Who is returning to public transport for non-work trips after COVID-19? Evidence from older citizens' smart cards in the UK's second largest city region

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ABSTRACT

Harnessing a unique data source – longitudinal travel smartcard data linked to passenger demographics from 2019 to 2022 – we use methods of survival analysis to model the recovery of public transport patronage among 183,891 senior citizens resident in the West Midlands metropolitan region in the United Kingdom. Comparing pre and peri-pandemic patronage, we identify pronounced social and spatial inequalities in the speed of return to public transport. We find that male, younger and non-White passengers are more likely to return to public transport as soon as movement restrictions were lifted, whereas passengers from White ethnic background and affluent areas do not return to public transport within the first year after the outbreak. Pronounced social inequalities persist into the middle of 2021, and only thence they began to attenuate as part of a wider return to public transport among passengers post retirement age. In 2022, 80% of these passengers have returned to public transport but the frequency of use has remained lower than prior to the pandemic. We discuss implications for transport policy and planning.

1. Introduction

A significant decline in demand for public transport services has been observed over the course of the COVID-19 pandemic throughout the United Kingdom and many other countries (Subbarao and Kadali, 2021; Vickerman, 2020). As restrictions eased at various times over the last two years, this demand recovered but it did not do so homogenously across demographic and socioeconomic groups and different types of urban areas.

Although there have been several studies monitoring the impact of lockdowns on public transport patronage, relatively few studies have focused on unequal recovery of ridership levels during the pandemic. As the future of local public transport funding is debated in the UK and elsewhere, understanding ridership recovery is critical to anticipate impacts of adapted public transport delivery on mobility and social exclusion of vulnerable populations and sustainable travel.

This study draws on over three years' worth of smart card data to identify, quantify and contextualise unequal paces of bus and tram ridership recovery in the West Midlands Combined Authority (WMCA), which is the second largest metropolitan region in the UK centred around the city of Birmingham. We focus on a particularly vulnerable segment of the population, older citizens, who are entitled for free bus travel in the region. We use survival analysis techniques to trace differential boarding rates through the pandemic period among different ethnic groups and relate them to geographical context. The pandemic period in the UK includes national lockdowns with severe restrictions in place over three periods between spring 2020 and spring 2021 followed by a full lift of all restrictions in summer 2021 We discuss implications for transport policy and delivery that aims to afford socially equitable and environmentally sustainable mobility in the future.

2. The impact on COVID-19 on public transport demand

Since the outbreak of COVID-19, there has been extensive research into the impact of the pandemic on travel demand. Much of this research has focused on aggregate demand across the transport networks, sometimes with an explicitly spatial description of changing demand levels (Jenelius and Cebecauer, 2020; Mützel and Scheiner, 2021; Orro et al., 2020; Wielechowski et al., 2020; Zhang et al., 2021). Location of trip origins is also used to link changes in travel to socio-demographic and economic neighbourhood compositions (Almlöf et al., 2021; Liu et al., 2020; Sy et al., 2020). Some studies collected survey data to

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capture travel alongside a trip-maker's socio-demographics (Bohman et al., 2021; He et al., 2022; Kopsidas et al., 2021; Palm et al., 2021). Wherever social characteristics were studied, differential impacts on trip rates and mode choice were found, especially between people or neighbourhoods with different socio-economic characteristics.

2.1. Unequal magnitudes of change in public transport demand

The outbreak of COVID-19 in early 2020 and the subsequent restrictions that were put in place to curb the spread of the virus resulted in a major decline in public transport demand. The decline can be attributed to both a lower number of active users and a lower number of trips being undertaken per user (Jenelius and Cebecauer, 2020). Many former passengers continue to refrain from using public transport services completely, substituting public transport trips with tele-working, e-shopping, home delivery services as well as walking, cycling and ride-hailing services (Matson et al., 2021). For many public transport systems, this decline was greatest at the early stages of the COVID-19 (Hu and Chen, 2021; Kim and Kwan, 2021), and there is less evidence on later trends in recovery when restrictions where eased.

Although similar temporal trends of decline were observed across transport regions, some studies have also found that this has not been homogenous across population groups. Poorer, more deprived populations maintained higher levels of public transport demand during the pandemic (Almlöf et al., 2021; Kim and Kwan, 2021; Liu et al., 2020; Parker et al., 2021). Research by Almlöf et al. (2021) found that the largest decreases in public transport use in Stockholm were linked to areas with a population of high socioeconomic status. During spring 2020, rural dwellers were most likely to continue travelling via public transport, followed by impoverished and working-class populations. Similarly, Liu et al. (2020) found that in the US, communities with higher proportions of essential workers and vulnerable populations, including African Americans, Hispanic people, women and people aged over 45, maintained higher levels of public transport demand during the pandemic.

In addition, survey-based research identified social differences regarding the stated willingness to return to public transport. Przybylowski et al. (2021) observes that 90% of those surveyed limited or realigned their use of public transport since the outbreak of the pandemic, with only 75% planning to return to using public transport services. Those that responded that they would not return to public transport were said to have lost hope that these services will ever be safe. Willingness to return to public transport services also appears to depend on whether an individual was a frequent public transport user before the pandemic. Additionally, younger age groups were found to be more likely to return to public transport services post-pandemic (Kopsidas et al., 2021).

2.2. Unequal shifts in the purpose and mode of travel

Several studies have specifically focused on the impacts of lockdowns and restrictions on existing inequalities in mobility and travel. Campbell et al. find that a lockdown in New Zealand exposed and exacerbated disadvantage among residents in deprived neighbourhoods. Similarly, Kar et al. (2021) identify disparities in travel and mobility across socioeconomic classes in Columbus, US. Previously diffused travel patterns of high and moderate socioeconomic status populations became more localised, whereas the previously localised travel patterns of low socioeconomic status populations became diffused. Those of low and moderate socioeconomic status travel primarily for work, whereas high socioeconomic status individuals travel mostly for recreational and other non-work purposes.

A detailed report by Teuton et al. (2020) for Public Health Scotland studied how changed use of transport systems affects population health and well-being. The authors anticipate that COVID-19 will continue to have a lasting impact on the number of trips that people make, their choice of mode, and access to goods and services. Whereas public transport journeys declined the most, car journeys initially declined and subsequently rose steadily. This trend poses a substantial challenge to sustainable mobility, even though walking and cycling trips also increased. In addition, reduced capacity of public transport services further restricted transport options and added financial strain for those on low incomes, those without access to private modes of transport, and vulnerable populations such as those that are older or disabled. The result is that the pandemic's impact on public transport will likely be felt the most by those who were already transport disadvantaged prior to the pandemic (Vickerman, 2020).

A shift towards private transport and active travel, an increase in home-working and use of e-commerce also has the potential to increase inequalities (Matson et al., 2021). Although many of these shifts were already underway, the pandemic has accelerated them (Shamshiripour et al., 2020) and the increased pace of change could rapidly exclude those who lack access to technology or the ability to work from home. Although technology and internet use has accelerated within the older population, a large proportion of the older population remain excluded from digital services, such as e-commerce, as they lack access to the Internet and technology devices or are inexperienced in using them (Carney and Kandt, 2022; Seifert, 2020; Seifert et al.). An increase in technology and Internet use facilitated by COVID-19 has the potential to reinforce the digital divide between those that are 'tech-savvy' and sectors of the older population that are less connected. This could have a knock-on impact on social exclusion and disadvantage in the older population.

2.3. Social patterns of recovery in public transport ridership

Although some studies reveal socio-demographic differences in public transport re-uptake, gaps remain, and more research is needed to explore the lasting socio-demographic and economic inequalities in public transport use. First, many studies have focused on the decline in demand that occurred during the first phase of travel restrictions, i.e. the first few weeks from March 2020. There has been less attention on the pace and pattern of recovery of public transport patronage, although such studies are emerging (e.g. Parker et al., 2021).

Second, where studies did not collect small sample survey data, travel could not be directly linked to a trip-makers demographic and social characteristics. Studies that use smart card or mobile phone data often have to rely on small area statistics to infer socio-demographic context (e.g. Campbell et al., 2021; Kim and Kwan, 2021; Liu et al., 2020). This approach prevented researchers from estimating and quantifying different paces of using and resuming trips by public transport across different groups. In particular, differential trips by ethnic groups have not been studied and analysed while controlling for other social or contextual characteristics, such as area deprivation.

Our study contributes evidence from the UK based on a longer-term analysis of smart card data pertaining to older passengers with linked socio-demographic characteristics including gender, age and ethnic group. We analyse all concessionary smart card transactions for the period of March 2020 to May 2022, compare them with pre-pandemic transaction in 2019 and explore differential public transport recovery rates covering subsequent waves of COVID-19 infections. The direct link to socio-demographics allows us to estimate differences in pace of public transport ridership recovery by age, gender and ethnic group while controlling for contextual neighbourhood characteristics. Based on these estimations, we are able to estimate how patterns in social inequalities in public transport patronage evolve as the pandemic progresses.

The focus on older trip-makers (details below) adds two further angles to the debate. First, we focus on a particularly vulnerable group, a group that traditionally shows higher dependence on public transport. In our case study area, this group is entitled to free travel, which removes monetary cost barriers and thus may offer a better picture of demand. The analysis of these passengers then reveals which groups are

particularly hard-hit by pandemic-induced changes in public transport safety or level of service.

Second, we focus on non-work-related travel, which has hitherto been less attended to in studies on changes in travel demand caused by the pandemic. Since the smart card transactions pertain to senior citizens, the proportion of commuters is low (we estimate <1% of transactions, (Carney), 159), and hence the data provide an opportunity to explore non-work-related travel, specifically shopping and leisure, and view recovery of demand without the impact of tele-commuting.

3. Research design

3.1. Data

The primary data used in this study consists of smart card transactions made by passengers who travel under the English National Concession Travel Scheme (ENCTS) on the bus network in the West Midland Combined Authority (WMCA), the UK's second largest metropolitan area centred on the city of Birmingham. ENCTS grants free bus and rail travel to all passengers of above state pension age and younger people with disabilities after 9.30 am on weekdays and all-day during weekends. Here we focus on passengers at retirement age, who are unlikely to travel for work. The age-related selection criterion implies that in 2019, all registered passengers were at least nearly 66 years old.

The travel smart card data are provided by Transport for West Midlands (TfWM), the regional transport provider, and analysed under an academic user licence from the ESRC Consumer Data Research Centre (CDRC). Smart card transactions record for each passenger the exact date and time of boardings, the service used and several operational details. The records can be linked to anonymous cardholder databases, which hold data on gender, age, ethnic group and residential area of passengers. Residential areas are recorded as Lower Layer Super Output Areas (LSOAs), which are census areas of on average 1500 residents.

The linked data enable us to analyse boardings for different socio-demographic groups within concessionary passengers and to further link contextual variables through official neighbourhood statistics based on LSOA identifiers. We compare boarding patterns of two time periods, a pre-pandemic period which is defined as a year prior to the date of the first lockdown, i.e. 1 April 2019 to 26 March 2020, and a pandemic period from the first day of the lockdown, i.e. 27 March 2020, to 5 May 2022. The latter was the latest available date in the dataset.

We analyse cardholder demographics including age, gender, ethnicity and residential context to investigate the socio-demographic and geographical distribution of returning to public transport. Age is recorded as 5-year age bands and ethnicity as White, Black, Asian, Mixed and Other, the same broad categories that are used by the UK Census. Only active cardholders with full demographic records are included in these analyses; we excluded cardholders that have shown no activity in the study period. In 2020, there have been 432,074 registered cardholders, of whom 267,597 were active in the pre-pandemic period. Excluding the passengers with missing demographics, our analytical sample is 183,891 representing 43% of the regional population of age 66 or higher.

3.2. Analytical methods

We take weekly bus boardings as a measure of public transport use during the COVID-19 pandemic across the study period 1 April 2019 to 5 May 2022. For each individual cardholder, we calculate the number of boardings made per week to derive comparable measures of boarding volumes per passenger over the study period.

We apply methods of survival analysis to statistically estimate the speed of return to public transport in relation to age, gender and ethnic group. We also consider the level of each passenger's level of use pre-pandemic as measured by total number of boardings, as well as geographic characteristics of a passenger's residential LSOA. These

include a measure of deprivation, the Income Deprivation Affecting Older People Index (IDAOPI), which is a composite index reflecting the percentage of the 60 plus population that receive income support, income-based job seekers allowance, pension credit or child tax credit. This index has been prepared for 2019 by the UK Ministry of Housing, Communities and Local Government (MHCLG, 2020). We also include car ownership rates derived from the 2011 UK Census, which, though dated, we assume to correlate with current car ownership rates as the structure of car-dependent environments tends to change slowly.

We also include a variable representing public transport accessibility that measures average bus and tram journey times to daily shopping opportunities. We convert public transport data from Traveline (Traveline, 2021) into GTFS format using the CLI tool *transxchange2gtfs* (Norton, 2018). Joining OpenStreetMap (2021) routing data, we use OpenTripPlanner (2021) to generate shortest walking and transit journeys between Output Areas centroids pertaining to the residential location of the registered cardholders. To define the destinations for food shopping, we develop a composite measure from two datasets – Geolytix Supermarket Retail Points (Geolytix, 2021) and centroid points extracted from CDRC retail centre boundary data (CDRC, 2021). The data have been filtered to only contain supermarkets that were open during the study period and only those that with a size band of 'medium' or larger, and also only high streets larger than 'small local centres'. The rationale for this combination is that Geolytix only contains larger chain supermarkets and excludes independent food retailers. Using OpenTripPlanner, we calculate average travel times at 10-min intervals throughout a 'typical' Tuesday in April 2020 from 8 am to 8 pm. We calculated the average travel time by taking the mean of the three shortest journeys at each interval and then an average of these values for the whole day.

To estimate the speed of return to public transport by demographic, social and geographic characteristics, we first specify a Kaplan-Meier model (Goel et al., 2010) to calculate median return times for each group. The model calculates for each time point, in our case for each day after the first day of lockdown on 27 March 2020, the percentage of individuals to have returned to public transport. The successive calculation of patronage can be interpreted as inverse 'survival' curves, which track the cumulative proportion of each population group that has returned to public transport. The model can then be used to identify statistically significant differences between inverse 'survival' curves of different population groups.

We then specify a multivariable Cox Proportional Hazards model (Harrell, 2015), which allows us to estimate associations between patronage and passenger and contextual characteristics over time. We use the *coxph* function from the survival package (Therneau, 2022) in the programming language R. The model estimates odds ratios, which represent the increased chance of an individual returning to public transport at any date after the 0 day of the beginning of the pandemic given a passenger's socio-demographic and geographic situation. The odds ratio can be used to measure the increase or decrease in hazard due to a unit difference in the explanatory variable – in this case the socio-demographic and geographic variables.

To run the model, we reshape the data from a row-wise list of transactions into a longitudinal dataset with binary events for each individual. The resulting table indicates for each date whether or not an active cardholder as defined above uses public transport services with 1 for use and 0 for no use.

4. Results

4.1. Decline in active passengers during the pandemic

The demographic composition of passengers who are registered for the concessionary scheme broadly reflects the demographic distribution of the region (Table 1, columns a and b). The total figures mask a certain level of discrepancy between gender, wherein the proportion of women

Table 1
Distribution of active older concessionary cardholders in by age, gender and ethnic group.

	total registered	population estimate°	female					male				
	2020	2020	pre-pandemic*	2020 pandemic#	2020 perc. change	2021 pandemic†	2021 perc. change	pre-pandemic*	2020 pandemic#	2020 perc. change	2021 pandemic‡	2021 perc. change
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
age groups												
66–70	99,410	118,661	36,289	22,010	−39.3	31,019	−14.5	31,276	19,585	−37.4	26,841	−14.2
71–75	110,571	110,509	40,732	20,572	−49.5	26,356	−35.3	35,204	18,422	−47.7	23,275	−33.9
76–80	88,719	84,485	29,732	15,189	−48.9	18,325	−38.4	24,753	12,627	−49.0	15,019	−39.3
81–85	68,385	62,547	19,822	9623	−51.5	10,608	−46.5	16,051	7871	−51.0	8735	−45.6
>85	64,989	53,111	12,290	4831	−60.7	4686	−61.9	9973	4287	−57.0	4082	−59.1
total	432,074	429,313	138,865	72,225	−48.0	90,994	−34.5	117,257	62,792	−46.4	77,952	−33.5
ethnic groups												
Asian	32,197	29,403†	10,240	5614	−45.2	7957	−22.3	10,680	6736	−36.9	8297	−22.3
Black	12,023	13,684†	4237	2974	−29.8	3314	−21.8	3389	2423	−28.5	2595	−23.4
Mixed	1314	1694†	438	283	−35.4	353	−19.4	431	311	−27.8	342	−20.6
Other	9689	2252†	2897	1849	−36.2	2557	−11.7	2510	1665	−33.7	2285	−9.0
White	326,486	368,508†	103,594	52,473	−49.3	70,043	−32.4	84,596	43,131	−49.0	57,785	−31.7
unknown	53,428	n/a	17,583	9032	−48.6	11,575	−34.2	15,978	8526	−46.6	10,555	−33.9
total	435,137	415,541†	138,989	72,225	−48.0	95,799	−31.1	117,584	62,792	−46.6	81,859	−30.4

* 1 April 2019 to 26 March 2020 # 27 March to 31 December 2020 ‡1 Jan 2021 to 31 December 2021° from ONS (2021) † Figures from 2011 UK Census.

is higher in older age groups most likely due to different life expectancies as well as gender roles in this age cohort (Kandt and Leak, 2019). The ethnic composition of active passengers reflects the composition of the region. Over 80% of passengers are from a White ethnic background, followed by Asian with 10% and Black with nearly 4%.

The comparison of different time periods reveals unequal decline in and recovery of the number of passengers (Table 1, columns c to l). Passenger counts broken down by gender, age and ethnic group suggest that in 2020, women avoided public transport more than men, older senior citizens more than younger ones and White passengers more than those with other ethnic backgrounds. During the pandemic, more than half of men and women above the age of 70 avoided public transport altogether and did not return. One in two passengers from a White ethnic background abandoned public transport, compared to one in three in other ethnic groups except Asian. Gender differences are particularly pronounced for non-White ethnic groups: fewer non-White men abandoned public transport compared to non-White women, especially among the Asian and Mixed groups.

By the end of 2021, more groups have returned to public transport, but some more quickly than others, so that social inequalities appear to have widened further. At that time, about 70% of older passengers have taken public transport at least once since the pandemic.

4.2. Speed of return to public transport by passenger socio-demographics

The COVID-19 pandemic had a significant impact on bus boardings in 2020 (Fig. 1). Three major national lockdowns were imposed in the UK – from 26 March to 14 June, 5 November to 2 December 2020 and 6 January to 29 March 2021. During those periods, which are highlighted in Fig. 1, working from home was mandatory where it was possible, and people were obliged to remain within their neighbourhoods. Between these periods, less restrictive and more localised lockdowns were in place.

A large decline in boardings can be seen during the first lockdown in March–April 2020, with weekly boardings declining from an average of 597,349 per week across January and February 2020 to their lowest of
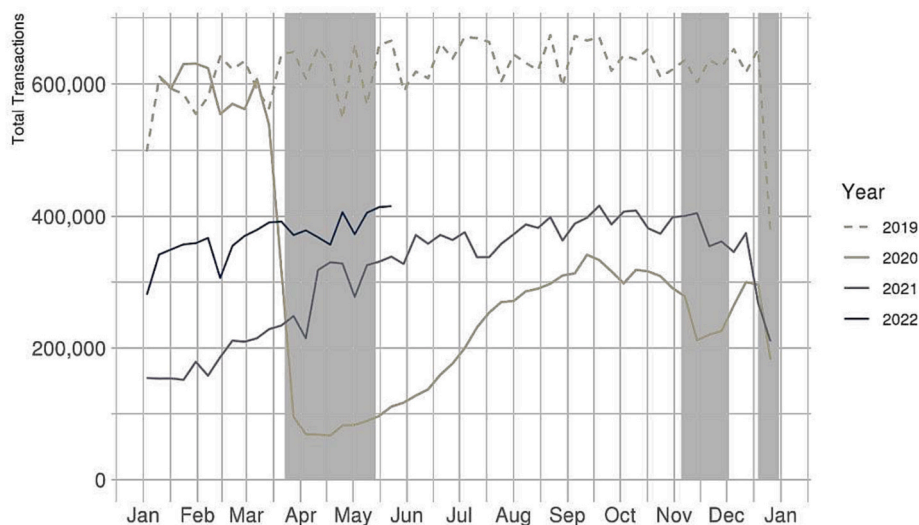
Fig. 1. Total number of weekly bus boardings made by ENCTS concessionary passengers in the sample selected for this analysis throughout 2019 to 2022 by week. The grey rectangles represent lockdowns in 2020.

67,125 in the week starting 13th April 2020. Although boardings remained low for much of spring 2020, once restrictions began to ease in May there was a steady increase in weekly bus usage. This increase began to level off in August and September, despite low stringency of restrictions at that time. Patronage levels recovered slowly until summer 2021, after which the recovery accelerated. The trend shows that, while a proportion of cardholders returned to public transport services once restrictions eased, boarding rates and frequencies recovered in different waves. By March 2022, a 80% of concessionary passengers have returned to public transport making on average 63% of weekly boardings compared to March 2019. Translated to the individual level, this means that those who have returned to public transport, travel on average 25% less frequently than prior to the pandemic.

The overall decline and recovery of boardings mask differences by socio-demographic groups. In terms of age, we find that initially all age groups steadily returned to public transport. But as the second wave of the pandemic occurred, differences between age groups began to widen, and they continue to do so in 2022. Differential susceptibility to illness or mortality among age groups may partly explain these patterns. Throughout the study period, cardholders below the age of 70 were more likely to both continue using bus services during lockdown periods and return to public transport more quickly.

The simple Kaplan-Meier survival model confirms the differential speed of groups returning to the transit system. The dotted horizontal line in Fig. 2 represents the point at which 50% of the group return to public transport. The differences in median return rate, measured in days, highlights the particularly slow return for the oldest age group, with a median of nearly 180 days compared to a value of 164 or below for all other groups.

Female cardholders generally made fewer boardings per week pre-pandemic than male cardholders and their boardings dropped to a lower level during the pandemic and remained lower than boarding rates by men throughout 2020 (Fig. 3). After an initial divergence of recovery rates during the first lockdown and during summer, the return rate by women caught up during late 2020, and the gender gap narrowed towards the end of that year before widening again in 2021. Overall, the median return rate between men and women differed by only four days with an average of 5.5 months.

Pronounced disparities are evident between ethnic groups (Fig. 4). Pre-pandemic, passengers from Black, Mixed and Asian ethnic backgrounds made the highest number of weekly boardings per cardholder.

During the first lockdown period, on average those of an Asian and White ethnic background reduced boardings the most; boarding rates dropped to a similar level of less than one boarding in three weeks on average. By contrast, Black and Mixed passengers retained one boarding per week.

Boarding rates recovered particularly quickly for passengers from Black ethnic background during the first months after the first lockdown in 2020. By July 2020, half of the passengers were using the system again, while less than a quarter of White passengers had returned to the system. Compared to Black passengers, it took White passengers over two months longer to recover 50% of their weekly boarding rates. Despite a sharp decline in patronage among Asian passengers, their return to public transport gained pace during the summer months. The difference by ethnic background persisted into spring 2021, after which White and Asian passengers returned to public transport more quickly than other passengers. This trend led to a narrowing of ethnic differences, although patronage by White passengers remain significantly lower than those of non-White groups.

4.3. Geographical patterns of return to public transport

Changes in and recovery of patronage also differ by neighbourhood deprivation affecting older people (Fig. 5), which we estimate using the IDAOPI measure described above. There is a clear gradient between levels of income deprivation. Prior to the pandemic, cardholders residing in the most deprived areas made more boardings per week on average than those in the least deprived areas. The boarding levels during the first lockdown period and the subsequent were also higher for cardholders residing in more deprived areas.

The median return period is 116 days or sooner for cardholders residing in the most deprived areas (decile 1), whereas passengers from the least deprived areas return on average five months later (decile) or not at all in 2020 (decile 10). Similar to the patterns associated with ethnic groups, inequalities between area deprivation levels widen until spring 2021, after which passengers from more affluent areas resume public transport travel more quickly than other groups. Despite these trends, in 2022, deprivation deciles continue to correspond to different levels of patronage and speeds of recovery.

The combined effect of socio-demographic and economic factors on bus patronage during the pandemic translates into pronounced geographic disparities (Fig. 6). In 2020, over 88% of LSOAs experienced
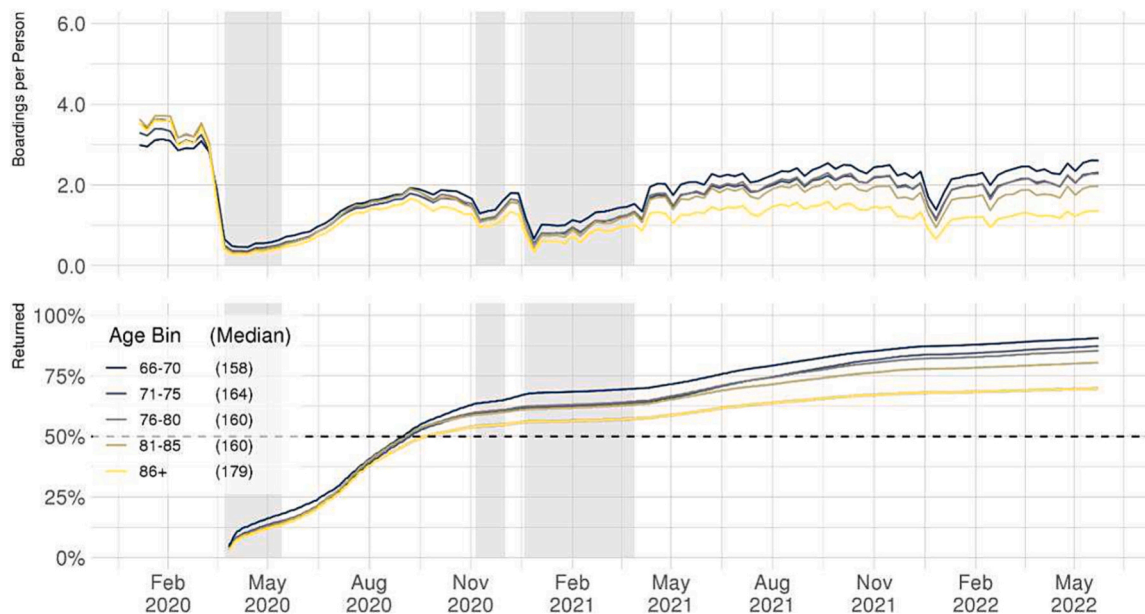

Fig. 2. Weekly boarding and return rates on the bus network by 5-year age bands. Shaded areas represent 95% confidence intervals.
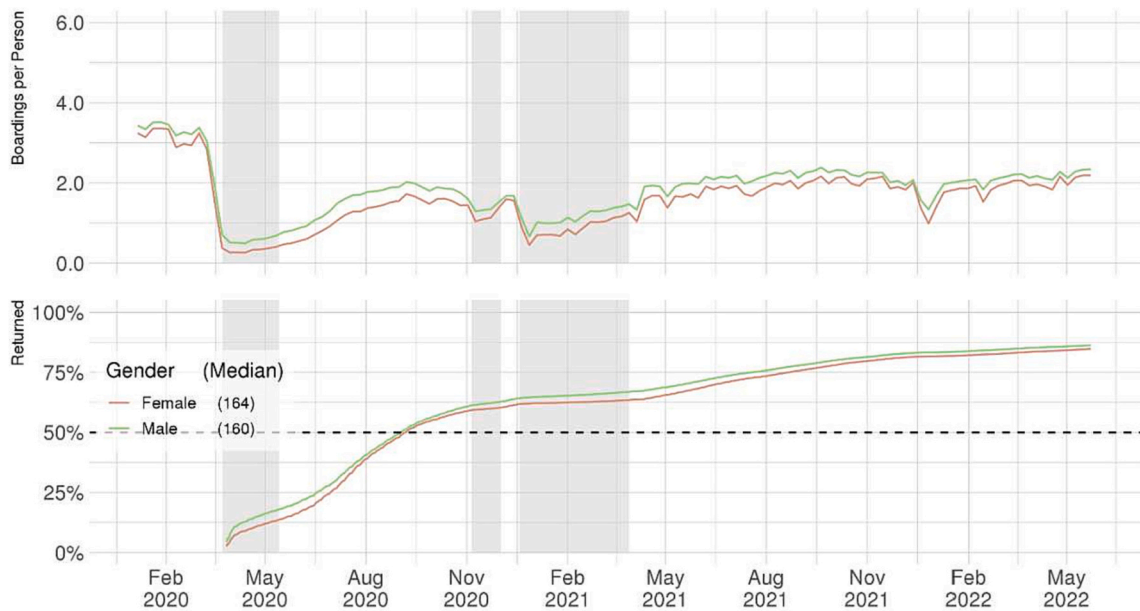
Fig. 3. Weekly boarding and return rates on the bus network by gender. Shaded areas represent 95% confidence intervals.
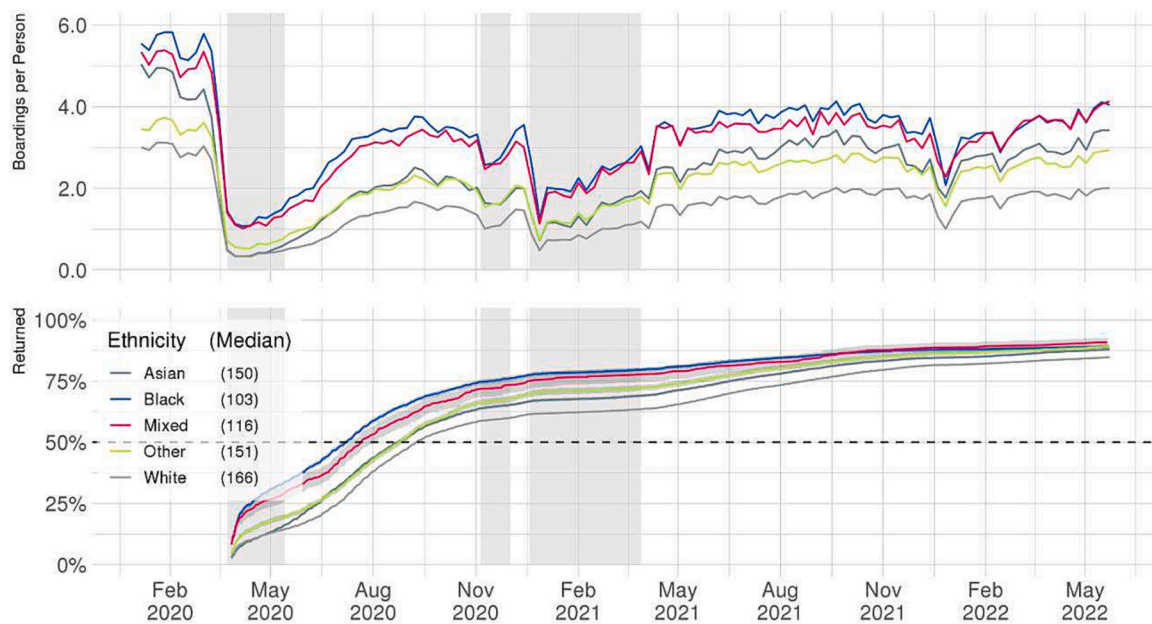

Fig. 4. Weekly boarding and return rates on the bus network by ethnic group. Shaded areas represent 95% confidence intervals.

at least a 75% decline in boardings made by cardholders residing within them. Boardings by cardholders residing in rural areas tended to decline the most, with significant declines seen in the large green belt area in Solihull as well as rural and suburban areas of Walsall and north Birmingham. In central urban areas, passengers returned on average five to six months earlier than in suburban passengers. In many more rural areas, fewer than half of passengers returned to the bus system by the end of 2020, as indicated by a median return rate exceeding 280 days. In 2022, all LSOA more than half of the passengers have returned to public transport but significant differences remain between denser, central and more urban areas compared with less dense and less served parts of the region.

4.4. Social and geographical determinants of bus and tram ridership recovery

The Kaplan-Meier survival analysis is effective in describing the evolution of unequal resumption of public transport travel. To take the analysis further, specifically to estimate the influence of multiple confounding influences on the patterns, we specify the Cox Proportional Hazards model. In particular, we may assume that groups with a higher share of frequent passengers – prior to the pandemic – will 'naturally' exhibit quicker return to public transport, and this may moderate the associations between return to public transport and passengers' socio-demographic, economic and geographic attributes. We distinguish passenger characteristics and characteristics of their area of residence.

In terms of passenger characteristics, the pre-pandemic level of patronage shows a strong association with the likelihood to return to the
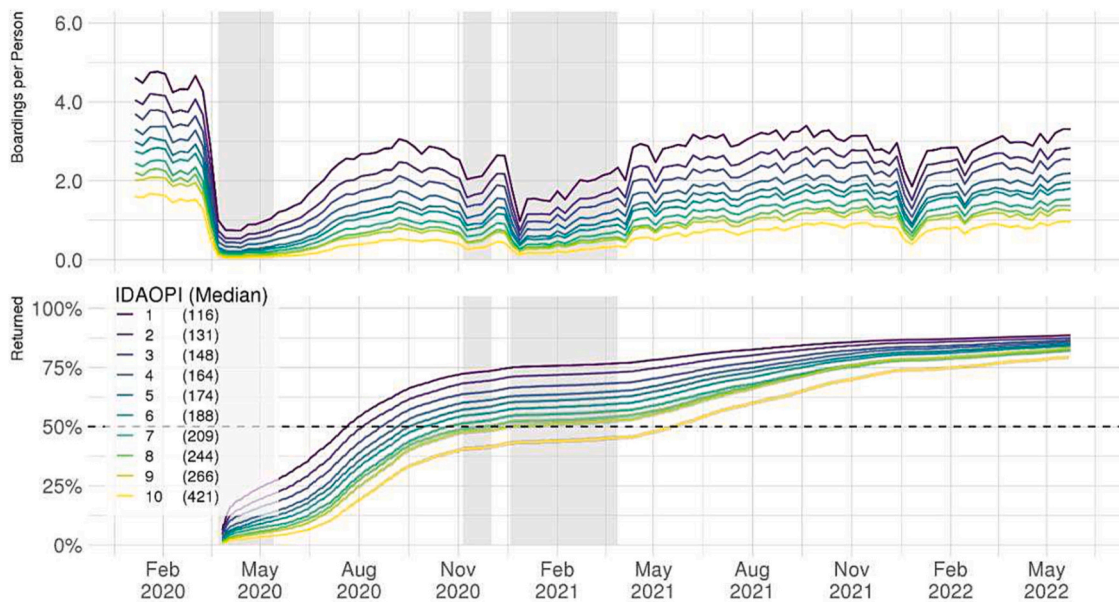
Fig. 5. Weekly boarding and return rates on the bus network by IDAOPI deprivation decile. Shaded areas represent 95% confidence intervals.
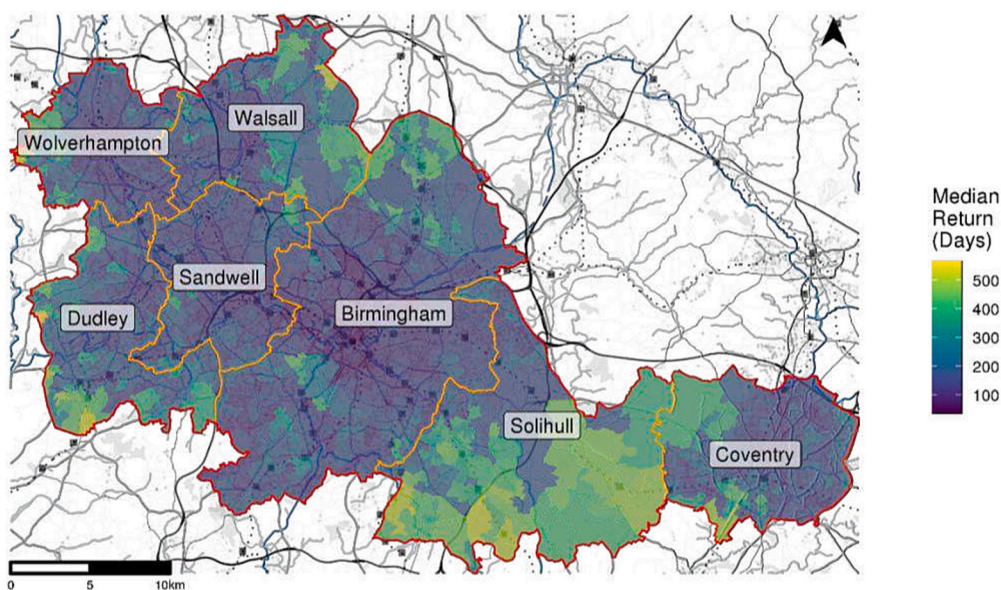

Fig. 6. Median return in days by LSOA.

bus network Table 2. Passengers who travelled several times per week pre-pandemic tend to resume public transport earlier than less frequent passengers. Despite this adjustment, the patterns associated with socio-demographics found in the bivariable survival analyses above persist. Men are more likely to resume bus travel earlier during the pandemic, and so are younger senior citizens.

The fully adjusted model also confirms differences between ethnic groups. Controlling for pre-pandemic boarding levels as well as neighbourhood deprivation, Asians are now even less likely to return to public transport than passengers of White ethnic background. Black passengers continue to be more likely to return soon to the network.

The social gradient – represented as the IDAOPI measure of deprivation – is evident in the fully adjusted model, too. Since many of the more deprived areas in the WMCA are located in central urban areas, deprivation is associated with higher level of public transport service. Therefore, it is important to consider other spatial confounders, specifically public transport accessibility and car ownership rates.

Among these geographical characteristics, LSOA deprivation emerged as the strongest predictor of return rate. Passengers residing in more deprived areas are significantly more likely to return to public transport. Car ownership rates and bus travel times to amenities, the flip side of bus accessibility, are each negatively associated with return rates, suggesting that higher car ownership on lower levels of public transport service contribute to longer-term avoidance of the bus network.

The overall model fit, which is reflected by a concordance value of 0.701, indicates that the model has a good explanatory power (Harrell, 2015). Concordance is calculated by pairwise comparison of all data points to represent the proportion of pairs where the data point with a higher hazard ratio undergoes the event earlier than that with a lower one. Values can range in theory from 0 to 1; a value of 0.5 indicates that model-based predictions are random, and a value of 0.8 reflects very high fit. We therefore conclude that our model is informative as to what

Table 2

Cox Proportional Hazards model and odds ratio with binary return rate as the dependent variable.

	Coefficient	Std. Error	Odds Ratio	Sig.
Pre-pandemic log number of boardings	0.382	0.002	1.466	***
Age	−0.033	0.000	0.967	***
Gender: male	0.158	0.005	1.171	***
Ethnicity (reference: white)				
Asian	−0.212	0.009	0.809	***
Black	0.095	0.014	1.100	***
Mixed	0.043	0.039	1.044	
Other	0.000	0.017	1.000	
LSOA deprivation in later life score	0.402	0.035	1.494	***
LSOA car ownership rate	−0.004	0.000	0.996	***
OA bus travel time	−0.001	0.001	0.999	*
Concordance	0.701	0.001	–	–

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' | $n = 183{,}891$.

might drive differences in the recovery of bus patronage.

5. Discussion

5.1. Amplified social inequalities within a vulnerable group

The recovery of bus ridership remains unequal throughout all stages of the pandemic. Although differences in bus patronage by social background and geography appear to be narrowing in 2022, they follow a period of unequal patronage that intensified in pace during the first waves of COVID-19. The analysis of trajectories reveals that many Black senior citizens and citizens residing in deprived areas with low car ownership return to public transport as soon as it was possible. White passengers continued to avoid public transport to a greater extent than non-White passengers, and this suggests that the former have been better able to find alternatives in terms of modes or physical trip substitution. These trends raise questions as to the unequal exposure not only to infectious diseases but also the lasting impacts of service reductions in response to initially lower ridership.

Ethnic inequalities persist even when we control for neighbourhood deprivation and public transport accessibility. In equally deprived neighbourhoods, non-White groups are still more likely to return to public transport more quickly. Therefore, in addition to the well-known fact that passengers from more deprived areas tend to rely on bus services in the absence of alternative means of transport, there appears to be a specifically ethnic dimension to the unequal recovery of public transport patronage in the WMCA.

Other than the ethnic dimension, we find a clear social gradient in public transport ridership resumption, consistent with findings from studies focusing on the impact of the outbreak on public transport demand. Age also plays a role, wherein older passengers refrain from using public transport. Therefore, there is a need to understand how those potentially more vulnerable and mobility-restricted populations satisfy their mobility and social needs. We also found that men were quicker to return to public transport, and although women caught up with men during summer 2020, gender gaps appeared to be widening again 2021. This finding on differential travel adaptations by gender during the pandemic is consistent with survey-based studies (e.g. He et al., 2022; Palm et al., 2021) but our longer term view suggests that gender difference may persist for some cohorts of passengers.

Finally, we note that passengers who travelled more frequently pre-pandemic returned to public transport earlier even when we consider social and geographical characteristics that are often associated with higher ridership. This pattern may imply that those passengers who have had alternative means of travel will be even harder to convince to use public transport in the near future. All in all, we still perceive a stronger socio-spatial divide across modes than prior to the pandemic, even

though it may be less pronounced than it may seem in the literature on public transport recovery to date. Therefore, there remains a need for decisive policy action to stimulate demand to public transport across all groups.

5.2. Policy implications

Two years after the outbreak of COVID-19, after a period of widening gaps in public transport demand recovery between different socio-demographic groups and geographical contexts among senior citizens, public transport use is still below pre-pandemic levels in UK cities, in the WMCA at approximately 20% (TfWM, 2022) and in London 50% (TfL, 2022). These figures reflect new working-from-home practices and, as our findings suggest, mask a slow and socially unequal trend of public transport demand recovery among the non-working population. Given the hard-to-predict possibility of new pandemic waves, the future course of demand is uncertain. In this context, government and public authorities should triggering a vicious circle through cuts in services motivated by lower aggregate demand, which would further restrict the mobility of the non-working population, further reduce demand and in turn lower the viability of services, encouraging new cuts. This vicious circle would particularly affect the mobility of vulnerable groups.

At other times, more vulnerable population groups may have decreased their travel precisely when restrictions were lifted, due to fear of higher infection risks as more people use the network. These complexities render likely that the observed social and geographical inequalities may reflect fluctuations in individual patronage, all of which may re-intensify should new waves or virus mutations occur. In such events, policy may react to support the specific needs of some groups to maintain and revive public transport patronage for all at the appropriate time.

Our findings also plausibly suggest that public transport avoidance by some groups can last longer and thus durably influence the passenger composition and by extension the image of public transport services. Yet, the narrowing of social inequalities in patronage offer hopeful signs; and they underline the importance of providing attractive levels of public transport service in all areas of the metropolitan region in order to avoid lasting lower ridership, increased social selectivity and further disadvantage of transit-dependent users (Carney et al., 2022). Indeed, prior to the pandemic, the WMCA region had already experienced persistent decline in bus patronage from passengers from more affluent areas, and this trend posed a significant challenge to the delivery of inclusive and sustainable transport in the region (Kandt and Leak, 2019).

Further cuts in bus services, which are underway in the England as central Government commitment to funding services remains uncertain, will therefore hit the slow and fragile restoration of more inclusive patronage. If changes in travel behaviour, such as an increase in active travel and private transport use (Teuton et al., 2020) persist beyond the COVID-19 pandemic and if more vulnerable populations are unable to make use of public transport services due to reduced capacity and provision, these groups may experience an increased level of social exclusion and health and well-being disadvantage (Vickerman, 2020). Consequently, commitment to high quality public transport will need to be significantly greater than prior to the pandemic to retain in and attract White and more affluent people to public transport. At the same time, services must continue to accommodate the needs of mobility-restricted and vulnerable groups in the region.

In linking large volumes of smartcard transactions to socio-demographics covering more than three years, our study contributes evidence on the social and geographical characteristics that are associated with unequal paces of recovery of public transport demand. Inequalities within the vulnerable group of senior citizens have particularly strong implications for policy aimed at delivering socially inclusive transport systems and promoting health and well-being for all. In view of the dual challenge of lower ridership, especially in lower

density areas, and increasing social selectivity in mode choice, we concur with Vickerman (2020) that governments and transport authorities visibly commit to public transport and accordingly rethink the funding mechanisms for and governance of public transport in the UK. The proposals set out in the UK's new National Bus Strategy (DfT, 2021) may offer suitable starting points if such efforts are grounded in a recognition of public transport as critical enablers of inclusion, well-being, environmental sustainability, and prosperity in society.

5.3. Study limitations

While our study reveals critical factors that are involved in the unequal recovery of public transport demand during the pandemic, a few limitations should be mentioned. First, we acknowledge that social and economic circumstances among senior citizens are diverse, and they cannot be captured by a limited number of variables. Details on incomes, vehicle access, digital technology, everyday life activities and social networks are important factors of citizens' life situation influencing mobility patterns. Nevertheless, in our study we are able to estimate direct association of age, gender and ethnicity with bus patronage for nearly the regional population at retirement age, and we thus deliver important quantitative evidence public transport demand and patterns of social inclusion during the pandemic.

Second, a more detailed analysis of trip origins and destinations would add further insights into changed destinations and travel distance during the pandemic. Although a more detailed analysis is unlikely to change the overall findings, it may reveal specific shifts in travel demand by different groups and help characterise types of public transport dependency and realigned patronage.

Third, no direct data on trip destination has been collected. However, external datasets from the National Travel Survey suggests that the main trip purposes among this group includes shopping and leisure ((Carney), 159). Records of trip purpose would also help characterise specific types of participation that depend on public transport. A more detailed analysis of trip destination would add more information about this aspect of travel.

As with all smart card or similar types of big data, there is no information on the reasons for, drivers of and barriers to travel. Therefore, we can only speculate about the causes of unequal recovery rates based on our explanatory models. Yet, our analyses reveal areas for possible further, low sampled yet more detailed investigations into the experience of diverse citizens. For example, qualitative studies with members of different ethnic groups in different geographical context could be targeted and structured based on the findings of this study.

6. Concluding remarks

As the future of public transport delivery continues to be heavily debated, the pandemic appears to have amplified well-known social and geographical inequalities in transport, and these may persist over a longer time or return at the next wave of the pandemic. Stronger social selectivity and stratification of mode use in the region not only puts social inclusion at risk but also impedes efforts to meet required carbon emission targets. Therefore, policy should recognise the steady recovery of patronage while addressing newly emerging barriers in moving regional transport system towards greater levels sharing as part of inclusive, healthy and more sustainable travel through and beyond COVID-19.

CRediT authorship contribution statement

Alfie Long: Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Ffion Carney:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Jens Kandt:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Project

administration.

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