity differently. Secondly, this is a very small sample in Kunming terms. Thirdly, the Cronbach's alpha value of Wave 3 perceived accessibility was below the satisfactory level (0.7), but no items were eliminated because the values for W1 and W2 were acceptable. This low alpha value is because the level of leisure activity participation was considerably lower than social interactions; however, our qualitative data cannot interpret this result. Fourthly, perceived accessibility was only measured for three specific outcomes whilst accessibility to other activities such as work was not included. This is because food, leisure activities, and social interactions were the three most important accessibility-related themes that emerged from the qualitative analysis and the first wave of data collection was completed when the work resumption had just started. Hence, it is unknown whether there were fewer smartphone-related activities and how the relationship with transport equity for these purposes is explained. Lastly, although the impact of the ease of using smartphone-based services has emerged from the qualitative data, it lacks a grounded theoretical foundation that can indicate the mechanism of the interaction between the ease of using smartphones and other determinants of transport equity. Nevertheless, the results are sufficiently clear to suggest that smartphone-based services had significantly influenced perceived accessibility to services and further socially excluded the disadvantaged populations during the COVID-19 pandemic.

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References

Alonso-González, M.J., Hoogendoorn-Lanser, S., van Oort, N., Cats, O., Hoogendoorn, S., 2020. Drivers and barriers in adopting Mobility as a Service (MaaS)–A latent class cluster analysis of attitudes. Transp. Res. Part A: Policy Pract. 132, 378–401.
Armitage, R., Nellums, L.B., 2020. COVID-19 and the consequences of isolating the elderly. Lancet Public Health 5 (5), e256.
Banskota, S., Healy, M., Goldberg, E.M., 2020. 15 smartphone apps for older adults to use while in isolation during the COVID-19 pandemic. West. J. Emerg. Med. 21 (3), 514.
Barter, P.A., 1999. Transport and urban poverty in Asia: a brief introduction to the key issues. Reg. Devel. Dial. 20 (1), 143–163.
Beck, A.T., Steer, R.A., Brown, G., 1996. Beck depression inventory–II. San Antonio 78 (2), 490–498.
Ben-Akiva, M., Lerman, S.R., 1977. Disaggregate Travel and Mobility Choice Models and Measures of Accessibility. In: Hensher, D.A., Sopher, P.R. (Eds.), Behavioural Travel Modelling. Croom Helm, Andover, Hants, pp. 654–679.
Berry, D., Willoughby, M.T., 2017. On the practical interpretability of cross-lagged panel models: Rethinking a developmental workhorse. Child Dev. 88 (4), 1186–1206.
Bills, T.S., Walker, J.L., 2017. Looking beyond the mean for equity analysis: Examining distributional impacts of transportation improvements. Transp. Policy 54, 61–69.
Bivina, G.R., Gupta, A., Parida, M., 2019. Influence of microscale environmental factors on perceived walk accessibility to metro stations. Transp. Res. Part D: Transp. Environ. 67, 142–155.
Bollen, K.A., 1989. A new incremental fit index for general structural equation models. Sociol. Meth. Res. 17 (3), 303–316.
Budd, J.W., Mumford, K.A., 2006. Family-friendly work practices in Britain, availability and perceived accessibility. Human Resour. Manage. 45 (1), 23–42.
Burns, L.D., 1979. Transportation, temporal, and spatial components of accessibility. Lexington Books.
Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), 2021. COVID-19 Dashboard. Retrieved 1 February 2021 via https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6.
Cerami, C., Santi, G.C., Galandra, C., Dodich, A., Cappa, S.F., Vecchi, T., Crespi, C., 2020. Covid-19 outbreak in Italy: are we ready for the psychosocial and the economic crisis? Baseline findings from the PsyCovid study. Front. Psych. 11, 556.
Chang, Z., Chen, J., Li, W., Li, X., 2019. Public transportation and the spatial inequality of urban park accessibility: New evidence from Hong Kong. Transp. Res. Part D: Transp. Environ. 76, 111–122.
Cheng, L., Caset, F., De Vos, J., Derudder, B., Witlox, F., 2019. Investigating walking accessibility to recreational amenities for elderly people in Nanjing, China. Transp. Res. part D: Transp. Environ. 76, 85–99.
Cheng, Y.H., Chen, S.Y., 2015. Perceived accessibility, mobility, and connectivity of public transportation systems. Transp. Res. Part A: Policy Pract. 77, 386–403.
Church, A., Frost, M., Sullivan, K., 2000. Transport and social exclusion in London. Transp. Policy 7 (3), 195–205.
Cole, S., Zhang, Y., Wang, W., Hu, C.M., 2019. The influence of accessibility and motivation on leisure travel participation of people with disabilities. J. Travel Tour. Market. 36 (1), 119–130.
Cui, B., Boisjoly, G., El-Geneidy, A., Levinson, D., 2019. Accessibility and the journey to work through the lens of equity. J. Transp. Geogr. 74, 269–277.
Curl, A., 2018. The importance of understanding perceptions of accessibility when addressing transport equity. J. Transp. Land Use 11 (1), 1147–1162.
Curl, A., Nelson, J.D., Anable, J., 2011. Does accessibility planning address what matters? A review of current practice and practitioner perspectives. Res. Transp. Bus. Manage. 2, 3–11.
Curl, A., Nelson, J.D., Anable, J., 2015. Same question, different answer: A comparison of GIS-based journey time accessibility with self-reported measures from the National Travel Survey in England. Comput. Environ. Urban Syst. 49, 86–97.
Dalvi, M.Q., Martin, K.M., 1976. The measurement of accessibility: some preliminary results. Transp. 5 (1), 17–42.
David, M.E., Roberts, J.A., 2021. Smartphone Use during the COVID-19 Pandemic: Social Versus Physical Distancing. Int. J. Environ. Res. Public Health 18 (3), 1034.
Deboosere, R., El-Geneidy, A., 2018. Evaluating equity and accessibility to jobs by public transport across Canada. J. Transp. Geogr. 73, 54–63.
Deboosere, R., El-Geneidy, A.M., Levinson, D., 2018. Accessibility-oriented development. J. Transp. Geogr. 70, 11–20.

Dill, J., McNeil, N., 2020. Are Shared Vehicles Shared by All? A Review of Equity and Vehicle Sharing. J. Plan. Literat. 0885412220966732.
Dixit, M., Sivakumar, A., 2020. Capturing the impact of individual characteristics on transport accessibility and equity analysis. Transp. Res. part D: Transp. Environ. 87, 102473.
Elhai, J.D., Yang, H., McKay, D., Asmundson, G.J., 2020. COVID-19 anxiety symptoms associated with problematic smartphone use severity in Chinese adults. J. Affect. Disord. 274, 576–582.
Ermagun, A., Tilahun, N., 2020. Equity of transit accessibility across Chicago. Transp. Res. Part D: Transp. Environ. 86, 102461.
Fairchild, A., Gostin, L., Bayer, R., 2020. Vexing, veiled, and inequitable: Social distancing and the "rights" divide in the age of COVID-19. Am. J. Bioethics 20 (7), 55–61.
Fitt, H., 2018. Exploring how older people might experience future transport systems. In: Curl, Musselwhite (Eds.), Geographies of Transport and Ageing. Palgrave Macmillan, Cham, pp. 199–225.
Fleming, K.L., 2018. Social equity considerations in the new age of transportation: Electric, automated, and shared mobility. J. Sci. Policy Govern. 13 (1), 1–20.
Fraiberger, S.P., Astudillo, P., Candeago, L., Chunet, A., Jones, N.K., Khan, M.F., et al., 2020. Uncovering socioeconomic gaps in mobility reduction during the COVID-19 pandemic using location data. arXiv preprint arXiv:2006.15195.
Frederickson, H.G., 2015. Social equity and public administration: Origins, developments, and applications: Origins, developments, and applications. Routledge.
Friman, M., Lättman, K., Olsson, L.E., 2020. Public transport quality, safety, and perceived accessibility. Sustainability 12 (9), 3563.
Gatto, M., Bertuzzo, E., Mari, L., Miccoli, S., Carraro, L., Casagrandi, R., Rinaldo, A., 2020. Spread and dynamics of the COVID-19 epidemic in Italy: Effects of emergency containment measures. Proc. Natl. Acad. Sci. 117 (19), 10484–10491.
Geurs, K., Zondag, B., De Jong, G., de Bok, M., 2010. Accessibility appraisal of land-use/transport policy strategies: More than just adding up travel-time savings. Transp. Res. Part D: Transp. Environ. 15 (7), 382–393.
Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. J. Transp. Geogr. 12 (2), 127–140.
Golob, T.F., 2003. Structural equation modeling for travel behavior research. Transp. Res. Part B: Methodol. 37 (1), 1–25.
Groth, S., 2019. Multimodal divide: Reproduction of transport poverty in smart mobility trends. Transp. Res. Part A: Policy Pract. 125, 56–71.
Groß, M., 2015. Exploring the acceptance of technology for mobile shopping: an empirical investigation among Smartphone users. Int. Rev. Retail Distrib. Consum. Res. 25 (3), 215–235.
Guzman, L.A., Oviedo, D., Rivera, C., 2017. Assessing equity in transport accessibility to work and study: The Bogotá region. J. Transp. Geogr. 58, 236–246.
Hamaker, E.L., Kuiper, R.M., Grasman, R.P., 2015. A critique of the cross-lagged panel model. Psychol. Methods 20 (1), 102.
Hananel, R., Berechman, J., 2016. Justice and transportation decision-making: The capabilities approach. Transp. Policy 49, 78–85.
Handy, S., 2020. Is accessibility an idea whose time has finally come? Transp. Res. part D: Transp. Environ. 83, 102319.
Hansen, W.G., 1959. How accessibility shapes land use. J. Am. Instit. Plan. 25 (2), 73–76.
Hooper, D., Coughlan, J., Mullen, M., 2008. Structural equation modelling: Guidelines for determining model fit. Electron. J. Bus. Res. Meth. 6 (1), 53–60.
Hu, L., Cao, J., Yang, J., 2020. Planning for accessibility. Transp. Res. Part D: Transp. Environ. 88, 102575.
Jiao, J., Wang, F., 2020. Shared mobility and transit-dependent population: A new equity opportunity or issue? Int. J. Sustai. Transp. 1–12.
Kardefelt-Winther, D., 2014. A conceptual and methodological critique of internet addiction research: Towards a model of compensatory internet use. Comput. Hum. Behav. 31, 351–354.
Kearney, M.W., 2017. Cross lagged panel analysis. SAGE Encycl. Commun. Res. Meth. 312–314.
Kenny, D.A., 2014. Cross-lagged panel design. Wiley StatsRef: Statistics Reference Online.
Kline, R.B., 2015. Principles and practice of structural equation modeling. Guilford Publications, New York.
Koufteros, X.A., 1999. Testing a model of pull production: a paradigm for manufacturing research using structural equation modeling. J. Oper. Manage. 17 (4), 467–488.
Kriston, L., Scholl, I., Hölzel, L., Simon, D., Loh, A., Härter, M., 2010. The 9-item Shared Decision Making Questionnaire (SDM-Q-9). Development and psychometric properties in a primary care sample. Patient Educ. Couns. 80 (1), 94–99.
Kuiper, R.M., Ryan, O., 2018. Drawing conclusions from cross-lagged relationships: Re-considering the role of the time-interval. Struct. Eq. Model.: Multidiscip. J. 25 (5), 809–823.
Lättman, K., Friman, M., Olsson, L.E., 2016a. Perceived accessibility of public transport as a potential indicator of social inclusion. Social Inclusion 4 (3), 36–45.
Lättman, K., Friman, M., Olsson, L.E., 2020. Restricted car-use and perceived accessibility. Transp. Res. part D: Transp. Environ. 78, 102213.
Lättman, K., Olsson, L.E., Friman, M., 2016b. Development and test of the perceived accessibility scale (PAC) in public transport. J. Transp. Geogr. 54, 257–263.
Lättman, K., Olsson, L.E., Friman, M., 2018. A new approach to accessibility–Examining perceived accessibility in contrast to objectively measured accessibility in daily travel. Res. Res. Transp. Econ. 69, 501–511.
Lättman, K., Olsson, L.E., Friman, M., Fujii, S., 2019. Perceived accessibility, satisfaction with daily travel, and life satisfaction among the elderly. Int. J. Environ. Res. Public Health 16 (22), 4498.
Levine, J., 2020. A century of evolution of the accessibility concept. Transp. Res. part D: Transp. Environ. 83, 102309.
Link, C., Strasser, C., Hinterreiter, M., 2020. Free-floating bikesharing in Vienna–A user behaviour analysis. Transp. Res. Part A: Policy Pract. 135, 168–182.
Litman, T., 2015. Transportation Affordability. Evaluation and Improvements Strategies. Victoria Transport Policy Institute, Victoria, Canada.
Liu, Q., Liu, Y., Zhang, C., An, Z., Zhao, P., 2021. Elderly Mobility During the COVID-19 Pandemic: A Qualitative Exploration in Kunming, China. *J. Transp. Geogr.* (in press).
Liu, Q., Lucas, K., Marsden, G., 2019a. Public acceptability of congestion charging in Beijing, China: How transferrable are Western ideas of public acceptability? Int. J. Sustai. Transp. 1–14.
Liu, Q., Lucas, K., Marsden, G., Liu, Y., 2019b. Egalitarianism and public perception of social inequities: A case study of Beijing congestion charge. Transp. Policy 74, 47–62.
Liu, R., Chen, Y., Wu, J., Xu, T., Gao, L., Zhao, X., 2018. Mapping spatial accessibility of public transportation network in an urban area–A case study of Shanghai Hongqiao Transportation Hub. Transp. Res. part D: Transp. Environ. 59, 478–495.
Lotfi, S., Koohsari, M.J., 2009. Analyzing accessibility dimension of urban quality of life: Where urban designers face duality between subjective and objective reading of place. Soc. Indic. Res. 94 (3), 417–435.
Lucas, K., 2006. Providing transport for social inclusion within a framework for environmental justice in the UK. Transp. Res. Part A: Policy Pract. 40 (10), 801–809.
Lucas, K., 2012. Transport and social exclusion: Where are we now? Transp. Policy 20, 105–113.
Lucas, K., 2019. A new evolution for transport-related social exclusion research? J. Transp. Geogr. 81, 102529.
Lucas, K., Mattioli, G., Verlinghieri, E., Guzman, A., 2016a. Transport poverty and its adverse social consequences. Proc. Instit. Civil Eng.-Transp. 169, 353–365.
Lucas, K., Van Wee, B., Maat, K., 2016b. A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. Transp.ation 43 (3), 473–490.
Márquez, L., Poveda, J.C., Vega, L.A., 2019. Factors affecting personal autonomy and perceived accessibility of people with mobility impairments in an urban transportation choice context. J. Transp. Health 14, 100583.
Mattioli, G., Lucas, K., Marsden, G., 2017. Transport poverty and fuel poverty in the UK: From analogy to comparison. Transp. Policy 59, 93–105.
Martens, K., 2012. Justice in transport as justice in accessibility: applying Walzer's 'Spheres of Justice'to the transport sector. Transportation 39 (6), 1035–1053.
Martens, K., Golub A., 2012. A justice- theoretic exploration of accessibility measures. In: Geurs, K.T., Krizek, K.J., Reggiani, A. (Eds.), Accessibility Analysis and Transport Planning: Challenges for Europe and North America, Edward Elgar Publishing, pp. 195–210. http://dx.doi.10.4337/9781781000113.00020.
Mackett, R.L., Thoreau, R., 2015. Transport, social exclusion and health. J. Transp. Health 2 (4), 610–617.
Marangunić, N., Granić, A., 2015. Technology acceptance model: a literature review from 1986 to 2013. Univ. Access Inf. Soc. 14 (1), 81–95.
Martens, K., Golub, A., 2018. A fair distribution of accessibility: interpreting civil rights regulations for regional transportation plans. J. Plan. Educ. Res. 0739456X18791014.

McCahill, C., Jain, S., Brenneis, M., 2020. Comparative assessment of accessibility metrics across the US. Transp. Res. part D: Transp. Environ. 83, 102328.
Mund, M., Nestler, S., 2019. Beyond the cross-lagged panel model: Next-generation statistical tools for analyzing interdependencies across the life course. Adv. Res. Life Course Res. 41, 100249.
Morris, J.M., Dumple, P., Wigan, M.R., 1979. Accessibility indicators for transport planning. Transp. Res. A Gen. 13 (2), 91–109.
Osborne, J.W., Costello, A.B., Kellow, J.T., 2008. Best practices in exploratory factor analysis: Four recommendations for getting most form your analysis. Pract. Assess., Res. Eval. 10, 1–9.
Pangbourne, K., Mladenović, M.N., Stead, D., Milakis, D., 2020. Questioning mobility as a service: Unanticipated implications for society and governance. Transp. Res. part A: Policy Pract. 131, 35–49.
Pereira, R.H., Schwanen, T., Banister, D., 2017. Distributive justice and equity in transportation. Transp. Rev. 37 (2), 170–191.
Ricciardi, A.M., Xia, J.C., Currie, G., 2015. Exploring public transport equity between separate disadvantaged cohorts: a case study in Perth, Australia. J. Transp. Geogr. 43, 111–122.
Rietveld, P., 2000. The accessibility of railway stations: the role of the bicycle in The Netherlands. Transp. Res. Part D: Transp. Environ. 5 (1), 71–75.
Roos, D., Hahn, R., 2017. Does shared consumption affect consumers' values, attitudes, and norms? A panel study. J. Business Res. 77, 113–123.
Rout, N., 2020. Risks to the elderly during the coronavirus (COVID-19) pandemic 2019–2020. J. Geriatr. Care Res. 7 (1), 27–28.
Ryan, M., Lin, T., Xia, J.C., Robinson, T., 2016. Comparison of perceived and measured accessibility between different age groups and travel modes at Greenwood Station, Perth, Australia. Eur. J. Transp. Infrastruct. Res. 16 (2), 406–423.
Ryan, J., Wretstrand, A., Schmidt, S.M., 2015. Exploring public transport as an element of older persons' mobility: A Capability Approach perspective. J. Transp. Geogr. 48, 105–114.
Salon, D., Gulyani, S., 2010. Mobility, poverty, and gender: travel 'choices' of slum residents in Nairobi, Kenya. *Transp. Rev.* 30 (5), 641–657.
Scheepers, C.E., Wendel-Vos, G.C.W., Van Kempen, E., De Hollander, E., van Wijnen, H.J., Maas, J., Schuit, A.J., 2016. Perceived accessibility is an important factor in transport choice—results from the AVENUE project. J. Transp. Health 3 (1), 96–106.
Schlegel, K., Grandjean, D., Scherer, K.R., 2012. Emotion recognition: Unidimensional ability or a set of modality-and emotion-specific skills? Person. Individ. Differ. 53 (1), 16–21.
Schwanen, T., Lucas, K., Akyelken, N., Solsona, D.C., Carrasco, J.A., Neutens, T., 2015. Rethinking the links between social exclusion and transport disadvantage through the lens of social capital. Transp. Res. Part A: Policy Pract. 74, 123–135.
Seifert, A., Hofer, M., Rössel, J., 2018. Older adults' perceived sense of social exclusion from the digital world. Educ. Gerontol. 44 (12), 775–785.
Shirgaokar, M., 2020. Expanding seniors' mobility through phone apps: Potential responses from the private and public sectors. J. Plan. Educ. Res. 40 (4), 405–415.
Slovic, A.D., Tomasiello, D.B., Giannotti, M., de Fatima Andrade, M., Nardocci, A.C., 2019. The long road to achieving equity: Job accessibility restrictions and overlapping inequalities in the city of São Paulo. J. Transp. Geogr. 78, 181–193.
Song, Y., Liu, T., Wang, X., Guan, T., 2020. Fragmented restrictions, fractured resonances: grassroots responses to Covid-19 in China. Crit. Asian Stud. 1–18.
Tavakol, M., Dennick, R., 2011. Making sense of Cronbach's alpha. Int. J. Med. Educ. 2, 53–55.
Tsetsi, E., Rains, S.A., 2017. Smartphone Internet access and use: Extending the digital divide and usage gap. Mobile Media Commun. 5 (3), 239–255.
van der Vlugt, A.L., Curl, A., Wittowsky, D., 2019. What about the people? Developing measures of perceived accessibility from case studies in Germany and the UK. Appl. Mobil. 4 (2), 142–162.
van Eldijk, J., Gil, J., Kuska, N., Patro, R.S., 2020. Missing links–Quantifying barrier effects of transport infrastructure on local accessibility. Transp. Res. Part D: Transp. Environ. 85, 102410.
Varghese, V., Jana, A., 2019. Interrelationships between ICT, social disadvantage, and activity participation behaviour: A case of Mumbai, India. Transp. Res. Part A: Policy Pract. 125, 248–267.
Velaga, N.R., Beecroft, M., Nelson, J.D., Corsar, D., Edwards, P., 2012. Transport poverty meets the digital divide: accessibility and connectivity in rural communities. J. Transp. Geogr. 21, 102–112.
Vitman-Schorr, A., Ayalon, L., Khalaila, R., 2019. Perceived accessibility to services and sites among Israeli older adults. J. Appl. Gerontol. 38 (1), 112–136.
Wadud, Z., 2017. Fully automated vehicles: A cost of ownership analysis to inform early adoption. Transp. Res. Part A: Policy Pract. 101, 163–176.
Wadud, Z., MacKenzie, D., Leiby, P., 2016. Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. Transp. Res. Part A: Policy Pract. 86, 1–18.
Walker, G., Day, R., 2012. Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth. Energy policy 49, 69–75.
Wang, T., Jia, F., 2021. The impact of health QR code system on older people in China during the COVID-19 outbreak. Age Ageing 50 (1), 55–56.
Wong, S.D., Broader, J.C., Shaheen, S.A., 2020. Can sharing economy platforms increase social equity for vulnerable populations in disaster response and relief? A case study of the 2017 and 2018 California wildfires. Transp. Res. Interdiscip. Perspect. 5, 100131.
Worthington, R.L., Whittaker, T.A., 2006. Scale development research: A content analysis and recommendations for best practices. Counsel. Psychol. 34 (6), 806–838.
Wu, J., Xie, X., Yang, L., Xu, X., Cai, Y., Wang, T., Xie, X., 2020. Mobile health technology combats COVID-19 in China. J. Infect.
Yasumoto, S., Nakaya, T., Jones, A.P., 2020. Quantitative Environmental Equity Analysis of Perceived Accessibility to Urban Parks in Osaka Prefecture, Japan. Appl. Spatial Anal. Policy 1–18.
Yoo, B., Donthu, N., 2001. Developing a scale to measure the perceived quality of an Internet shopping site (SITEQUAL). Quart. J. Electron. Comm. 2 (1), 31–45.
Zhang, M., He, S., Zhao, P., 2018. Revisiting inequalities in the commuting burden: Institutional constraints and job-housing relationships in Beijing. J. Transp. Geogr. 71, 58–71.
Zhang, M., Zhao, P., Qiao, S., 2020a. Smartness-induced transport inequality: Privacy concern, lacking knowledge of smartphone use and unequal access to transport information. Transp. Policy 99, 175–185.
Zhang, W., Zhao, Y., Cao, X.J., Lu, D., Chai, Y., 2020b. Nonlinear effect of accessibility on car ownership in Beijing: pedestrian-scale neighborhood planning. Transp. Res. part D: Transp. Environ. 86, 102445.
Zhao, P., Howden-Chapman, P., 2010. Social inequalities in mobility: the impact of the hukou system on migrants' job accessibility and commuting costs in Beijing. Int. Devel. Plan. Rev. 32 (3–4), 363–385.
Zhao, P., Li, S., 2016. Restraining transport inequality in growing cities: Can spatial planning play a role? Int. J. Sustai. Transp. 10 (10), 947–959.