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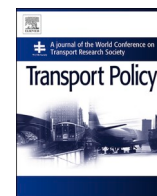
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Public transit use in the United States in the era of COVID-19: Transit riders' travel behavior in the COVID-19 impact and recovery period

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A B S T R A C T

COVID-19 has upended travel across the world, disrupting commute patterns, mode choices, and public transit systems. In the United States, changes to transit service and reductions in passenger volume due to COVID-19 are lasting longer than originally anticipated. In this paper we examine the impacts of the COVID-19 pandemic on individual travel behavior across the United States. We analyze mobility data from January to December 2020 from a sample drawn from a nationwide smartphone-based panel curated by a private firm, Embee Mobile. We combine this with a survey that we administered to that sample in August 2020. Our analysis provides insight into travel patterns and the immediate impacts of the COVID-19 pandemic on transit riders.

We investigate three questions. First, how do transit riders differ socio-demographically from non-riders? Second, how has the travel behavior of transit riders changed due to the pandemic in comparison to non-riders, controlling for other factors? And third, how has this travel behavior varied across different types of transit riders?

The travel patterns of transit riders were more significantly disrupted by the pandemic than the travel of non-riders, as measured by the average weekly number of trips and distance traveled before and after the onset of the pandemic. This was calculated using GPS traces from panel member smartphones. Our survey of the panel revealed that of transit riders, 75% reported taking transit less since the pandemic, likely due to a combination of being affected by transit service changes, concerns about infection risk on transit, and trip reductions due to shelter-in-place rules. Less than 10 percent of transit riders in our sample reported that they were comfortable using transit despite COVID-19 infection risk, and were not affected by transit service reductions. Transit riders were also more likely to have changed their travel behavior in other ways, including reporting an increase in walking. However, lower-income transit riders were different from higher-income riders in that they had a significantly smaller reduction in the number of trips and distance traveled, suggesting that these lower-income households had less discretion over the amount of travel they carried out during the pandemic. These results have significant implications for understanding the way welfare has been affected for transportation-disadvantaged populations during the course of the pandemic, and insight into the recovery of U.S. transit systems.

The evidence from this unique dataset helps us understand the future effects of the pandemic on transit riders in the United States, either in further recovery from the pandemic with the anticipated effects of mass vaccination, or in response to additional waves of COVID-19 and other pandemics.

1. Introduction

COVID-19 has upended travel across the world. In the United States, transit service reductions and concomitant reductions in passenger volume due to COVID-19 are lasting past the recovery of many other forms of transport. In this study we examine the impacts of the COVID-19 pandemic on individual travel behavior across the United States. We analyze mobility data from January to December 2020 from a sample of

individuals drawn from a nationwide smartphone-based panel curated by a private firm, Embee Mobile, which we combine with a survey that we administered to that sample in August 2020.

Recent research has examined the initial impacts of COVID-19 on travel behavior and public transit use across the world in the immediate wake of the pandemic (De Vos, 2020; Tirachini and Cats, 2020; Jenelius and Cebecauer, 2020; Brinkman and Magnum, 2020; Arellana et al., 2020; Shamshiriour et al., 2020). Other research has outlined frameworks for the future of the transport sector (Zhang, 2020), and has begun to investigate changes in travel behavior among different populations (Brough et al., 2020). But it is not clear how the identified trends will persist or evolve in the "new normal" that has emerged in the months following the initial outbreak of the pandemic, with implications both for the following years and for potentially-lengthy recovery periods in future pandemics. Additionally, these trends greatly vary across different geographic contexts. This paper contributes to the literature by providing insight into how United States transit riders' mobility has been affected due to the pandemic, compared to the mobility of non-transit riders. A combination of survey and passive location data allow us to answer this question at the individual level.

We investigated three questions. First, how do transit riders differ socio-demographically from non-riders? Second, how has the travel behavior of transit riders changed due to the pandemic in comparison to non-riders, controlling for other factors? And third, how has this travel behavior varied across different types of transit riders? The dataset we analyzed contains an oversampling of U.S. public transit riders, with 531 occasional to frequent riders out of a sample of 1,267. We examined how the travel behavior of transit riders has changed during the COVID-19 pandemic. Using self-reported survey data on travel modes, we compared the extent and nature of mode substitution by transit riders and non-riders.

The remaining sections of the paper describe prior literature; our data and research design; how transit riders differ demographically from non-riders; how their travel behavior differs from non-riders; how transit riders modified their behavior during the pandemic; controlling for other factors, how the travel of transit riders differed from that of non-riders; among transit riders, how travel behavior varied among different subgroups; and a conclusion including policy recommendations.

2. Literature

This paper joins other literature focusing on transit riders in the aftermath of COVID-19, documenting the decline in transit ridership (Arellana et al., 2020) and transit service related to COVID-19 (DeWeese et al., 2020). In response to the COVID-19 pandemic, declines in ridership, and consequent reductions in revenue, transit agencies across the U.S. have made significant adjustments to their service. While a few agencies have been able to increase service frequency to allow for social distancing on transit, most agencies have reduced service levels, decreasing frequency and sometimes cutting or merging transit routes (DeWeese et al., 2020).

Many studies have examined the impacts of the pandemic on transit ridership at large, using transit ridership and congestion data. Some research has hypothesized that demand for transit may decline less than for private modes, due to the different populations relying on each mode. For example, research conducted in seven Colombian cities found a greater reduction in overall congestion levels than reductions in demand for public transport (Arellana et al., 2020). Research conducted in India similarly saw a smaller reduction in transit than driving and walking (Dandapat et al., 2020). In contrast, a study in three regions of Sweden, a country which had few reductions in transit service, nevertheless found transit ridership reductions of 40–60 percent (Jenelius and Cebecauer, 2020). A study in Japan found a greater decrease in public transit and walking than car travel in three of the four cities studied (Morita et al., 2020a). The vast majority of respondents to a survey

conducted in Turkey said they observed a shift from public transportation to personal cars (Ozaydin and Ulengin, 2020). A study conducted in A Coruña, Spain, found that the impacts of the lockdown there on transit ridership were more significant than those on general traffic, though effects were not uniform across the network (Orro et al., 2020). An analysis of ridership decreases in ten U.S. cities looking at both ridership levels and service levels found that service changes did not have a significant relationship with ridership, though there were ridership declines in all cities from March to April 2020 (Ahangari et al., 2020). A study using mobility data from a web mapping service in China found that people preferred modes like walking, bicycling, and private vehicles to transit in the wake of the pandemic (Huang et al., 2020). Research conducted across 131 countries indicated that the closing of public transit has a strong effect on behavior change (Morita et al., 2020b).

Other research has used survey data to examine reported changes in travel behavior by mode. A large-scale survey conducted with individual participants in Japan found the greatest reported change as a decline in the use of public transit (36%), with a resulting increase in car trips (29%) and walking and cycling (27%) (Zhang, 2021). A worldwide expert survey came to similar conclusions, with a large modal shift to cars, and additional shifts to walking and bicycle and motorcycle use (Zhang et al., 2021). Research in Seattle, WA, U.S., using a combination of survey data and public transit ridership data found that travel declined less among individuals with lower incomes and lower educational attainment, even when accounting for impacts of public transit service reductions (Brough et al., 2020). In China, approximately 40% of public transit users reported switching to motor vehicles, and more than half of people without cars said they had plans to buy cars after the pandemic (Zhou et al., 2020).

Surveys have examined reasons for reported changes in travel behavior. A study conducted in China found that commuters think there is a larger probability of being infected in public transit than when traveling by other modes of transport, and as would be expected, commuters who think the risk of infection is higher in public transit have a lower probability of using it (Tan and Ma, 2020). They found that those who did not choose to take rail transit during the pandemic substituted to private cars, walking, or bicycles, as opposed to buses, subways, or taxis (Tan and Ma, 2020). Other research in Korea has also demonstrated peoples' increases in concerns about infectious disease risk in public transit after the beginning of the COVID-19 pandemic, as well as increased concerns related to crowding (Cho and Park, 2021). Due to different transit rider populations, declines in ridership may differ geographically, both within and across countries. In the United States, a significant proportion of transit riders are transportation-disadvantaged, with many essential workers continuing to rely on transit (Sheller, 2020; Blumenberg and Thomas, 2014). Research in the United States using transit agency data found that transit ridership declined 77 percent in higher-income census tracts compared to 58 percent for lower-income census tracts in Nashville, TN (Wilbur et al., 2020). Similarly, an analysis of county-level smartphone data of transit riders found that higher proportions of women, Hispanics, African Americans, and over-45-year-olds were associated with higher continuing demand for transit (Liu et al., 2020).

Other research has examined policy implications for transit agencies regarding infection risk on transit. Research is mixed on the actual spread of COVID-19 in within-city public transit, and the ways public transit can be managed differently to reduce transmission yet sustain mobility (Luo et al., 2020). Research indicates that public transit played a role in the spread of COVID-19 between cities (Zhang et al., 2020), but transmission rates stay low if public transit has good ventilation, there is high coverage of face masks, and riders have short contact time (Jones et al., 2020). A worldwide expert survey found that physical distancing measures had been taken in public transit in the majority of cases (62%), with higher shares in the U.S., Canada, and Europe, and the use of high-tech to assist with distancing messages in India and other Asian

countries (Zhang et al., 2021). Research in China found inconclusive results on the relationship between built environment attributes and the spread of COVID-19, differing across geographic locations and indicating that policies should be tailored to individual geographic contexts (Li et al., 2021).

Other work has examined the future of transport, and the need for positive social and environmental outcomes through individual transportation choices (Budd and Ison, 2020). The road ahead for public transit looks difficult in many countries, including England, with the need for supplementary funding to compensate for reductions in ridership and a need for increased service to allow for distancing (Marsden et al., 2021; Qu et al., 2020). The need for distancing measures in public transportation would impose strict limitations on passenger loads in many contexts (Gkiotsalitis and Cats, 2021). A worldwide expert survey suggested the need for efforts to prevent increases in car dependence due to the pandemic, by improving public transit service among other actions (Zhang et al., 2021). More specifically, a literature review has indicated the serious lack of knowledge around the impact of the pandemic on public transportation and models for transport planning (Gkiotsalitis and Cats, 2020).

Our research adds to this literature by combining data on both transit riders and non-riders, as well as passive and survey data, to control for user characteristics in understanding behavior change. In doing so, it both provides a picture of the disproportionate impacts of the pandemic on transit riders and informs strategies for the future recovery of transit systems.

3. Data and research design

This paper employs a combination of survey and passive behavioral data analysis to understand the continuity of mode choices and other travel behavior during the "new normal" of the COVID-19 recovery period. This section describes information on the survey methodology and data.

Our paper adds to the literature by contributing a unique perspective from a focus on individual transit riders. Our use of a self-reported survey in combination with passive data provides insight into transportation impacts at the individual level, a factor not visible in transit ridership datasets, and allows for an investigation of substitutions (or the lack thereof) for transit riders. This provides a finer grain of detail than prior studies that have relied primarily on passive smartphone data or ridership data. More broadly, the study contributes to the literature on the importance of transit for low-income households who often depend on it (Blumenberg and Thomas, 2014). Access to transport is integral to economic outcomes, particularly among low-income people, and there is a significant association between social exclusion and transport poverty (Blumenberg, 2008; Lucas, 2012; King et al., 2019; Attoh, 2019). The spatial distribution of public transit systems is an important equity concern (Welch, 2013), and previous research has found fewer miles traveled and related reduced access to opportunity for lower-income people (Blumenberg and Agrawal, 2014).

3.1. Survey

We conducted a survey in August 2020 that we merged with mobility data from smartphones owned by individual panel respondents. The mobile phone data included a record of respondents' weekly trip numbers and distances between January and December 2020. We targeted panelists on the Embee Mobile panel to obtain a sample representative of the U.S. population, both demographically and geographically, spanning 97 metropolitan and rural counties and 26 states across the U.S. The August survey was fielded to 14,651 panelists, of whom 6,968 were active, with a response rate of 19 percent and a total of 1,321 complete respondents passing attention check questions. Of these respondents, 1,267 responded to our primary questions of interest about public transit use.

The August survey consisted of 78 questions covering topics including travel behavior, economic factors, household dynamics, physical and mental health, personality characteristics, political views, adherence to COVID-19 related measures, and demographics. We drew survey questions from previously validated high-quality surveys when possible, including the National Household Travel Survey, the Patient Health Questionnaire (PHQ-4), the U.S. Census American Community Survey, the U.S. Federal Reserve Board Survey of Household Economics and Decisionmaking, and the Big Five Inventory (BFI-10). The survey included two attention-check questions, and respondents who answered either question incorrectly were excluded from the analysis. Respondents were allowed to select "I prefer not to answer" for any question.

Three survey questions were used to classify respondents as transit riders. In total, there were 531 respondents reporting either that they had either used transit in the seven days prior to the August survey (n = 219), or that they had not used transit in the seven days prior, but reported their transit use had decreased since the beginning of the pandemic (n = 312), excluding respondents who had responded "I do not use transit" in a follow-up question. This is a generous estimate of transit riders, including those who only occasionally use transit.

3.2. Passive mobility data

Our passive data consists of continuous time and location information from smartphone GPS data. An algorithm based on pings and dwell time picked up smartphone locations, processed by Embee Mobile to determine visits by respondents to different locations from the home. (Thus a simple round trip from home and back would be counted as two trips.) This information does not distinguish between modes, but provides information on the number of trips outside the home and distance traveled for each trip. We calculated the number of trips and total distance traveled for all weeks in the year 2020 (January to December).

4. How do transit riders differ from non-riders?

Transit riders differed from the rest of the sample in many ways, reinforcing previous evidence showing how transportation disadvantage overlaps with social exclusion in the United States (Lucas, 2012). Table 1 displays a selection of demographic characteristics between transit riders and non-riders. A higher proportion of transit riders were people of color (63.7% of transit riders compared to 43.2% of non-riders) and had decreased incomes since the start of the pandemic (57.1% of transit

Table 1

Demographic characteristics of transit riders and non-riders (August 2020).

	Non-transit rider	Transit rider
No household vehicle access	4.5%	23.5%***
Person of color[a]	43.2%	63.7%***
Female	61.1%	56.1%
Decreased income since pandemic	45.5%	57.1%***
Conservative	25.2%	20.6%
Living in a Census-defined urbanized area	83.2%	94.5%***
Caring for an elderly or disabled person	24.3%	26.1%
Child under 6 at home	23.8%	20.8%
Living in a building with 20+ units	8.9%	17.8%***
Home is crowded (person/room >1)	12.3%	15.1%
Worked this year	64.6%	62.3%
Conflict with household members makes it hard to spend time at home	7.5%	12.9%**
Yearly household income over $100,000	11.4%	9.3%
Yearly household income under $25,000	34.9%	43.4%**

*p < 0.05 **p < 0.01 ***p < 0.001 (compared to non-transit riders) – 2-way *t*-test.

[a] Person of color includes respondents identifying as Hispanic, Asian or Pacific Islander, Black or African American, Native American or Alaska Native, mixed racial background, or other race.

riders compared to 45.5% of non-riders). A higher share of transit riders had yearly household incomes under $25,000 than non-riders (43.4% of transit riders compared to 34.9% of non-riders), though there was no statistical difference in the share with yearly household incomes over $100,000. Several geographic factors were also significantly different between the groups: a higher proportion of transit riders lived in urban areas, occupied buildings with 20 or more units, or had conflict with household members that made it difficult to spend time at home. Transit riders were less likely to have alternative transportation options: 23.5% of transit riders did not have access to a household vehicle, compared to 4.5% of non-riders.

In a separate controlled analysis we estimated a logit model predicting the individual probability of being a transit rider as a function of exogenous demographic characteristics. In that model (Appendix 1), living in an urban area, living in an apartment building with over 20 units, experiencing a decreased income since the pandemic, and being a person of color were all associated with a higher likelihood of being a transit rider. For people of color, the odds of being a transit rider are 1.8 times larger than the odds for non-Hispanic white people, controlling for other factors, and people who had a reduced income since the beginning of the pandemic had 1.6 times larger odds of being a transit rider than others. These results underscore the extent to which transit riders are among the most historically burdened and economically threatened individuals in the U.S.

Transit riders in the U.S. have been disproportionately affected due to the pandemic (Sheller, 2020). Transit riders may be concerned about using transit due to concerns about COVID-19 transmission; may be affected by transit service changes; and may have changes in activity timing and personal characteristics making transit a less viable transportation option after the start of the COVID-19 pandemic.

In our sample, 531 respondents were classified as transit riders (42%). A significant portion were affected by transit service changes: 48.5 percent of transit riders stated that they had been affected by transit cuts in the August wave of the survey. In the August survey, 231 respondents reported that they had used transit in the previous seven days. Of these, over half (58%) reported they had been affected by transit cuts. Another concern is infection risk related to the pandemic: only 14.7% of transit riders said they were already comfortable taking transit during the pandemic. Travel behavior changes, and the implications of both of these factors when it comes to travel behavior, are discussed in Section 6.

5. How does the travel behavior of transit riders compare to that of non-riders?

Next we examined how travel patterns differ between transit riders and non-riders, before and after the start of the pandemic. March 15 was selected as the cutoff date, because this was the end of the week in which COVID-19 was declared a global pandemic, and the start of a large number of U.S. states adopting stay-at-home orders. We graphed week-by-week averages for the number of trips and distance traveled for a 12-month period, comparing transit riders to non-riders (Fig. 1). The
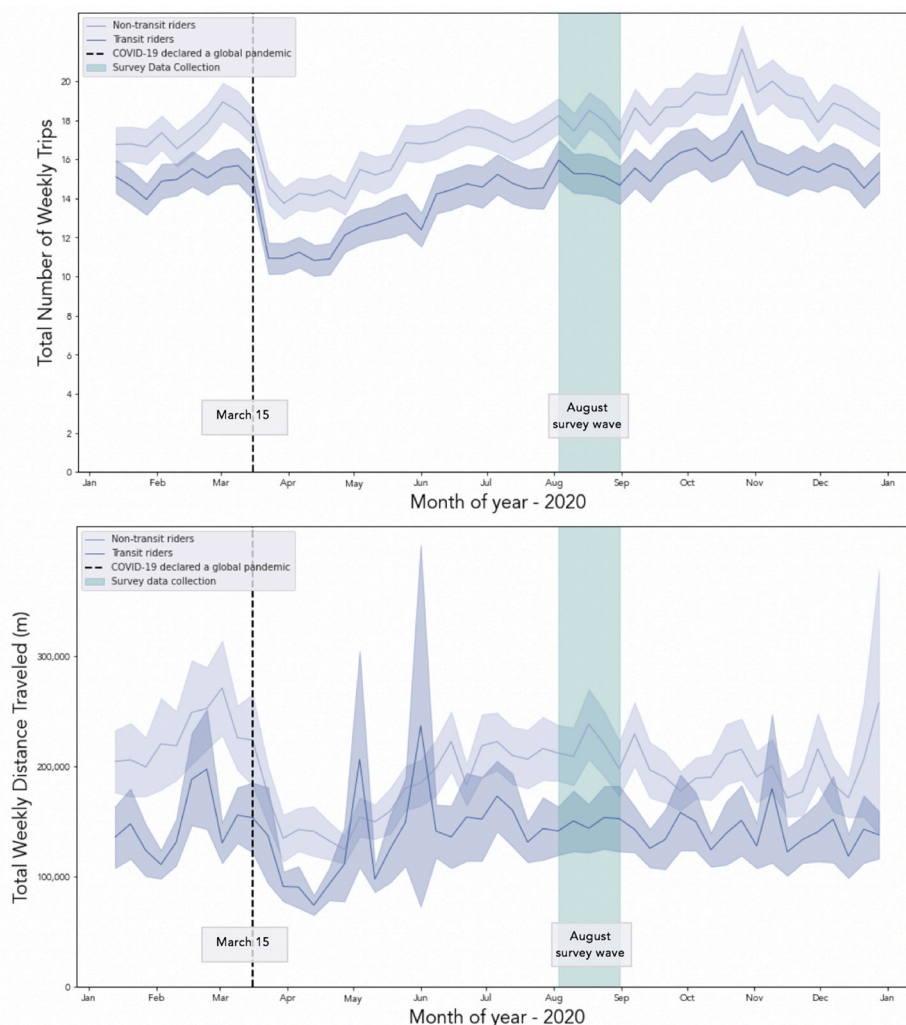

Fig. 1. Number of weekly trips and distance traveled by transit riders and non-transit riders.

weekly trip graph shows a steep reduction in the number of total trips for both sets of respondents in March, with a slightly larger difference between groups after the pandemic. Mid-year, in approximately August, weekly trip numbers rose for both groups above their respective levels pre-pandemic. The total *distance* traveled, which has much more variability, does not drop as much for transit riders than non-riders after the pandemic, perhaps related to the lower baseline level of non-riders.

The average number of weekly trips per respondent before the pandemic was similar to the average number of weekly trips respondents took through the rest of the year (Table 2). This is likely due to the increase of activity in the second half of the year, in which travel returned to previous levels. Transit riders' average weekly number of trips and total weekly distance traveled, as well as average weekly distance traveled, all were lower than non-riders', both before and after the pandemic.

Note that our sample over-represents lower-income transit riders. As we discuss below, this is the likely explanation for the fact that in our sample transit rider daily travel had largely returned to pre-pandemic levels by the end of 2020 despite the fact that evidence from U.S. transit systems generally shows a reduced level of ridership in the present day compared to pre-pandemic ridership levels.

6. How did transit riders modify their behavior during the pandemic and why?

Unlike the mobility data, which give us total trips and distances but no further details, the survey data provide insight into potential modal substitution. Of transit riders, 74.5% reported taking transit less since the pandemic, likely due to a combination of being affected by transit service changes and concerns about infection risk on public transit due to the pandemic, along with trip reductions due to the pandemic. In fact, only 8.7% of riders in our sample reported that they were comfortable using transit during the pandemic and were not affected by transit service reductions. Table 3 demonstrates the concerns of transit riders: 85.3% expressed concerns over the risk of infection on transit, reporting that one or more safety factors would encourage their increased use of transit. Forty-three percent of transit riders in our sample reported that they took transit less frequently due to infection risk and were also being affected by transit service reductions. (We defined "affected by transit service reductions" as self-reporting that transit cuts were a minor or significant issue, or that a return to regular service levels would encourage their increased use of transit.)

It would appear that the impacts of both service cuts and concerns over possible COVID-19 infection resulted in the differences in travel behavior found in the smartphone GPS data. Survey data bear out this hypothesis. Almost exactly half of transit riders reported a modal shift in their travel behavior, compared to only 32 percent of non-riders (difference significant at $p < 0.001$). We define a "modal shift" as reporting more walking, biking, driving, or ridesharing since the start of the pandemic in March, or making a car or bicycle purchase in that period of

Table 2
Travel behavior in 2020 before and after March 15 by transit rider status.

	Before March 15 (January – March 15, 2020)		After March 15 (March 15 – December 31, 2020)	
	Non-transit rider	Transit rider	Non-transit rider	Transit rider
Weekly number of trips	15.9	13.8**	16.2	12.7***
Weekly total distance (km)	198.8	135.3***	177.1	115.1***
Weekly average distance (km)	12.1	8.8**	10.7	8.4**

*p < 0.05 **p < 0.01 ***p < 0.001 (compared to non-transit riders) – 2-way *t*-test.

Table 3
Transit riders affected by transit service reductions and COVID-19 concerns.

	Affected by transit service reductions	Not affected by transit service reductions
Concern over COVID-19 infection risk	42.5% (n = 225)	42.8% (n = 227)
Already comfortable using transit	6.0% (n = 32)	8.7% (n = 46)

Total *n* = 530.

time.

A much smaller proportion of transit riders reported that their use of most modes remained the same as it was prior to the start of the pandemic compared to non-transit riders, as shown in Fig. 2. A smaller proportion of transit riders said their driving frequency, biking frequency, ridesharing behavior, and carpooling behavior remained the same as prior to the pandemic than non-riders. This signals a larger disruption in travel behavior for transit riders.

7. Controlling for other factors, how did being a transit rider affect people's travel activity?

This section examines the impact of the COVID-19 pandemic on the travel of transit riders as measured by total trips, total distance traveled, and average distance traveled, when controlling for other factors. Above we established that travel patterns, as measured by GPS traces and, particularly, survey-reported shifts in travel behavior, were statistically different for transit riders compared to non-riders. But it is unclear to what extent this may have been due to underlying demographic differences between the two populations, such as income, race/ethnicity, and household life cycle (e.g. presence of children).

We first show the results of a negative binomial regression on panel data in which the dependent variable was the number of weekly trips, measured multiple times for the same respondents over the course of the year (Table 4). This panel data model allows us to account for changing travel behavior over time (by week) for each respondent. Regional fixed effects are used to control for the differences in travel behavior across geographies in the United States (using U.S. Census-defined regions), and two time-trend variables are used, to control for the period leading up to March 15, and the period since March 15. Exponentiated coefficients (incidence risk ratios) are shown. Significant coefficients less than 1 represent a negative correlation, and significant coefficients more than 1, a positive correlation.

In a parsimonious model, transit riders did not make fewer weekly trips prior to the pandemic, but did through the rest of the year following the start of the pandemic (Table 4, column 1). These results are very similar when controlling for demographic and other characteristics (Table 4, column 2). In the controlled model, after March 15, the average panel member made about 77 percent as many trips as prior to the pandemic, but transit riders made about 83 percent of that total (that is, a *further* reduction of about 17 percent). Age, having a high household income, living in an urban area, being an essential worker, and having increased travel to work since the beginning of the pandemic are all associated with a larger number of trips. The time trend coefficients indicate an increasing trend in trips up to March 15, and an increasing trend since the reduction occurring around March 15. Caring for an elderly or disabled person, having a child at home, and being a person of color were associated with fewer trips.

Because the coefficient estimates are from a nonlinear regression model, a better way to understand the size of the pandemic effect upon transit riders in comparison to non-riders is to look at predicted estimates using the model when holding control variables at their means. Fig. 3 shows the predicted number of weekly trips for transit riders and non-riders. Holding other characteristics constant, non-riders took five fewer weekly trips on average after the onset of the pandemic and
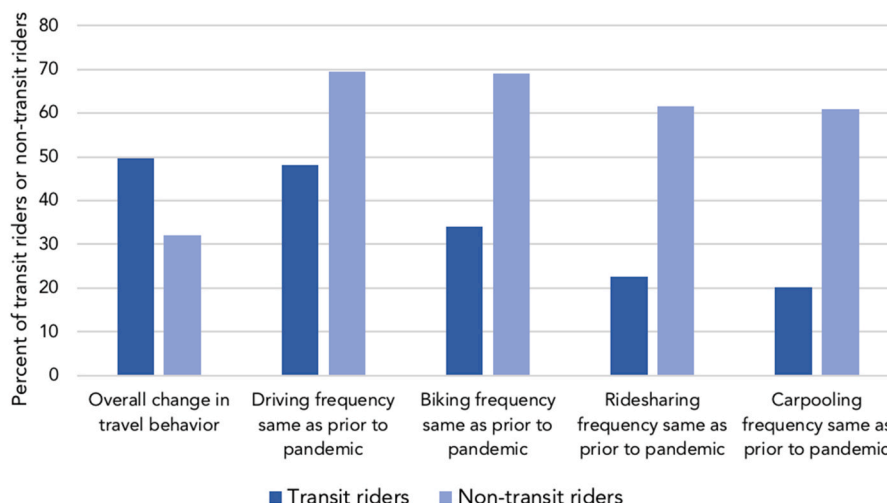
Fig. 2. Travel behavior compared to prior to the pandemic by transit rider status.

Table 4
Weekly trips regressed upon transit rider status and controls (negative binomial regression, exponentiated coefficients).

	(1)	(2)
	Weekly visits	Weekly visits
Transit riders, pre-March 15	0.953	0.981
After March 15	0.966***	0.768***
Transit riders, after March 15	0.829***	0.829***
Age		1.003***
Caring for an Elderly or Disabled Person		0.875***
Household income over $100,000		1.266***
Children at home		0.935**
Living in a building with 20+ units		0.954
Urban area		1.172***
Essential worker		1.402***
Increased travel to work since beginning of the pandemic		1.177***
Person of Color		0.896***
Region: Midwest		1.008
Region: South		1.037
Region: West		1.015
Before March 15 weeks (time trend)		1.007**
After March 15 weeks (time trend)		1.009***
n	33,028	33,028

Incidence Risk Ratio (exponentiated).
*p < 0.05 **p < 0.01 ***p < 0.001.

through the end of 2020, while transit riders took eight fewer weekly trips after the onset of the pandemic and through the end of the year. In other words, transit riders reduced their travel by about 50 percent more than non-riders. This is a significant result, representing nearly 20 percent of average weekly post-pandemic onset trip making.

Total and average distances traveled were also reduced after the onset of the pandemic, as expected. Table 5 shows Tobit regressions of total and average distance traveled over time, by week for each respondent. In uncontrolled models, transit riders traveled shorter distances both during and after the start of the pandemic (Table 5, columns 3 and 5). When controlling for demographic characteristics, being a transit rider was associated with a lower total and average weekly distance only *after* March 15 (Table 5, columns 4 and 6). Characteristics related to a greater total weekly distance traveled include being an essential worker, being in the Midwest, South, or West (compared to the East), and the post-March 15 time trend. Living in an urban area is associated with a shorter average weekly distance traveled, while being

an essential worker and being in the Midwest are associated with a greater average weekly distance traveled.

One additional factor to note is vehicle access. We used a modified version in our survey of the household vehicle access question from the National Household Travel Survey, requesting the number of cars available for use by members of the household. Twenty four percent of transit riders did not have access to a household vehicle, in comparison to five percent of non-transit riders. This shows that a significant proportion of transit riders do have access to a household vehicle, though may not have consistent access due to the number of people in their household. (Though we do not include vehicle access as an independent variable in the models shown because it is an endogenous variable, it did not have a significant impact in models not shown that included it.)

8. Among transit riders, who changed travel activity the most?

We have seen that weekly trips and distance traveled decreased more for transit riders than for non-riders after the onset of the COVID-19 pandemic. We used similar models to those above, restricted only to transit riders, to examine how weekly trips (Table 6) and total and average distance traveled (Table 7) were affected by the pandemic for different subsets of transit riders. We focused on two demographic characteristics that often correlate with transportation disadvantage in the United States and are significantly more common among transit riders in our sample, namely being a person of color and having a low household income (under $25,000). These two characteristics were each interacted with the after-March 15 time period variable in each regression, controlling for other demographic characteristics.

The first model was a negative binomial regression examining the relationship between being a person of color and number of weekly visits before and after the start of the pandemic (among transit riders). We found that people of color did not take a different number of weekly trips than other transit riders prior to the pandemic, but they took somewhat fewer weekly trips after the onset of the pandemic and through the end of 2020 than non-Hispanic white respondents, with an odds ratio of 0.93 (Table 6, column 1). Interestingly, we see the opposite result when focusing on transit riders with household incomes under $25,000 in comparison to other transit riders: low-income riders took fewer weekly trips pre-pandemic, and but did not decrease their weekly trips after the start of the pandemic as much as transit riders with household incomes over $25,000 did, with an odds ratio of 1.14 (Table 6, column 2).

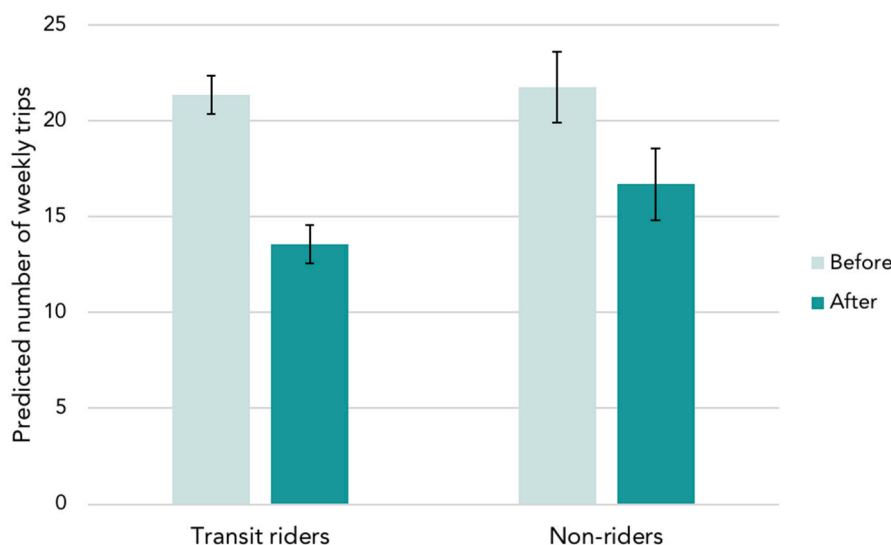Looking at the total and average distances traveled, transit riders

Fig. 3. Predicted number of trips by transit rider status and time period (other values held at means).

Table 5
Total and average distance traveled, in kilometers, regressed on transit rider status and controls (Tobit regression).

	(3) Total distance (ln)	(4) Total distance (ln)	(5) Average distance (ln)	(6) Average distance (ln)
Transit riders, pre-March 15	−0.389**	−0.156	−0.334**	−0.180
After March 15	−0.384***	−0.557***	−0.358***	−0.293**
Transit riders, after March 15	−0.370***	−0.379***	−0.192*	−0.197*
Living in a building with 20+ units		−0.348*		−0.162
Urban area		−0.341		−0.286*
Essential worker		0.886***		0.595***
Region: Midwest		0.710***		0.517***
Region: South		0.404*		0.246
Region: West		0.363*		0.215
Before March 15 weeks (time trend)		0.0113		0.00378
After March 15 weeks (time trend)		0.00803***		−0.00124
constant	11.14***	10.65***	8.588***	8.341***
sigma_u	1.836***	1.750***	1.447***	1.392***
sigma_e	2.631***	2.630***	2.466***	2.466***
n	26,327	26,327	26,327	26,327

$*p < 0.05 \;**p < 0.01 \;***p < 0.001.$

Table 6
Weekly trips for transit riders regressed upon controls (negative binomial regression, exponentiated coefficients).

	(1) Weekly visits	(2) Weekly visits
Person of color, pre-March 15	0.982	
Household income under $25,000, pre-March 15		0.770***
After March 15	0.631***	0.578***
Person of color, after March 15	0.932**	
Household income under $25,000, after March 15		1.140***
Age	1.002	1.002
Caring for an Elderly or Disabled Person	0.858***	0.863***
Children at home	0.948	0.945
Urban area	1.494***	1.485***
Essential worker	1.245***	1.252***
Increased travel to work since beginning of the pandemic	1.348***	1.335***
Household income under $25,000	0.859***	
Person of color		0.925*
Region: Midwest	1.289***	1.287***
Region: South	1.282***	1.276***
Region: West	1.105*	1.105*
Before March 15 weeks (time trend)	0.998	0.997
After March 15 weeks (time trend)	1.009***	1.009***
n	33,028	33,028

Incidence Risk Ratio (exponentiated).
$*p < 0.05 \;**p < 0.01 \;***p < 0.001.$

who were people of color did not see a different change in their travel than that of other transit riders. Transit riders with lower incomes traveled shorter distances than other transit riders before COVID-19, but did not show a difference after the onset of the pandemic.

These two results indicate that a different dynamic is occurring for low-income transit riders than for other riders. Possible explanations include an increase in use of transit by lower-income riders due to free-fare policy changes during the pandemic, or that transit riders with household incomes over $25,000 were able to, and chose to, reduce their travel (even with potential negative welfare repercussions), while lower-income transit riders were not able to. Our survey data reinforces this

hypothesis, as a smaller share of transit riders with low household incomes decreased their travel to work (28.4%) after the start of the pandemic than transit riders with higher incomes (38.2%) (difference significant at $p < 0.05$). Eighty percent of low-income riders indicated that they would take transit more if certain safety measures would be taken on transit, compared to 88.7% of other riders (difference significant at $p < 0.01$), indicating that more are taking transit regardless of other concerns.

Another important consideration when discussing mode substitution is vehicle access. A smaller percentage of transit riders had access to a household vehicle (76.5%) than non-transit riders (95.5%) (difference significant at $p < 0.001$). Among transit riders, there were discrepancies in access to household vehicles by income but not by race (broadly defined). Twenty-five percent of transit riders who were people of color did not have access to a household vehicle, compared to 25.1% of transit

Table 7
Total and average distance traveled for transit riders, in kilometers, regressed on controls (Tobit regression).

	(3)	(4)	(5)	(6)
	Total distance (ln)	Total distance (ln)	Average distance (ln)	Average distance (ln)
Person of color, pre-March 15	−0.202		−0.148	
Household income under $25,000, pre-March 15		−0.698**		−0.443*
After March 15	−1.087***	−0.984***	−0.646**	−0.439*
Person of color, after March 15	0.262		0.328*	
Household income under $25,000, after March 15		0.142		−0.0346
Person of color		0.0179		0.128
Household income under $25,000	−0.582**		−0.474**	
Living in a building with 20+ units	−0.303	−0.304	−0.203	−0.202
Urban area	−0.0109	−0.0133	−0.0694	−0.0724
Essential worker	0.880***	0.878***	0.611***	0.612***
Region: Midwest	0.947***	0.950***	0.662**	0.670**
Region: South	0.577*	0.580*	0.439*	0.446*
Region: West	0.481*	0.487*	0.307	0.317
Before March 15 weeks (time trend)	0.00609	0.00549	0.00740	0.00681
After March 15 weeks (time trend)	0.00694*	0.00700*	−0.00171	−0.00165
constant	10.46***	10.37***	8.128***	7.946***
sigma_u	1.782***	1.782***	1.451***	1.451***
sigma_e	2.800***	2.800***	2.627***	2.627***
n	11,474	11,474	11,474	11,474

*$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

riders who were not people of color (difference not significant at $p < 0.01$). Thirty-six percent of transit riders with household incomes under $25,000/year did not have access to a household vehicle, while 16.1% of transit riders with household incomes above $25,000/year did not have access to a household vehicle (difference significant at $p < 0.01$). This has implications for the differential impacts that different groups of transit riders faced during the pandemic.

9. Conclusions and policy takeaways

COVID-19 has affected people's travel behavior across the United States in countless ways. Many transit systems have seen lower fare revenues and have reduced service levels in response to the pandemic. Transit riders affected by these decisions have faced compounding impacts, both directly from the pandemic and from transit service changes, as well as concerns about taking shared transport during the pandemic due to infection risk. This analysis demonstrates the significant disruption in people's lives, revealed through both mode substitutions and a reduction in weekly trips. Using a combination of survey and passive mobile phone GPS data, this study finds that in the United States, transit riders' travel behavior has been more affected in the post-COVID-19 time period than that of non-riders. Despite attempts to use other modes, they had on average a greater reduction in weekly trips than non-transit riders. Controlling for other characteristics, transit riders took on average three fewer weekly trips after the onset of COVID-19 in 2020 than non-transit riders, representing a 20 percent reduction of the post-pandemic weekly average. This difference is significant even after controlling for demographic characteristics; people of color, people living in urban areas, and people with a low income were more likely to be transit riders. Among transit riders, lower-income riders did not

reduce their travel as much as other transit riders, indicating a bifurcation between lower-income riders, with somewhat inelastic demand for travel, and other riders, whose travel was more affected by hesitations to use transit at this time.

9.1. A return to transit

What might encourage a return to transit? A survey conducted in Canada in May 2020 found that commuters planned to use mass transit less and cars more due to COVID-19, and more frequent sanitation and hand washing were likely to reduce the decline in use of mass transit (Labonté-LeMoyne et al., 2020). Other research suggests that measures to reduce crowding will be essential to restoring the perceptions of the service (Tirachini and Cats, 2020).

We asked our respondents, "Which of the following measures would increase your use of transit (including bus, subway, train, etc.)?" The most important factors listed (detailed in Appendix 2) were increased sanitation/cleaning, the widespread use of face masks, an effective COVID-19 treatment or vaccine, a reduction of COVID-19 rates, and reduced crowding. These factors appeared to take greater priority than the return to regular service levels, indicating that while service levels are important to those affected by them, other developments and initiatives may be necessary for broader returns to transit use. Fifteen percent of transit riders said they were already comfortable taking transit.

9.2. Policy implications

This study shows there are significant equity implications of impacts to transit in the United States in the COVID-19 time period. People with lower incomes or decreased incomes due to the pandemic, people of color, and people living in urban areas and apartments are more likely to be transit riders. Transit riders had significant impacts to their travel behavior, as measured in mobile phone GPS data as well as in self-reported survey data on changes of mode and purchases of cars and bicycles. This research affirms the importance of protecting transit services for those who need them, with a focus on transit riders in the United States (Sheller, 2020; Blumenberg and Thomas, 2014). When the transportation impacts of the COVID-19 pandemic fall upon already disadvantaged members of society (who are affected by the COVID-19 pandemic to a greater extent than other population groups), the impacts of these policy decisions become an even more concerning social justice issue.

Transit riders' behavior changes are likely related to a combination of being affected by transit service changes and concerns about infection risk in public transit due to the pandemic. Transit providers can respond to both of these factors, by providing additional levels of service and by instituting clear safety measures and related messaging. Nearly two-thirds of transit riders reported that transit agency responses could increase their use of transit, and only 15% of transit riders reported being already comfortable with using transit. Lower-income transit riders did not reduce their travel as much as other transit riders did, even when having similar concerns and experiencing similar impacts. This indicates that a significant population of severely disadvantaged riders have continued to rely on public transit service. Increasing rider comfort, and increasing transit service levels, would be a boon to both transit ridership and the mobility and related welfare of a disadvantaged class in the United States.

9.3. Limitations

There are several limitations related to our analysis. Our sample has a higher proportion of lower-income respondents than the population at large. The overrepresentation of lower-income people in some ways is an advantage, as it means we also have an over sampling of transit riders. However, we may have an underrepresentation of choice riders. The

survey response rate is low, at 19%, though similar to many travel behavior surveys. Another limitation is our limited controls for neighborhood-scale built environment factors. Due to data constraints and the breadth of our survey respondent locations, we were unable to control for the built environment at a smaller scale than our urban, regional, and housing type variables.

9.4. Future research

This research opens the door to several areas of future work. First, methodologically it is useful to be able to examine both rider characteristics as well as their mobility data, and there is an opportunity for further research using a combination of passive GPS data in combination with survey data. Second, the significant population of transit riders who are hesitant to return to transit, despite facing less mobility as a result, highlights the need for understanding effective strategies, both in operations and messaging, to bring riders back to transit. Third, this research only highlights the overall lack of mobility among populations, and not the details and tradeoffs transit riders at different income levels are making. More detailed, qualitative or ethnographic work would be useful to help understand the patterns we are seeing among the most vulnerable U.S. travelers.

Author contributions

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Appendix 1. Probability of being a transit rider as a function of demographic characteristics (logit model, exponentiated coefficients)

	Transit riders
Caring for an elderly or disabled person	1.118
Household income under $25,000	1.326
Household income over $100,000	0.847
Living in a building with 20+ units	1.880**
Urban area	2.565***
Employed in last 12 months	0.951
Young children at home	0.760
Person of color^	1.845***
Conservative	0.855
Decreased income since beginning of the pandemic	1.602**
Female	0.817
n	917

Odds Ratio (exponentiated).
*p < 0.05 **p < 0.01 ***p < 0.001.
Note: n is smaller than total sample due to non-response on certain questions.

Appendix 2. Factors that would encourage increased use of transit (transit riders only)

Increased sanitation/cleaning	44.3%
Widespread use of face masks	44.8%
Effective COVID-19 treatment or vaccine	38.8%
Reduction of COVID-19 rates in area	36.7%
Reduced crowding	36.6%
Return to regular service levels/schedule frequency	21.1%
I am already comfortable using transit	14.7%
None of the above	12.4%

Note: Respondents were asked to select all that applied, so percentages do not sum to 100.

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