THE IMPACT OF COVID-19 ON FUTURE PUBLIC TRANSPORT USE IN SCOTLAND

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Abstract This paper examines the determinants of changes in future public transport use in Scotland after the COVID-19 pandemic. An online questionnaire was distributed to 994 Scottish residents in order to identify travel habits, attitudes and preferences during the different phases of the COVID-19 outbreak and travel intentions after the pandemic. Quota constraints were enforced for age, gender and household income to ensure the sample was representative of the Scottish population. The respondents indicated that they anticipated they would make less use of buses and trains at the end of the pandemic. Over a third expect to use buses (36%) and trains (34%) less, whilst a quarter expect to drive their cars more. As part of the analysis, a random parameter bivariate probit model with heterogeneity in the means of random parameters was estimated to provide insights into the socio-demographic, behavioural and perceptual factors which might affect future public transport usage. The inclusion of random parameters allows for the potential effects of unobserved heterogeneity within the independent variables to be captured, whilst making allowances for heterogeneity in the means of the random parameters. The model estimation showed that several factors, including: pre-lockdown travel choices, perceived risk of COVID-19 infection, household size and region, significantly affected intended future use of public transport. In addition, several variables related to age, region, pre-lockdown travel choices and employment status resulted in random parameters. The current paper contributes to our understanding of the potential loss of demand for public transport and the consequences for future equitable and sustainable mobility. Our findings are highly relevant for transport policy when developing measures to strengthen the resilience of the public transport system during and after the pandemic.

Keywords: public transport, COVID-19, travel intentions, random parameters, bivariate probit

1. INTRODUCTION AND BACKGROUND

COVID-19 was declared a pandemic by the World Health Organisation (WHO) in March 2020. The UK and the Scottish Governments initially responded to the threat of COVID-19 by imposing a ‘lockdown’ to restrict everyday life activities to the essential minimum. Individuals’ decisions to limit their travel, in order to reduce their own exposure to COVID-19, along with the implications of the Government imposed lockdown significantly affected transport and travel patterns. There was, for example, a dramatic decrease in vehicular activity (Transport Scotland, 2021a) and many more employees started working from home (Office for National Statistics, 2020). Prior to the pandemic there were 96.4 million Scottish passenger journeys by rail and 379 million journeys by bus per year (Transport Scotland, 2021b). During the first national lockdown imposed on 24th March 2020 Scottish commercial bus travel fell by 85% and Scottish rail travel fell by 92% (Transport Scotland, 2021a).

Although circumstances vary, from country to country, large reductions in public transport use, during the pandemic, have been reported elsewhere. In Hong Kong during the early stage of the COVID-19 pandemic, 40% of survey respondents reported that they would avoiding public transport as a preventative measure (Kwok et al., 2020). A study conducted in Turkey concluded that avoidance of public transport was among the most adopted preventative behaviour during COVID-19 (Yıldırım et al., 2021). Similarly, in Sweden where the public was asked to work at home if possible and only use public transport if it was necessary, research (Jenelius and Cebecauer, 2020) found a 60% reduction in public transport trips in Stockholm and a 40% reduction in Västra Götaland. In Budapest, Hungary, when COVID-19 travel restrictions were introduced car usage increased from 43% to 65% and public transport usage fell from 43% to 18% (Bucsky, 2020).

A limited number of studies have considered factors that influence mode choice during the pandemic. Abdullah et al., (2020) have found that socio-demographic factors such as gender, car ownership, employment and travel habits (e.g., travel distance) were significant predictors of mode choice during the COVID-19 pandemic. Tan and Ma, (2021) developed a logistic regression model to analyse survey data from China to show how occupation type, commuting modes used before the pandemic, walking time to the nearest subway station, the possibility of being infected in cars and in public transport all influence the commuters' travel choices. In a UK study, Marsden et al., (2021) found that those who continued to travel by bus during the pandemic were to a large extent, a captive market with 60% of bus users agreeing that they had no choice but to use the bus for some journeys. Recent studies (Fountas et al., 2021; Semple et al., 2021) showed that the COVID-19 commuting behaviour and outdoor exercise trips in Scotland were significantly influenced by a variety of socioeconomic factors, linked to occupation type, and demographic factors, including, disability, gender, ethnic background and region of residence.

Many researchers have explored the relationship between the perceptions of risk, associated with COVID-19, and changes in travel behavior. It was found that concerns regarding the perceived risk of COVID-19 were associated with increases in the probability of staying at home and the probability of reducing trip frequencies (Hotle et al., 2020; Neuburger and Egger, 2021; Parady et al., 2020). A survey conducted by Transport Scotland, (2021a) during the first 6 months of the pandemic found high levels of concern (64% either very or fairly concerned) about contracting the virus on buses and trains. In fact, evidence from epidemiological and modelling studies associate public transport use with transmission of respiratory infections (Hayward et al., 2020; Troko et al., 2011; Zhao et al., 2020). However, research has found that public transport use was not robustly associated with COVID-19 mortality and there is little evidence linking major COVID-19 outbreaks to buses or trains when everyone was wearing masks (Scannell Bryan et al., 2021; Tirachini and Cats, 2020).

Ozbilen et al., (2021) and Shamshiripour et al., (2020) concluded that individuals find shared modes riskier compared to non-shared modes when it comes to COVID-19 exposure and car users are more likely to view shared modes as riskier compared to their car. Others have reported on precautionary behaviour in response to a perceived pandemic threat, with significant reduced travel by modes appraised as being the riskiest (Barbieri et al., 2021; Tan and Ma, 2021). Tirachini and Cats, (2020) have suggested that reduced public transport use since the onset of COVID-19 has been exacerbated by the perception of public transportation as riskier than private or personal means of transport because of the closer contact to other people that is possible, sometimes unavoidable, in public transportation vehicles and stations.

In April 2021, during the second national lockdown, the Scottish Government (Transport Scotland, 2021c) undertook a survey which indicated that concerns about using public transport were high with 72% saying they were concerned about people contracting or spreading the virus while using public transport. As restrictions associated with the second national lockdown were eased, bus and rail use returned to 50% and 30% of their 2019 levels, respectively, while weekly car usage was at 90% of the equivalent 2019 levels (Transport Scotland, 2021c).

There remains uncertainty about the extent to which temporary changes in travel demand and behavior, brought about by COVID-19, will continue into the future. The Transport Scotland COVID-19 Public Attitudes Survey (Transport Scotland, 2021c), conducted in April 2021, found that 45% of respondents agreed with the statement “I will avoid public transport and use my car or other vehicle more than I did before when restrictions on transport are lifted”. The main reasons given for avoiding public transport in rank order were as follows: the risk that others are still carrying the disease; convenience; unable to stay 1m apart; and cleanliness or hygiene on-board public transport. Although two-thirds (65%) of Scottish respondents (Transport Scotland, 2021c) agreed with the statement “I will walk or cycle more’, the potential future shift away from public transport to car usage, may have implications regarding achieving the overall aims outlined in the National Transport Strategy (Transport Scotland, 2020a) about mitigation of climate change impacts and is worthy of further investigation.

In order to examine intentions to use public transport in the future an online travel behaviour questionnaire was developed focusing on daily travel as well as people’s long-term travel habits, attitudes and preferences during the different phases of the pandemic as well as post-pandemic. Specifically, expectations related to the post-pandemic use of bus and train were statistically analysed in order to identify which socio-demographic, behavioural and perceptual factors are associated with a decrease of the demand for public transport. For this purpose, a random parameter bivariate probit model with heterogeneity in the means of the random parameters was estimated. The outcomes of the analysis can provide insights into how COVID-19 will affect travel choices related to public transport in the near future and beyond as well as a better understanding of the potential long-term consequences of COVID-19 on mobility. The findings of the study can assist both the UK and Scottish Governments as well as transport providers in ensuring both the resilience and the efficiency of the public transport systems, particularly when future events may result in major mobility restrictions.

2. METHODOLOGY

2.1. Data collection

The survey was conducted using the online platform, Qualtrics during the second national lockdown, between 3rd February and 17th February 2021. The survey was restricted to Scottish residents and involved the application of quota constraints for age, gender and household income to ensure the sample was representative of the Scottish population.

A managed pilot study was initially conducted on 2nd February 2021 to review the setup, check data quality, questionnaire performance, incidences of potential straight lining, speeding and invalid responses. The median time for survey completion was 17 minutes and the mean time was 21 minutes. A speeding check (measured as half the median pilot survey time) was added which automatically terminated those who were not responding thoughtfully.

The questionnaire received ethical and governance approval from Edinburgh Napier University. In order to comply with UK General Data Protection Regulation, potential survey participants were provided with a privacy notice detailing how their personal data would be used. Informed consent was required before the respondent could participate in the study.

The questionnaire was structured as a series of largely closed-ended items covering the following topics: risk perceptions associated with using different types of transport modes; mode choice (before COVID, during various stages of lockdown and anticipated mode choice in the future); travel related activities (e.g. working from home, online shopping etc.); perceived effectiveness of various measures to reduce the spread of COVID-19 on public transport; and socio-demographic characteristics (age, gender, ethnicity, education qualifications, employment status, household income, car availability, household type and residential location).

2.2. Profile of respondents

A total of 994 responses were collected through the online survey. Consideration was given to how representative the survey sample was to that of those living in Scotland as a whole in terms of socio-demographic characteristics. Figure 2.1 show details of the gender split, age distributions, income distributions and regional distributions of the survey respondents' residences, respectively. The Figure also provide details of the equivalent distribution, for Scotland as a whole, which were derived from Census data obtained from National Records of Scotland, (2020) and Scottish Household Survey (Scottish Government, 2020). The characteristics of the sample were representative of Scotland for gender and residential location. However, there were slightly fewer of those aged '45 years or older' among the survey sample, when compared to the Scottish population. Furthermore, the proportion of households with an income greater than £15,000 per annum was higher than that of the Scottish population. Previous research has indicated that some socio-demographic variables such as age and income might affect a participants' willingness or opportunity to complete online surveys. For example, Millar et al., (2009) found that respondents involved in internet surveys were younger than mail survey respondents and had higher levels of education and higher incomes. Given that our statistical analysis is primarily concerned with differences between groups rather than generalizations about the population as a whole, weighting was not applied to the survey data.

In addition to determining age, gender, income and region, the survey identified ethnicity, educational attainment, employment status and household car ownership. These characteristics are summarised as follows: 96% (n=993) of respondents described their ethnic group as 'white'; over half (56%) of respondents were employed (either part-time of full-time) and 21% were retired at the time of data collection. The remaining 23% were either in education, looking after home, full time carers or unemployed; and over a fifth (21%) of respondents lived in households without access to a car and 29% lived households with two or more cars available.

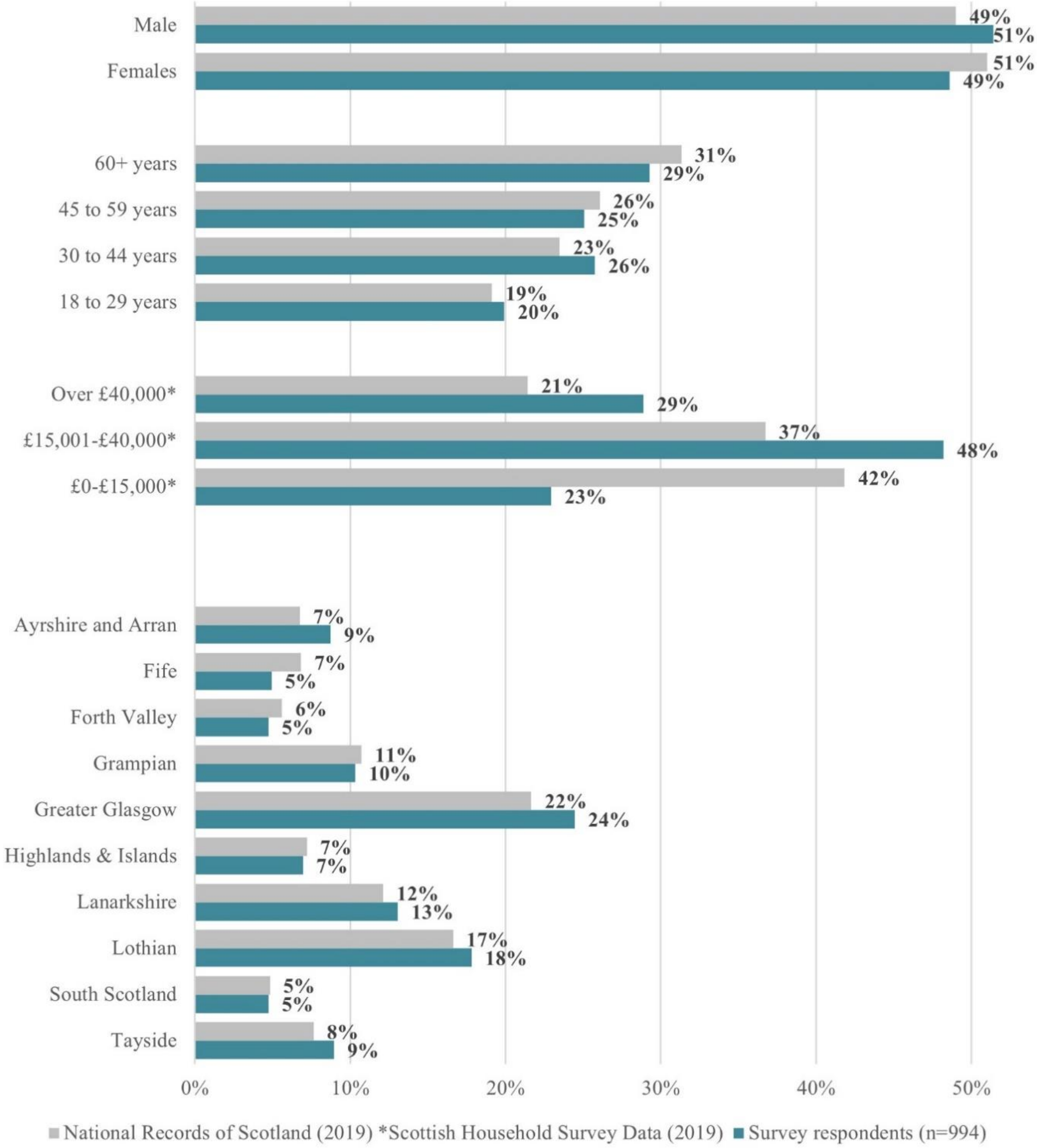

Figure 2. 1 Distribution of survey respondents and Scottish population for gender, age household income and region of Scotland

2.3. Statistical Analysis Methodology

A random parameters bivariate probit model was estimated to examine factors affecting expectations to use public transport in the future. In scenarios where two dependent variables are expected to be interrelated as in the case of the intention of use of two different forms of public transport, bivariate frameworks can account for the possible correlation of the error terms corresponding to these dependent variables (Washington, 2020) .The framework was extended to include random parameters to capture the potential effects of unobserved heterogeneity within the observed independent variables. Past research has shown that the inclusion of random parameters often significantly improves the explanatory power of models (Mannering et al., 2016; Paleti and

Balan, 2019).We also account for heterogeneity in the means of random parameters, which allow additional layers of unobserved heterogeneity to be better understood. The overall approach, referred to as the Random Parameters Bivariate Probit with Heterogeneity in the Means of Random Parameters (RPBPHM), is considered a more comprehensive approach for capturing multi-level nuances of unobserved heterogeneity (compared to the conventional random parameter approaches), as the distributional effects of the random parameters are allowed to vary by mean-specific exogenous factors for both dependent variables ((Seraneeprakarn et al., 2017; Yu et al., 2020), Following the formulation of (Washington, 2020) the bivariate binary probit model can be defined as follows:

$$\Upsilon_{n,1} = \boldsymbol{\beta}_{n,1}\,\mathbf{X}_{n,1} + \varepsilon_{n,1},\ y_{n,1} = 1 \text{ if } \Upsilon_{n,1} > 0, \text{and } y_{n,1} = 0 \text{ otherwise}$$
$$\Upsilon_{n,2} = \boldsymbol{\beta}_{n,2}\,\mathbf{X}_{n,2} + \varepsilon_{n,2},\ y_{n,2} = 1 \text{ if } \Upsilon_{n,2} > 0, \text{and } y_{n,2} = 0 \text{ otherwise.} \quad (1)$$

where values of $\mathbf{X}$ are vectors of independent variables for observation *n*, $\boldsymbol{\beta}$ are vectors of estimable parameters corresponding to $\mathbf{X}$'s, y correspond to the binary outcomes of the dependent variables (i.e., 0 if to use PT the same amount or more in the future and 1 if to use less in the future) and ε's are normally distributed error terms.

In instances where the two binary dependent variables are correlated, the error terms of the univariate probit analysis of each outcome are also correlated. Such correlation is explicitly accounted for in the bivariate probit formulation, with the correlated cross-equation error terms are written as follows:

$$\begin{pmatrix}\varepsilon_{n,1}\\ \varepsilon_{n,2}\end{pmatrix} \sim N[\begin{pmatrix}0\\0\end{pmatrix}, \begin{pmatrix}1 & \rho\\ \rho & 1\end{pmatrix}], \quad (2)$$

where ρ is the coefficient of cross-equation correlation between the error terms that correspond to the two dependent variables of the bivariate model. As discussed previously, unobserved heterogeneity within independent variables can be captured through including random parameters in the modelling framework, while heterogeneity in the means of random parameters is also accounted for, as follows:

$$\boldsymbol{\beta}_i = \beta + \boldsymbol{\lambda}\boldsymbol{\Theta}_{\mathrm{i}} + \boldsymbol{\delta}_{\boldsymbol{i}}, \quad (3)$$

where β is the mean for a given random parameter i, $\boldsymbol{\Theta}$ is a vector of independent variables that affect the mean of $\boldsymbol{\beta}_i$, $\boldsymbol{\lambda}$ is a vector of estimable parameters relating to $\boldsymbol{\Theta}_{\mathrm{i}}$, and $\boldsymbol{\delta}_{\boldsymbol{i}}$ is a randomly distributed term with mean=0 and variance=σ^2.

Following model estimation, average marginal effects are computed to show how the probabilities of the binary outcomes change for a one-unit change per independent variable. In addition, statistical tests, such as the Likelihood Ratio Test (LRT), are adopted to assess the statistical power of competing modeling frameworks that were investigated throughout the modelling process, and in particular to statistically justify the inclusion of random parameters and the allowances for heterogeneity in the means of random parameters in the final model.

3. RESULTS AND DISCUSSION

3.1. Introduction

This study has examined travel behaviour, attitudes and perceptions in Scotland after COVID-19 was declared a pandemic. Survey responses were analyzed to understand risk perceptions, anticipated future transport activity after the COVID-19 pandemics and the factors that influence future demand for public transport. Consideration is now given to the findings from the online survey including the factors that were found in the statistical analysis to be associated with the anticipated changes in public transport usage and the policy and planning implications of such anticipated changes.

3.2. Transport Activity Before, During and After the Covid-19 Pandemic

The ‘lockdown’ restrictions imposed by the UK and Scottish Governments resulted in unprecedented numbers of people furloughed or working from home and most out-of-home leisure activities cancelled. The survey responses confirmed that there had been significant reductions in weekly car travel, bus use and train use during lockdown (February 2021), by the respondents, compared to pre-pandemic levels.

Figure 3.1 shows the frequency with which the respondents stated they used cars (as driver and passenger), public transport, cycling and walking before the COVID-19 pandemic (i.e., before 11th March 2020). Prior to the COVID-19 pandemic, on at least three days a week, 60% of respondents walked, 57% drove a household vehicle, 19% travelled as passengers in a household vehicle, 16% travelled on a bus, 7% travelled by train and 6% rode a bicycle.

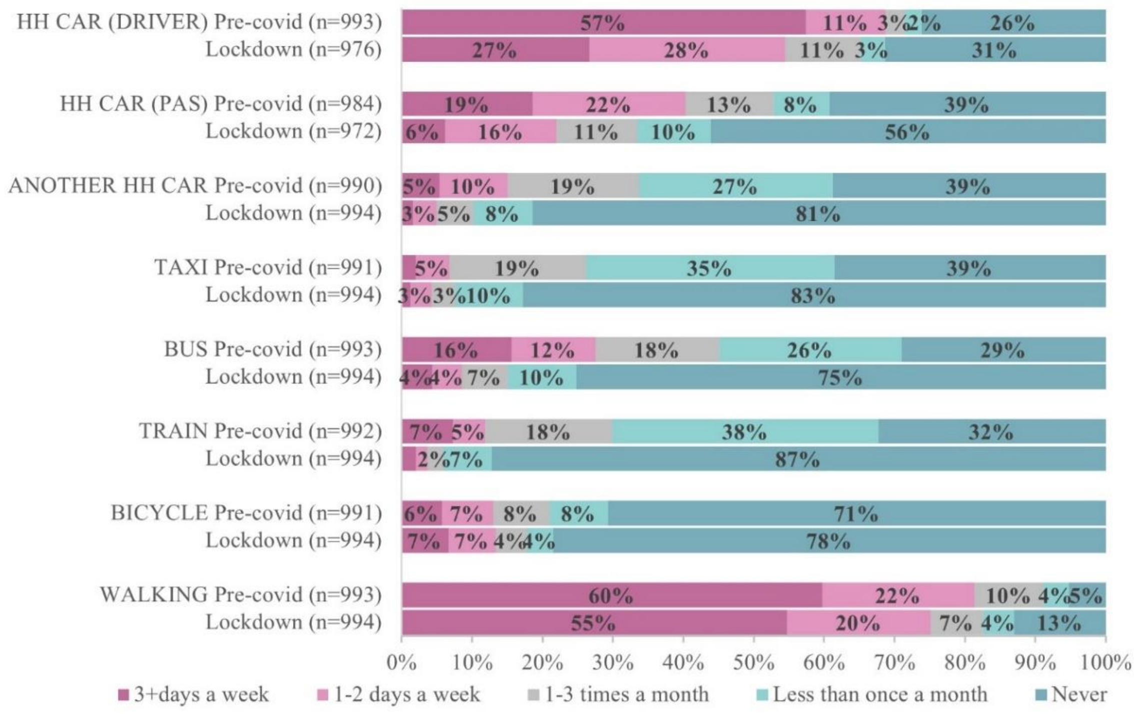

Figure 3. 1 Travel modes pre-COVID and during lockdown 2

Respondents were asked how frequently they used cars (as driver and passenger), public transport, cycling and walked more than half a mile during the second COVID-19 pandemic lockdown (5th January 2021 to 2nd April 2021). It may be seen from Figure 3.1 that there was a slight decrease in those walking over half a mile at least once a week from 81% before the pandemic to 75% during lockdown 2. The percentages for those driving their own cars reduced from 69% to 55%. For those using public transport at least once a week, the proportion travelling by bus fell from 27% to 9% and from 12% to 4% among train users.

With reference to Figure 3.2 it may be seen that the survey responses indicated that, after the COVID-19 pandemic was over (12 to 18 months ahead) when an effective vaccine has been deployed on a large scale, 45% or respondents expected to walk more, 29% expected to cycle more and 25% expected to drive their car more. In contrast, 42% of respondents anticipated flying less, 36% anticipated using buses less and 34% anticipated using trains less. For public transport, there is a larger proportion of respondents who intend to reduce their use when compared to those who anticipate increasing their use. Whereas for car driving, walking and cycling more people think they will increase their use. It should be noted that the sample size was lower for some modes due to respondents selecting either ‘do not know’ or ‘not applicable’.

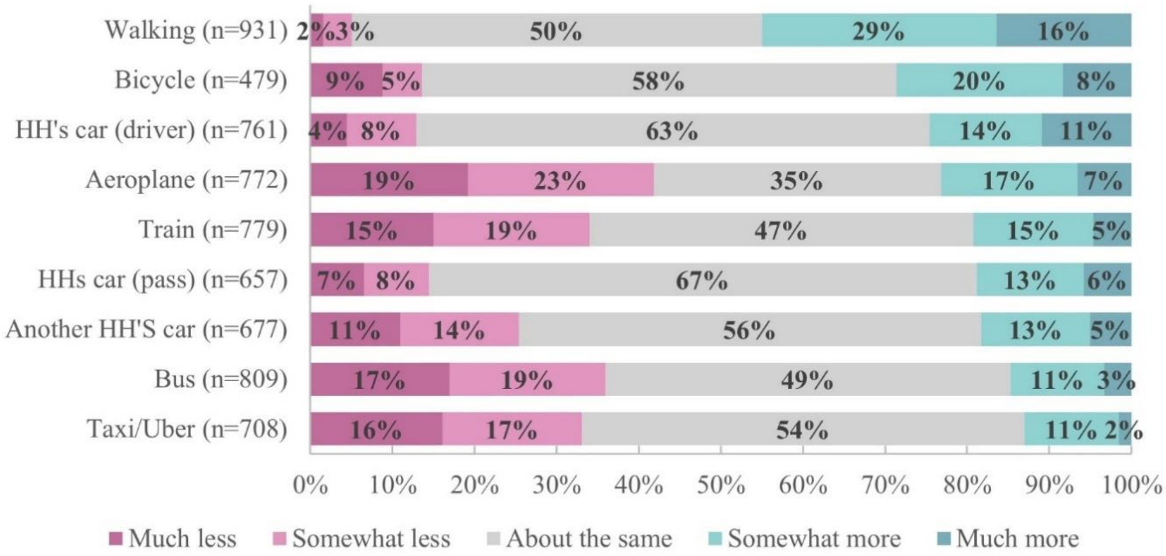

Figure 3. 2 Anticipated future mode usage

3.3. Factors affecting anticipated future transport activity after the COVID-19 pandemic - model estimation results

The current survey responses do suggest that anticipated public transport usage will be less post-pandemic compared with pre-pandemic conditions. Model estimation suggests that this might be associated with a number of socio-demographic, behavioural and perceptual factors.

The dependent variables being jointly modeled in the RPBPHM are derived from the questions reflecting intentions to travel using bus and train in the future less, same, or more. The results of this analysis are shown in Table 3.1 to Table 3.3. Descriptive statistics for the independent variables found to significantly affect future travel intentions are shown in Table 3.2. Details of all the independent variables trialed in the model are provided in the Appendix.

Table 3. 1 Descriptive statistics for dependent variables (travel intentions for bus and train) of the RPBPHM

Variable	0 (respondent intends to use the same or more in the future)	1 (respondent intends to use less in the future)

Future bus travel (n=615)	62.76%	37.24%
Future train travel (n=615)	65.04%	34.96%

Table 3. 2 Descriptive statistics for independent variables found to significantly affect future travel intentions

Variable Category	Definition		Distribution	
	1	0	1	0
Age	18-24	Otherwise	12.52%	87.48%
Unable to work	long-term illness or disabled and unable to work	Otherwise	4.56%	95.44%
Highest education level	Higher (Secondary school qualification), Higher National Certificate or Higher National Diploma (Non-degree tertiary qualification)	Otherwise	36.42%	63.58%
Resides in Central Belt	Lothian/Greater Glasgow/Clyde	Otherwise	44.55%	55.45%
Resides in Lothian	Lothian	Otherwise	19.84%	80.16%
Household size	>= 3 or more	< 3	34.63%	65.37%
PT use prior to COVID-19	>= 1 day per week	< 1 day a week	26.50%	73.50%
Car use prior to COVID-19	>= 3 days per week	< 3 days a week	64.55%	35.45%
COVID-19 bus risk perceptions	High risk	Medium or low risk	61.79%	38.21%
COVID-19 train risk perceptions	High risk	Medium or low risk	52.03%	47.97%
Social media COVID-19 information	Frequent	Otherwise	37.07%	62.93%
Websites or online news pages COVID-19 information	Frequent	Otherwise	58.05%	41.95%

Table 3.3 displays the estimation results of RPBPHM, estimated in NLOGIT 6 (Econometric Software Inc, 2016). The effect of independent variables can be interpreted as follows: independent variables with significantly positive coefficients are associated with less future public transport usage (y=1), whereas independent variables with significantly negative coefficients increase the likelihood of similar, or greater, public transport usage in the future (y=0). Independent variables that result in random parameters are those yielding statistically significant standard deviations of the random parameters' distributions at least at a 90% level of confidence (i.e., |t-stat| >1.65). The normal distribution was considered for fitting the random parameters, as previous research has extensively shown that it provides the most robust statistical fit (Fountas et al., 2019; Washington, 2020). In addition, the average marginal effects allow the change in probabilities for the dependent variable to be gauged, following a one-unit change in each independent variable. The results of the RPBPHM model show that a variety of sociodemographic, behavioural and perceptual factors influence the future public transport travel intentions of Scottish residents.

Table 3. 3 RPBPHM model estimation results and marginal effects for public transport travel intentions

Variable category	**Bus** Coefficient	**Bus** *t*-stat[a]	**Train** Coefficient	**Train** *t*-stat[a]	**Marginal effects on the likelihood of reducing bus use [y=1]**	**Marginal effects on the likelihood of reducing train use [y=1]**
Constant	-0.702	6.60	-0.689	-7.05	-	-
Car use prior to COVID-19	0.365	3.20	0.392	3.38	0.0640	0.0817
COVID-19 bus risk perceptions	0.195	2.59	-	-	0.0312	-
COVID-19 train risk perceptions	-	-	0.225	3.01	-	0.0449
Household size	-	-	-0.196	-2.40	-	-0.0422
Random Parameters						
Age	-	-	-0.213	-1.60	-	-0.0502
Standard deviation of parameter density function	-	-	*0.315*	*2.62*	-	-
Unable to work	-0.580	-1.96	-	-	-0.1364	-
Standard deviation of parameter density function	*0.502*	*2.06*	-	-	-	-
Resides in Lothian	-0.225	-2.29	-	-	-0.0413	-
Standard deviation of parameter density function	*0.302*	*3.41*	-	-	-	-
PT use prior to COVID-19	0.148	1.46	-	-	0.0190	-
Standard deviation of parameter density function	*0.447*	*5.21*	-	-	-	-
Heterogeneity in the mean of RP *the term preceding ":" is the random parameter and the succeeding term is the exogenous influence.*						
Resides in Lothian (Lothian) : Highest Education level (Higher, Non-degree tertiary level)	0.387	2.22	-	-	-	-
PT use prior to COVID-19 (>= 1 day per week) : Social media COVID-19 information (frequent)	0.277	2.01	-	-	-	-
PT use prior to COVID-19 (>= 1 day per week): Resides in Central Belt (Lothian/Greater Glasgow/Clyde)	-0.364	2.42	-	-	-	-
Unable to work (long-term illness or disabled) : Websites or online news pages COVID-19 information (frequent)	0.820	1.75	-	-	-	-
Cross-equation correlation coefficient (t-stat in parentheses)	0.988*(180.50)*					
Number of observations	615					
Halton draws	500					
LL(0)	-762.12					
LL(β_{FP}), fixed parameters bivariate probit model (FPBP)	-561.84					
LL(β_{RP}), random parameters bivariate probit model (RPBP)	-555.48					
LL(β_{RPHM}), random parameters model with heterogeneity in the means of random parameters (RPBPHM)	-548.65					

[a] *Variables with |t-stat| > 1.65 are significant at >90% level of confidence, those with and |t-stat| > 1.96 are significant at >95% level of confidence.*

PT=public transport; RP=Random Parameter; -=not applicable; LL (0)=log-likelihood at zero; LL(β)=log-likelihood at convergence

Likelihood Ratio Test (I): RPBP > FPBP with >95% level of confidence

Likelihood Ratio Test (II): RPBPHM > RPBP with >99% level of confidence

The following factors were found to significantly influence future bus or train travel intentions: car use pre-covid and perceived risk of COVID-19 infection risk of travelling by bus significantly influence future bus travel intention. Number of occupants in the household and perceived risk of COVID-19 infection risk of travelling by train were found to significantly influence future train travel intentions.

Several independent variables, including those aged 18-24, those with a long-term illness or a disability that prevents work, those residing in Lothian (See Figure 3.3), and those who travelled by public transport one or more times per week prior to COVID-19, resulted in statistically significant random parameters. The discovery of multiple random parameters shows highly heterogeneous effects on the future public transport travel intentions of these groups. The distributional effects of the random parameter variables are shown in Table 3.4. The values in the positive effect column show the percentage of observations found to increase the probability of outcome 1 (i.e., the respondent intends to use less in the future) of the dependent variable per each independent variable resulting in a random parameter, while the opposite occurs for the negative effect column.

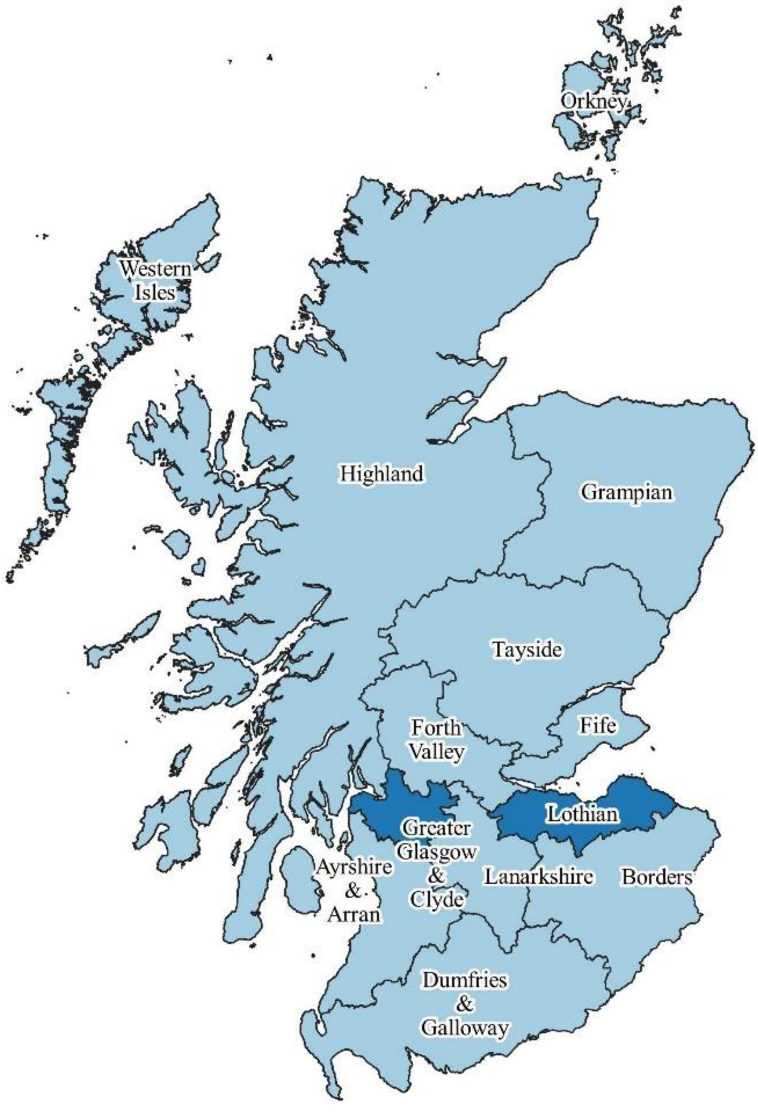

Figure 3. 3 Scottish regions

Table 3. 4 Distributional effects of random parameters

Variable as random parameter	Negative Effect	Positive Effect
Age (1 if 18-24, 0 otherwise) (Train)	75.05%	24.95%
Employment status (1 if long-term illness or disabled and unable to work, 0 otherwise) (Bus)	87.60%	12.40%
Region of Scotland (1 if resides in Lothian, 0 otherwise) (Bus)	77.19%	22.81%
Mode of travel used prior to COVID-19 (1 if public transport at least one day per week, 0 otherwise) (Bus)	37.03%	62.97%

Among the variables yielding random parameters, four instances of heterogeneity in the means of random parameters were found. These were associated with Lothian residents, those who travelled at least one day per week by public transport prior to COVID-19 and those who were unemployed because of a long-term illness or disability.

The statistically significant cross-equation correlation coefficient (as shown in Table 3.3) validates the use of the bivariate framework, as the error terms of both outcomes are shown to be strongly correlated. Furthermore, the statistically significant results of LRT (I) and LRT (II) justify the inclusion of random parameters and heterogeneity in the means of random parameters, respectively.

3.4. Perceptual factors and future public transport usage

The RPBPHM model estimation found that those who perceive bus travel to be high risk, in terms of COVID-19 infection, were significantly less likely than those who think bus travel is not particularly risky (i.e., low or medium risk) to travel by this mode in the future. The RPBPHM model also found that those who perceive train travel to be high risk are significantly more likely to travel less by train in the future. This is in agreement with other research which found that the unconcerned were least likely to reduce their public transport use (Labonte-LeMoyne et al., 2020). Also, Thombre and Agarwal, (2021) found that respondents were willing to pay 1.25 times their pre-covid expenses for safer and more resilient public transport. The RPBPHM model outputs therefore suggest that restoring confidence in the safety of public transportation might contribute to increasing public transport usage in the future to the pre-pandemic levels of patronage. As a consequence, central and local governments in the UK together with transport planners and transport operators might consider implementing or maintaining measures which might address the high-risk perceptions associated with public transport such as hand sanitising, mask-wearing, or physical cleaning of the environment. However, the presence of such measures also has the potential to further increase risk perceptions.

At the time of the survey, three-fifths (63%) of those who intended to use public transport less viewed the possibility of getting COVID-19 infections carried by other passengers as a factor influencing their intentions to travel less by public transport in the future. Respondents also mentioned other factors that would discourage public transport use in the future such as journey times, cost, reliability, timings, and frequency (See Table 3.5).

Table 3. 5 Reasons for using public transport less in the future

Reason	Number of Responses*	Percentage* (n=333)
Possibility of getting infections (e.g., COVID-19) carried by other passengers	210	63%
Lack of cleanliness/hygiene on board public transport	163	49%
Public transport is too crowded	151	45%
I do not like travelling with strangers	72	22%
Public transport is too slow and/or takes too long	71	21%

Reason	Number of Responses*	Percentage* (n=333)
Public transport is too expensive	64	19%
Public transport is unreliable	60	18%
Public transport service not regular enough (infrequent)	50	15%
Public transport is too polluting	49	15%
Public transport is not available for my usual trips	47	14%
Public transport service starts too late or finish too early	36	11%
Health condition - difficult walking to/from the stop, get on and/or off the vehicle	27	8%
Working from home and/or use video conferencing	13	4%
Use other mode (car, cycle, walk)	11	3%
Changed destinations and/or purpose (e.g., changed job, retired, shop locally, moved to a new house ect.)	9	3%

*Multiple Responses; Base=respondents who expect to use buses or trains less often in the future (n=333)

Under normal circumstances deciding what form of transport to use depends on factors such as such as frequency, reliability, convenience, journey time, cost, weather, comfort, health, safety, and environment (Hansson et al., 2019; Redman et al., 2013). Evidence (Thombre and Agarwal, 2021) suggests that the factors influencing travel mode choice are not the same under special circumstances such as a pandemic because the perception of danger outweighs the other generalized cost factors in the utility function of the traditional mode choice model. Our finding from the RPBPHM estimation suggest that factors related to the perceived risk of catching COVID-19 whilst travelling on public transport also needs to be considered as a factor influencing the competitiveness of the public transport journey relative to other modes. Further research could compare the impact of risk perceptions with traditional mode choice factors.

3.5. Behavioural factors and future public transport usage

3.5.1. Pre-pandemic car usage

The RPBPHM analysis found that, those who drove their car frequently (at least three days a week) pre-pandemic were significantly more likely than infrequent car drivers (less than 3 days a week) to anticipate travelling less by bus or train in the future. This highlights the lack of attractiveness of public transport for some car users and the importance of understanding the background to modal choice and measures to discourage car usage.

It has been shown that the availability of a car for a particular journey has a major impact on the mode choice of the traveller. Evidence from the Scottish Household Survey (Barker and Connolly, 2005) found that 21% of trips made by adults from non-car owning households are made by car (as car passengers). This rises to 77% of trips made by adults from households with one car and to 87% for adults from households with two or more cars. Marsden et al., (2021) found that during the pandemic, overall there was no significant changes in average number of cars per household with as many people giving up a car as buying one. Furthermore, they found that around a third of the decisions around car increase, decrease, retention or borrowing were impacted by COVID-19. The pandemic was reported as being more important a factor in reducing car ownership than it has been in increasing it. The authors attribute this to some journeys being replaced by online activities such as teleworking. Of those who increased their car ownership during the pandemic, only 10% cited fear of using public transport as a reason. The survey results (Downey et al., 2021) indicated that there was no significant association between those who anticipate using public transport less often than they did before COVID-19 and intentions to purchase an additional car in the future.

Findings in Germany (Eisenmann et al., 2021) show that one third of individuals in households with no car available missed owning a car during the lockdown. The authors suggest that a great advantage of the car as a mode of individual transport during the pandemic might be that it provides a protected space for the occupants, and there is no need to fear virus infection from unwanted interaction with other people.

Scottish research (Stradling et al., 2000) found that car dependency can be reduced by altering the opportunities for travel (improve availability and accessibility of alternative modes); modifying preferences towards alternative modes (through marketing public transport and de-marketing car); and modifying the lifestyle pattern that generate obligations to travel from current origins to destinations. In the context of the post-COVID-19 public transport recovery, this suggests that in terms of opportunities for travel, the frequency of public transport services is either maintained at pre-pandemic levels or improved. In terms of preferences to alternative modes and COVID-19 public transport recovery, it highlights the importance of changing the perceptions of public transport as risky in terms of spreading/contracting virus (as discussed in Section 3.4).

In terms of lifestyle patterns, the use of digital technology in the workplace, driven by the COVID-19 pandemic, is changing the way we live and work and how companies operate and could reduce the need to travel for commuting purposes. A study into home working found that 44% of Scotland's workforce were working from home in April 2020 compared to 4% in 2019 (Office for National Statistics, 2020). Furthermore, (Transport Scotland, 2021c) found that 36% of people agree that they will work from home more often in the future. Cohen, (2020) has suggested that the digital transformation in business, work and commerce, could have a long-lasting impact by reducing the concentration of economic activity in cities with a reduction in urbanisation and greater use of local transport and local services. Although this could be positive for local services, it could result in reduced or dispersed demand for public transport and hinder a recovery of public transport in terms of passenger numbers. When considering the above it is important to note that, in the current study, utilising the RPBPHM model, working from home was not a significant predictor in anticipated reduction in public transport use.

3.5.2. Pre-pandemic bus usage

The RPBPHM model indicated that pre-pandemic bus use was influential in determining future public transport use. Among frequent bus users (at least one day a week pre-pandemic), two instances of heterogeneity in the means of random parameters were found. These involved respondents' residential location and respondents use of social media. These are considered separately.

Among those who travelled at least one day a week by public transport prior to COVID-19, those who reside in Scotland's Central Belt were found to be significantly more likely than those living in other regions of Scotland to anticipate not decreasing their bus use. The Central Belt covers Lothian, Greater Glasgow and Clyde (shaded dark blue on Figure 3.3) and includes the two largest Scottish urban areas – Glasgow and Edinburgh.

The nature of transport and travel is significantly different in densely populated areas such as Scotland's Central Belt. Findings from the Scottish Household Survey (Transport Scotland, 2020b) show those living in urban areas have lower car ownership than those living in rural areas, are more likely to use public transport and are more satisfied with public transport provision overall. In large, congested urban areas, public transport can be competitive with car travel in terms of costs and journey times. Also, parking can be difficult and costly. Therefore, the RPBPHM findings confirm that bus users experiencing good quality service in urban areas are less likely to abandon public transport post-pandemic.

The RPBPHM model also indicated that among those who travelled at least one day per week by public transport prior to COVID-19, those who frequently use social media as a COVID-19 information source are significantly more likely to travel less by bus in the future, in comparison with respondents who do not frequently use social media. One possible explanation for this finding is that the content of COVID related information shared on social media could contribute to discouraging bus use. During the COVID-19 pandemic social media platforms have enabled the faster and wider dissemination of new information than was possible with traditional news sources. However, there are negative consequences such as the high potential for misinformation to spread. The findings of the current study suggest that social media plays a part in reducing intentions to use buses, in the future, amongst those who were previously frequent users. This suggests that targeted publicity campaigns on social media aimed at restoring public confidence in buses, especially amongst those who frequently used buses prior to the pandemic, has the potential to help restore bus ridership to pre-pandemic levels.

3.6. Social demographic factors and future public transport usage

The RPBPHM analysis found that, those living in the Lothian region, in Scotland, were significantly more likely than those from other regions of Scotland to travel by bus in the future. Lothian region is made up of the four councils areas: East Lothian, Edinburgh, Midlothian and West Lothian. The high bus usage prior to the pandemic in most of the Lothian region and high satisfaction ratings of various aspects of bus operation (Transport Scotland, 2020b) might explain why residents in Lothian are more likely to travel by bus in the future when compared with residents of other Scottish regions.

The RPBPHM model found that those with a long-term illness or disability that prevents them from working are significantly more likely than those in other employment categories (e.g., part/full-time employment, self-employed, retired, student) to anticipate travelling the same amount or more by bus in the future. A report by the UK Department for Transport (Clery et al., 2017) found that having a disability explains variation in the use of different modes of transport. In particular, they found more frequent use of buses and taxis and less frequent use of other modes by people with disabilities. They also found that those with a disability were less likely to view walking and cycling as a viable option and were not able to use a private car as often as they would like. It may be that the lack of viable alternatives could make those with a disability or long-term illness unlikely to reduce their bus use post-pandemic. However, it should be noted that types of long-term illness and disabilities can be quite varied with different impacts on mobility and the ability to access various modes of transport. Furthermore, being unable to work due a disability or long-term illness would suggest that these respondents have different journey purposes compared to other population groups. Mode choice has been shown to vary with journey purpose. For example, the UK National Travel Survey (Department for Transport (Statistics), 2020) indicates that a fifth (20%) of commuting journeys were by public transport compared to only 8% of leisure journeys and 7% of shopping trips.

The RPBPHM model further showed that among the individuals who are unemployed because of a long-term illness or disability, those that frequently use websites or online news pages as a COVID-19 information source were found to be significantly more likely to travel less by bus in the future, compared to those among this demographic who do not frequently use online sources. This suggests that online news could play a part in reducing intention to use buses amongst the unemployed, hence publicity campaigns targeted to these groups of individuals could contribute to restoring confidence in buses.

The RPBPHM model found that among those who reside in Lothian, those whose highest education level is Higher (secondary school qualification), Higher National Certificate or Higher National Diploma (non-degree tertiary qualification) are more likely to travel less by bus in the future than those with higher academic qualifications (e.g., Bachelor's or postgraduate degrees, or any other professional qualifications). A possible explanation is differences in educational attainment and knowledge and perceptions of COVID-19. For example, Rattay et al., (2021) found that a lower level of education was associated with lower knowledge about COVID-19 and higher perceived severity.

The RPBPHM model found that and those living in households with three or more occupants are significantly more likely than smaller households (less than three occupants) to anticipate travelling by train in the future. A possible explanation may be that greater competition for car access in larger households may lead their members to use public transport more often.

3.7. Additional factors considered in future public transport usage

De Haas et al., (2020) suggested that the COVID-19 pandemic may permanently alter the way people work and travel with many workers expecting to telecommute more frequently and to continue holding remote meetings in the future. In the current survey (Downey et al., 2021) the Scottish respondents indicated that 66% worked from home more often during the pandemic and 54% expected to work more often at home in the future. This increase in remote working could reduce demand for commuter travel. A small proportion (4%) of survey respondents who anticipate reducing public transport use indicated that the ability to work from home more often was a contributing factor. The current RPBPHM model did not find that working from home was a significant predictor of anticipated future public transport use.

Gupta et al., (2021) found that for US cities, the COVID-19 pandemic led many residents to flee city centres to the suburbs in search for safer ground away from urban density. Such shifts will have the potential to have significant impacts on overall traffic activity. In the current study 33% of respondents indicated they were, prior to COVID-19 pandemic, contemplating moving from their current residence, in the future. During the COVID-19 pandemic this had increased to 40% with 17% of respondents who expect to move from their property in the future citing 'being able to work from home more often or permanently' as a contributing factor. However, the current RPBPHM model, did not find that intending to relocate in the future was a significant predictor of anticipated future public transport use.

Several additional variables such as household car ownership, age, gender, income and household type were trialled but not included in the model as their impact was identified as statistically insignificant. It might be anticipated that lower income groups are more captive users of public transport and might be less likely than those with higher income to reduce their use after the pandemic. However, findings from the model suggest that there is no difference in reductions in public transport use between different income categories. A possible explanation could be that during the pandemic a very limited and specific set of people continued to use public transport so the variability in terms of income was not adequate to allow identifying statistically significant differences.

4. CONCLUSIONS

This study has examined travel behaviour, attitudes, and perceptions in Scotland after COVID-19 was declared a pandemic. It is likely that there will be profound changes in travel in the years to come because of the lifestyles that have become popular during the pandemic – such as teleworking and e-shopping. We carried out a survey questionnaire to capture the anticipated changes in the future travel patterns of respondents. We found that a shift away from public transport can be expected with increases in car use, cycling and walking and more employees working-from-home.

Reduced demand for public transport will impact on the viability of public transport services. The travel intentions we observed will make delivering an attractive conventional public transport service harder than before the COVID-19 crisis. Public transport operators may need to respond to the demand decrease by reducing service frequency and capacity. The consequent loss of public transport revenues could further threaten the provision of services. Our research confirmed that bus users experiencing good quality services in urban areas are less likely to abandon public transport post-pandemic. This suggests that the deterioration of the bus services may trigger a negative loop of increasing reductions in demand and supply. Additional government subsidies may help break the loop. However, it may be difficult for Government to provide support in a context in which public finances could suffer because of the need to repay the debt generated by the COVID-19 measures and of the potential loss of tax revenues if the economy does not recover adequately.

The travel changes triggered by COVID-19 have mixed effects on the environment. The anticipated increase in car use and the reduced use of public transport identified in the study would have negative environmental implications and make it difficult to achieve the goals of the Scottish Governments Climate Change Act, including the ambitious target of reducing car kilometres on Scottish roads by 20% by 2030 (Scottish Parliament, 2019). On the plus side, however, the increased importance of cycling and walking, the diffusion of home working with the associated reduction in work related travel, and the anticipated reduction in air travel have the potential to reduce overall emissions.

In our survey, almost two thirds of those who indicated that they would use public transport less stated that they would do so because of the possibility of getting infections carried by other passengers. The RPBPHM model proves the importance of reducing risk perception as an important area of investment to increase ridership. Although risk perceptions are likely to change as the pandemic goes away, there is a real danger that the current perceptions may lead people to invest in private motorised mobility, which would reduce the possibility that they go back to public transport when the disease is no longer a threat. Policy measures and the public transport industry must adequately address public perceptions of health risks associated with public transport to ensure customer retention and the long-term viability of the public transport sector. The current study has found that not adhering to social distancing is perceived as a potential barrier to future public transport use, thus calling for a reflection on the tools to promote such distancing.

Out of those who indicated that they would use public transport less, almost half stated overcrowding as a reason, reiterating the importance of avoiding the reduction of capacity provision which would exacerbate the problem. The cleaning of public transport vehicles is highlighted by our respondents as a measure to improve risk perception, with one out of two among those who intend to use public transport less being concerned with the lack of cleanliness. Ensuring that public transport is perceived as at low risk of COVID-19 infections is expected to be challenging action for public authorities and industry given the anticipated difficult financial situation.

As well as social distancing and sanitisation, worldwide responses to reduce the spread of COVID-19 on public transport have included suspending public transport services, reducing frequency, discouraging public transport use, reduced capacity on vehicles to enable physical distancing, design interventions (e.g. installing screens), improved ventilation, the enforcement of face mask use and reducing crowding (e.g. boarding limits and real time crowding information) and redesigning services to accommodate new passenger demand patterns (Gkiotsalitis and Cats, 2020; Tirachini and Cats, 2020; Vitrano, 2021).

During the pandemic recovery phase, we are unlikely to see public transport usage return to pre-pandemic levels and patterns. Throughout the reopening it is essential that the public transport system offers safe, risk-free travel at an adequate service level (Coppola and de Fabiis, 2021). The Government should invest in measures to encourage passengers back on to public transport and ensure that service provision is maintained and protected for the future. Services may need to be reorganized to manage demand and adapt to new ways of working and living. For example, instead of weekday morning and evening peaks, travel could be spread more evenly throughout the day, aided by flexible working solutions, thus making provision of mass transit more difficult. Continuing to adhere to social distancing requirement during the re-opening phase presents a significant challenge for operators. Gkiotsalitis and Cats, (2020) suggest that of all the measures introduced, this is the most consequential measure for public transport, with operators having to transform their services in order to adhere to physical distancing requirements. From a longer-term perspective, it is important to ensure sufficient public investment in transport infrastructure, equipment, and services. However, during the recovery period, public budgets will be directed towards post-pandemic crisis mitigation and there may be limited amounts available for transport related investments (Christidis et al., 2021)

The study confirms that pre-lockdown travel choices significantly affect post-lockdown travel choices. Those who drove their car frequently (at least three days a week) pre-pandemic were significantly more likely than infrequent car drivers to anticipate travelling less by bus or train in the future. This suggests the lack of attractiveness of public transport for some car users. Actions documented in the Scottish Governments National Transport Strategy (Transport Scotland, 2020a), supports giving public transport precedence over private car use. The actual extent of a modal shift away from public transport and of its implications as well as the possibility of influence the car users' intention require further study. In any case, the Government will need to prioritise public transport options over single occupancy private car use.

Those with lower educational attainment (non-degree tertiary qualification or below) and those living in larger households were significantly more likely to reduce their bus or train use in the future. On the contrary, those with a long-term illness or disability that prevents them from working are significantly more likely than those in other employment categories to anticipate travelling the same amount or more by bus in the future – pointing to a potential captivity to public transport. Consistent with the priorities of the transport strategy (Transport Scotland, 2020a), the Scottish Government and transport industry will need to find ways to reduce inequality issues that have arisen due to the COVID-19 pandemic.

Using social media or websites to stay informed about COVID-19 plays a role in the intentions to use buses less in the future. Therefore, we stress the importance of online campaigns aiming at increasing public confidence in the bus service. These campaigns can be even more effective if targeted at specific populations groups, for example those who used buses frequently prior to the pandemic.

The current study is reliant on the self-reported future travel intentions. Of course, it is possible that the anticipated behaviour will not result in actual behaviour. Actual behaviour depends not only on intentions but also on the ability to realise the intentions (linked to the travel needs and the transport supply), and intentions are likely to vary with changing perceptions. However, it must be noted that those who expect to travel less by public transport may be inclined to invest in car mobility, thus leading to a self-fulfilling prophecy (Merton, 1948). The current survey was conducted during 'lockdown' when mobility was restricted and concerns particularly strong. Further public transport mode choice research in the future should be conducted after lockdown and beyond, when COVID-19 is no longer a threat.

Another limitation is that the study considered relative differences in public transport use (e.g., travel more often or travel less often). Further research could quantify the level of reduced public transport use to help understand the size of the effect. The modelling outputs suggest that expectation about continuing to work from home post-Covid does not reduce likelihood of using public transport in the future. The survey did not explore individual trip purposes (such as commuting) or quantify the increased number of days per week respondents expect to work from home. Consequently, the impact of working from home on future travel may not have been fully captured.

Overall, this research identifies a possible mode shift away from public transport and significant potential for increased car use amongst car drivers in the post-pandemic era. However, the consequences of such shift depends on the characteristics of the public transport journeys previously made by frequent car users. Further work should focus on the actual travel choices of people who reduce their public transport to better understand the extent of either a modal shift or reduced trip rates.

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APPENDIX

Table A1 All available independent variables

Variable No.	Variable Description
1	**Gender**: Male, Female, Non-binary
2	**Age**: 18-24, 25-34, 35-44, 45-54, 55-64, 65-74, 75+
3	**Highest education level**: O Grade, Standard Grade; Higher Grade/Advanced Higher; Higher National Certificate and Higher National Diploma (non-degree tertiary qualification); Bachelor's degree; Postgraduate degree; Other professional qualifications
4	**Ethnic group**: White, Mixed/multiple ethnic groups, Asian/Asian British/Asian Scottish, Black/African/Caribbean/Black British, Black Scottish
5	**Household income (GBP)**: 0-10,000, 10,001-20,000, 20,001-30,000, 30,001-40,000, 40,001-50,000, 50,001-60,000, 60,001-70,000, 70,001-80,000, Over 80,000
6	**Income concern**: Paying bills is a constant struggle and worry; Paying bills is tough and on my mind, but I get by; My monthly bills are affordable and I don't worry too much about paying them; I never worry about my monthly bills
7	**Employment status**: Currently employed, but have been furloughed; Currently employed and working from home; Currently employed and working outside of home; Currently employed and sometimes work from home and sometimes outside the home; In full-time education; Unemployed; Retired; Full-time carer; Looking after the household; Long-term illness or disabled and unable to work
8	**Future telecommuting**: Yes (intends to telecommute more frequently following COVID-19); No
9	**Region of Scotland**: Ayrshire and Arran; Borders, Dumfries and Galloway; Fife; Forth Valley; Grampian; Greater Glasgow and Clyde; Highland, Orkney, Shetland, Western Isles; Lanarkshire; Lothian; Tayside
10	**Car ownership**: no car, one car, two or more cars
11	**Household size**: one, two, three, four, five, six or more people
12	**Household risk**: At least one household occupant has an underlying medical condition (e.g. asthma, heart disease, diabetes)
13	**Other household types**: Multiple children, Multiple elderly occupants etc.
14	**Social norms (perceived importance)**: Work importance, Social life importance, Sport/exercise importance, Going to events/restaurants/pubs importance, Protecting the environment importance
15	**COVID-19 information sources**: Newspapers and magazines; Television or radio stations; Websites or online news pages; Social media (e.g. Facebook, Twitter, WhatsApp); Conversations with family, friends or colleagues
16	**Mode of travel used prior to COVID-19 (weekly frequency)**: Personal vehicle (car, van), Public transport (bus, train), Active travel (on-foot, by bicycle)
17	**COVID-19 risk perceptions (per travel mode)**: Low risk, Medium risk, High risk
18	**Relocation**: Yes (intends to relocate within 5 years); No