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An empirical analysis of the factors influencing Scottish residents' compliance with COVID-19 travel restrictions

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ABSTRACT

This study uses survey data to investigate the factors affecting compliance with the Scottish Government's COVID-19 travel restrictions. The survey contained self-reported data (n = 819) regarding various aspects of Scottish residents' COVID-19 travel behaviour. For a question gauging compliance with COVID-19 travel restrictions, ~57% of respondents complied fully, ~35% complied mostly and ~7% were slightly compliant or non-compliant. A random parameters ordered probit model, with allowances for heterogeneity in the means of random parameters, was estimated to unveil the factors affecting levels of compliance. The model estimation results showed that various sociodemographic characteristics of respondents, including age, gender and household income significantly affected compliance. Other significant independent variables were dominated by perceptual and behavioural characteristics of respondents, such as public trust in the Scottish Government, COVID-19 risk perceptions, COVID-19 information channels and travel mode choices at different stages of the pandemic. Two variables gauging car ownership (those with no car) and COVID-19 information channels (received through online sources) produced statistically significant random parameters, which suggests heterogeneous levels of compliance among these groups. In addition, one instance of heterogeneity in the mean of the online sources random parameter was discovered, such that levels of compliance among this group were dependent on a variable gauging highest education level. Policy implications are discussed in terms of tailoring the Scottish Government's public health messaging to certain demographics, while the most effective channels for delivering public health information, in the case of COVID-19 and future pandemics, are also explored.

1. Introduction

The COVID-19 pandemic, and subsequent government-enforced lockdowns, has had myriad effects on travel behaviour across the globe (Abdullah et al., 2020; Beck et al., 2021; Borkowski et al., 2021; Currie et al., 021; Downey et al., 2022; Kim and Kwan, 2021;

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Laverty et al., 2020; Loa et al., 2022; de Palma et al., 2022; Shelat et al., 2022). Since the UK's first lockdown in March 2020, the UK central and regional Governments have published various iterations of COVID-19 travel restrictions and guidance (Scottish Government, 2021; UK Government, 2021). In the early stages of the pandemic, this included prohibiting all non-essential travel such that travel was only permitted for key workers (those employed in healthcare, the emergency services etc.) or for essential shopping trips, while residents were also discouraged from travelling outside their local area. Further travel and transport restrictions followed, including reduced capacity on public transport modes, mask wearing and social distancing in public spaces, and prohibiting travel abroad and across different regions of the country (UK Government, 2021). Various studies have investigated the effectiveness of COVID-19 restrictions and preventative measures (Heald et al., 2021; Liu and Yamamoto, 2022; Zhong et al., 2021), and also the degree of compliance with COVID-19 restrictions (Hamerman et al., 2021; Hermans et al., 2021; Kearney et al., 2022). This study focuses on the sociodemographic, perceptual and behavioural factors affecting compliance with COVID-19 in Scotland, adding specific knowledge to the domain of compliance behaviour in the context of travel and transport restrictions.

Throughout the pandemic, governments across the globe have clashed over the most effective strategies to deliver public health messaging. This was evident in the UK, as the UK Government's COVID-19 restrictions occasionally differed from those in the devolved nations (Scotland, Wales and Northern Ireland). A similar problem emerged in the US, as COVID-19 restrictions varied on a state-by-state basis (Studdert et al., 2020), which is likely to have led to public confusion, particularly regarding interstate travel. This presents a problem for the COVID-19 responses of the UK and US Government, as various conflicting messages are likely to have affected public trust in policy measures and created confusion around restrictions. Past research has shown that trust in governments and clarity of public messaging is critical during public health emergencies (Enria et al., 2021; Pak et al., 2021) and it is possible that this confusion negatively impacted compliance with COVID-19 restrictions. It is also possible that the compliance behaviour of different regions varied due to lifestyle differences or region-specific population characteristics. For example, those living in urban, densely populated regions were at higher risk of contracting COVID-19 than those living in rural, sparsely populated areas, therefore, it is likely that urban dwellers adjusted their compliance behaviour to account for this. In addition, 25.1% of the UK's rural population is over the age of 65, compared to 17.0% in urban areas (UK Goverment, 2021), which will have affected COVID-19 working and mobility patterns throughout the pandemic and levels of compliance with government guidance. A recent report by Sustrans (2016) showed considerable differences in levels of "transport poverty" (typically measured on the basis of car ownership, access to public transport and availability of active travel links) across Scottish regions. It may also be the case that issues related to transport poverty and its implications could result in differing levels of compliance with COVID-19 travel restrictions in Scottish regions.

The way in which people seek public health information constitutes another important aspect of public trust and compliance during public health emergencies. Recent studies show that COVID-19 information sources and channels affect how the public perceives the virus, for example, Ho et al. (2020) found that those who seek information using online sources were often more worried about the pandemic than those who retrieved COVID-19-related information from academic literature. Battineni et al. (2020) show that a considerable proportion of public health information found on social media or online is misleading or false, and rarely originates from reliable sources (e.g., official government pages, scientific journals or health organizations). Recent studies have also shown that those who perceive COVID-19 to be dangerous, either to themselves or those around them, are significantly more likely to comply with restrictions and preventative measures (Dryhurst et al., 2020; Franzen et al., 2021).

Sociodemographic characteristics, such as age, gender and education level have previously been found to affect compliance with COVID-19 restrictions (Asnakew et al., 2020; Ceccato et al., 2021; Griffith et al., 2020). Asnakew et al. (2020) found that males were significantly less likely than females to comply with preventative measures, while low education level was also associated with non-compliance. Griffith et al. (2020) suggested that males are more likely to underestimate health risks than females, making them more likely to resist preventative measures. Furthermore, a study of German residents found that males with lower education levels were particularly susceptible to underestimating their likelihood of contracting COVID-19, while highly educated males had greater awareness of the pandemic and also had higher rates of compliance with social distancing measures (Rattay, et al., 2021). Given that rates of COVID-19 mortality are disproportionately high among over 65s (Office for National Statistics, 2021), it is not surprising that elderly individuals perceive COVID-19 to pose a high personal health risk (Ceccato et al., 2021). As a result, elderly individuals were often more likely to strictly adhere to COVID-19 restrictions, thus limiting their risk of contraction (Ceccato et al., 2021).

This study aims to investigate the sociodemographic, perceptual and behavioural factors affecting compliance with the Scottish Government's COVID-19 guidance and regulations for travel and transport. To achieve this, we use survey data ($n = 994$) collected during February 2021 in Scotland. The survey collected a wide range of data, including mode usage before and during the pandemic, compliance with travel restrictions, COVID-19 information channels and sources, trust in COVID-19 information sources, general COVID-19 perceptions, long-term travel intentions and sociodemographic characteristics of respondents. It should be noted that "information channels" refer to platforms where information can be accessed (e.g., television, websites and social media) whereas "information sources" refer to the origin of information (e.g., government advice or academic literature). To gain accurate insights into the factors influencing compliance with COVID-19 travel restrictions in Scotland, we estimate a Random Parameters Ordered Probit model with Heterogeneity in the Means of random parameters (RPOPHM). The statistical analysis provides insights into which sociodemographic groups showed a greater propensity to comply with restrictions in Scotland, whilst also providing a better understanding of the influence that COVID-19 information channels, trust in governments and general perceptions of COVID-19 have on compliance. All of these factors must be better understood if governments wish to improve the effectiveness of public health messaging and compliance with preventative health interventions. Given the relative novelty of social media platforms and other online channels as a tool to disseminate public health information, the results may also inform the Scottish Government's future public health communication strategy.

2. Data

During February 2021, an online questionnaire was conducted to assess the short and long-term impacts of COVID-19 on travel behaviour in Scotland. Informed consent was required prior to a respondent's participation in the study, as per the General Data Protection Regulation (GDPR), while effort was made to ensure the sample was approximately representative of the Scottish population, particularly in terms of age, gender and household income. This was achieved through enforcing quota restraints for the previously mentioned criteria. The survey was piloted prior to its formal release, with pilot respondents completing the survey within the expected duration and reporting no problems understanding terminology. Among the survey sample, 48.8% of respondents were male, 51.1% were female and 0.1% were non-binary, which very closely represents the gender breakdown of Scotland's population −48.8% male, 51.2% female (National Records of Scotland, 2020). The distribution of age groups achieved in the sample is displayed in Fig. 1 and compared to National Records of Scotland (2020) population statistics. The over 75 population is underrepresented in our sample, however the differences in other age categories are limited.

In our sample, 51.6% of respondents declared an annual household income of up to £30,000, which is approximately in line with the median UK value of £29,900 per year (Office for National Statistics, 2020). 14.1% of our survey respondents hold a postgraduate or doctoral degree. To the best of the authors' knowledge, there are limited official data available regarding highest education level across Scotland. However, the long-running UK household longitudinal study *Understanding Society*, showed that the rate of postgraduate degree holders in Scotland was 14.8% in the year 2020–2021 (Institute for Social and Economic Research, the University of Essex, 2021), in line with our sample.

The verbatim survey question to gauge compliance, which corresponds to our dependent variable, was as follows: "To what extent do you feel you are following Scottish Government COVID-19 regulations and guidance on travel and transport?". Responses were recorded using a seven-point Likert scale (i.e., Level 1 = non-compliance, Level 4 = slight compliance and Level 7 = full compliance, while Levels 1–2 and 5–6 describe further intermediate levels of compliance). The seven-point scale was later aggregated to three levels: Level 1 – those who were non-compliant or those with low levels of compliance (i.e., the original Levels 1, 2, 3 and 4 combined), Level 2 – those who complied mostly (i.e., original Levels 5 and 6 combined), and Level 3 – those who were fully compliant (i.e., original Level 7). To better understand what "compliance" may have meant to the survey respondents in February 2021, it is essential to understand the COVID-19 restrictions that were active at the time, as well as the risk of COVID-19 infection. According to data from the Scottish Government (Scottish Government, 2022), the average frequency of daily cases in Scotland during the first week of the survey dissemination period (3rd to 10th of February) was 830, whereas a few weeks earlier (i.e., the first week of January 2021) Scotland saw a record high since the onset of the pandemic recording more than 2,350 daily cases on average. Table 1 summarises key aspects of the Scottish Government's COVID-19 guidance and restrictions in early 2021, before and after the survey window (The Scottish Parliament Information Centre, 2022).

Fig. 2 shows the distribution of responses across the three levels of compliance, which are also disaggregated by the original seven-level outcomes. Among the respondents, 61 (7.45%) belonged to the non-compliance or low compliance outcome, 288 (35.17%) complied mostly and 470 (57.39%) were fully compliant. It should be noted that the number of observations reduced to 819 following

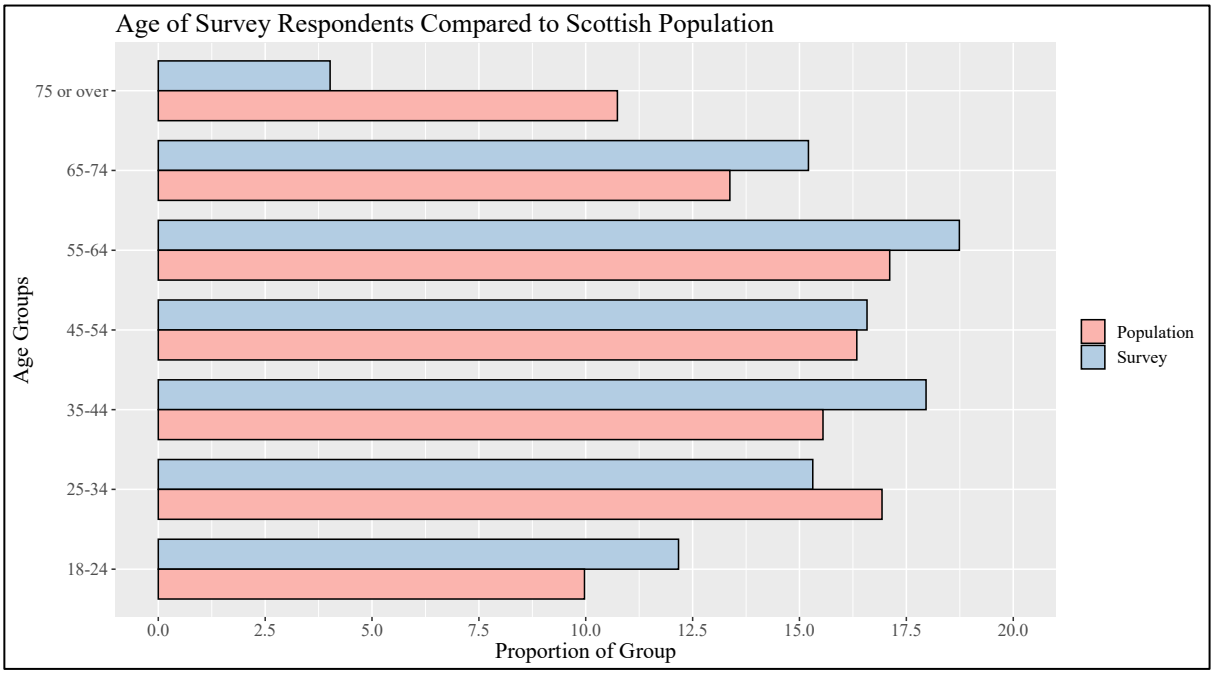

Fig. 1. Age of survey respondents compared to National Records of Scotland (NRS) statistics.

Table 1
Scottish Government's COVID-19 guidance and milestones during early 2021.

Date	Guidance/Milestone
5th January 2021	*Mainland Scotland goes into lockdown – only essential travel permitted*
8th January 2021	*Scottish Government announce university students will be taught online throughout January and February*
15th January 2021	*Scottish Government announce the suspension of all travel corridors (*i.e.*, international arrivals)*
10th February 2021	*Scottish Government announce the number of first dose vaccinations in Scotland has reached 1 million*
23rd February 2021	*Scottish Government publish the updated Strategic Framework, setting out the broad order of priority for re-opening and the conditions that need to be met to start lifting restrictions*
2nd March 2021	*Scottish Government announce Phase 2 of schools return. All remaining primary school children are set to return to school full-time from 15 March, with all secondary pupils returning on a part-time basis from that date.*
16th March 2021	*Scottish Government publish a timetable for easing restrictions. Stay at Home regulations are to be lifted on 2 April and replaced with guidance to Stay Local, with more services including hairdressers, garden centres and non-essential click and collect services able to open from 5 April.*

the omission of incomplete responses, including 18 respondents who answered "don't know". Overall, the distribution of responses indicates that a large majority of respondents (over 92%) complied mostly or fully with COVID-19 travel restrictions in Scotland. The survey also recorded sociodemographic (e.g., age, gender, ethnic background, income and car access), perceptual (e.g., perceived risk of contracting or spreading COVID-19, trust in the Scottish or British Government and perceived importance of protecting others/the environment) and behavioural (e.g., COVID-19 information sources and mode of travel choices before and during the pandemic) characteristics of respondents. For a comprehensive list of respondent characteristics, which would all be trialled as potential independent variables, see 'Model Estimation Results' – Table 2.

3. Methodology

An increasing number of recent studies have shown the statistical benefits of accounting for the potential effects of unobserved heterogeneity in survey data (Ahmed et al., 2021; Behnood et al., 2022; Bellizzi et al., 2020; Eker et al. 2020a; Guo et al., 2020; Mannering et al., 2016; Qiao et al., 2021). Unobserved heterogeneity reflects the varying impact of explanatory variables across the sample due to unobserved characteristics, which typically capture unobserved tastes, preferences or experiences of respondents that are often unable to be identified through survey questions. Not accounting for the effects of unobserved heterogeneity may lead to unreliable inferences and, subsequently, fallacious policy implications (Eker et al., 2020b; Fountas et al., 2019; Mannering et al., 2016).

Given the discrete, ordinal nature of the dependent variable, discrete outcome modelling, namely, the ordered probit modelling framework, was adopted for the statistical analysis (Washington et al., 2020). Random parameters are also incorporated in the ordered modelling framework, which in effect allow for the potential effects of unobserved heterogeneity within the independent variables to be accounted for (Mannering et al., 2016). Past studies have shown that the inclusion of random parameters often results in significantly greater explanatory power of models, compared to fixed parameters alternatives (Anastasopoulos and Mannering, 2009). From here on, the methodological formulation of the modelling framework is in accordance with Washington et al., (2020). The ordered probit model can be defined as follows:

$$z_n = \boldsymbol{\beta}\mathbf{X}_n + \varepsilon \tag{1}$$

where $\boldsymbol{\beta}$ is a vector of estimable parameters, $\mathbf{X}$ is a vector of independent variables dictating the discrete ordering for an observation, n, and ε is random disturbance, which is assumed to be normally distributed across observations (with mean = 0 and variance = 1). Given the previous equation, the ordered data, y, for each observation can be defined as follows:

$$y = 1 \text{ if } z \leq \boldsymbol{\mu}_0$$

$$y = 2 \text{ if } \boldsymbol{\mu}_0 < z \leq \boldsymbol{\mu}_1$$

$$y = "\ldots"$$

$$y = I \text{if } z \geq \boldsymbol{\mu}_{I-1} \tag{2}$$

where $\boldsymbol{\mu}_i$ are estimable parameters that explain y, which corresponds to integer ordering where I is the highest integer response (Level 3 – full compliance, in the case of this research). Estimable parameters, $\boldsymbol{\mu}_i$, are estimated in conjunction with model parameters, $\boldsymbol{\beta}$.

To account for the effects of unobserved heterogeneity, the model coefficients are allowed to vary across observations for certain independent variables. This approach, known as random parameters ordered probit (RPOP) modelling, often leads to significantly improved explanatory power of the framework (Mannering et al., 2016; Seraneeprakarn et al., 2017; Fountas et al., 2021), when compared to the standard ordered probit. To optimize the layers of unobserved heterogeneity captured by the modelling framework, allowances are also made for heterogeneity in the means of random parameters; hence, the complete modelling approach used for the statistical analysis shall be referred to as the Random Parameters Ordered Probit with Heterogeneity in the Means of random

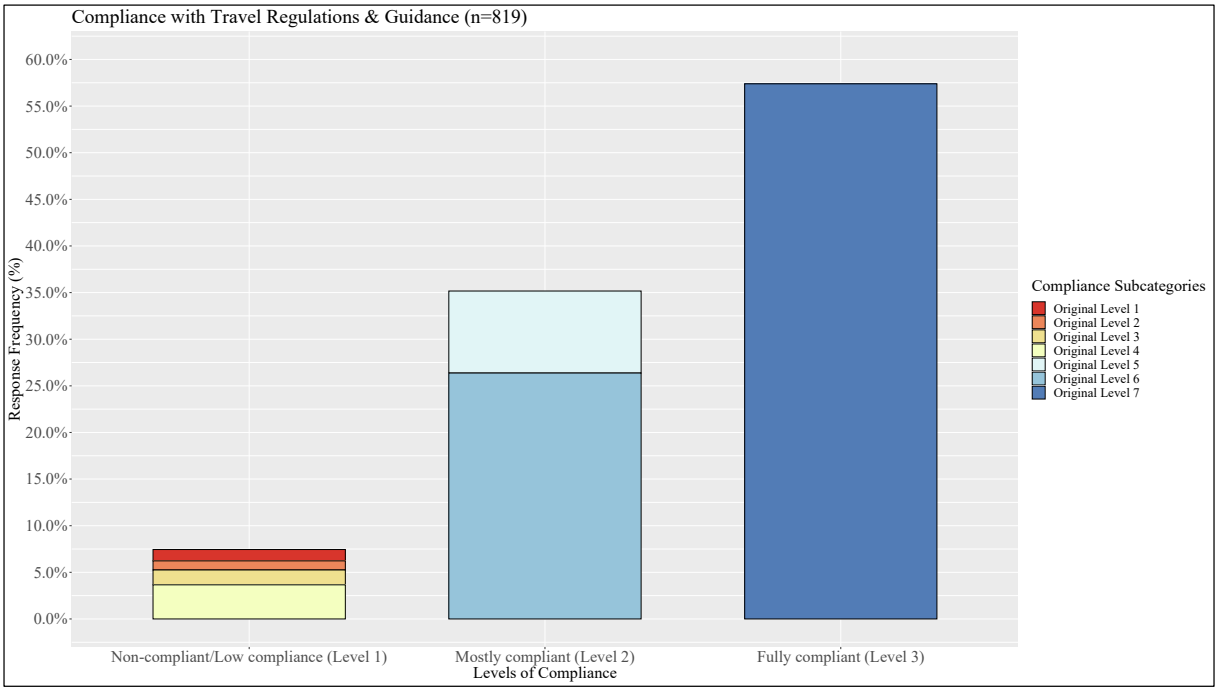

Fig. 2. Compliance with the Scottish Government's COVID-19 regulations and guidance on travel and transport.

parameters (RPOPHM). The RPOPHM approach is considered a more sophisticated means of capturing unobserved heterogeneity, given that random parameters are allowed to vary by explanatory variables (Fountas et al., 2021; Seraneeprakarn et al., 2017). The revised framework can be written as follows:

$$\boldsymbol{\beta}_n = \boldsymbol{\beta} + \boldsymbol{\Theta}\mathbf{Z}_n + \boldsymbol{\xi}_n \tag{3}$$

where $\boldsymbol{\beta}_n$ is a vector of estimable parameters that may vary across observations, n, $\boldsymbol{\beta}$ is the vector of mean parameter estimates across the dataset, $\mathbf{Z}_n$ is a vector of explanatory variables from observation n, that influence the mean of $\boldsymbol{\beta}_n$, $\boldsymbol{\Theta}$ is a vector of estimable parameters and $\boldsymbol{\xi}_n$ is a vector of randomly distributed terms. The calculation of the probabilities for RPOP models is complex, therefore, a simulation-based maximum likelihood is used for model estimation (Washington et al., 2020). For this process, Halton draws are often considered a more effective alternative to random draws (Halton, 1960), therefore, we use Halton draws for model calibration in this paper.

The average marginal effects, which are the change in the levels of the dependent variable as a result of a one unit change in the explanatory variable, can be calculated to gauge the influence of independent variables on the dependent variable's interior categories (Washington et al., 2020). For explanatory variables that result in statistically significant random parameters, observation-specific parameters ($\boldsymbol{\beta}_n$) can be used for the calculation of the marginal effects, significantly enhancing their robustness (Anastasopoulos, 2016). Observation-specific parameters can be derived through a built-in capability of the modelling software (R package: 'Rchoice' (Sarrias, 2020)). Following model estimation, a Likelihood Ratio Test (LRT) will be performed to compare the statistical fit of competing modelling frameworks.

4. Model estimation results

Table 2 shows all available independent variables that were trialled during the model estimation[1]. Table 3 shows the descriptive statistics of the independent variables, derived from the original list of variables in Table 2, that were found to significantly affect compliance with COVID-19 travel restrictions. The variables shown in Table 3 are binary indicator variables, in other words, they can only take the values of 1 (the indicator group) or 0 (the control group). Given that nearly all of the available independent variables are nominal (without inherent order), binary categorisation was deemed the most effective way to structure the independent variables. Following the binary categorisation of all available independent variables, forwards stepwise regression, which is an iterative selection

[1] The distributions of available independent variables shown in Table 2 apply to the original survey data (n=994), however, the distributions of significant independent variables in Table 3 were calculated following the omission of incomplete observations, as a result of the independent variables included in the RPOPHM model (n=819). Consequently, there are minor inconsistencies between both tables, e.g., females account for 51.1% of the original sample but only 48.5% of complete responses.

Table 2
All available independent variables[2].

Variable No.	Variable Description (distribution of responses in parentheses)
1	**Gender**: Male (48.8%), Female (51.1%), Non-binary (0.1%)
2	**Age**: 18–24 (12.5%), 25–34 (15.4%), 35–44 (17.5%), 45–54 (16.2%), 55–64 (19.1%), 65–74 (15.2%), 75+ (4.1%)
3	**Highest education level**: O Grade/Standard Grade (21.8%); Higher Grade/Advanced Higher/HNC/HND (38.1%); Bachelor's degree (19.9%); Postgraduate degree, e.g. MSc/PhD (14.1%), Other qualifications (6.1%)
4	**Ethnic background**: White (96.3%), Mixed/multiple ethnic groups (1.0%), Asian/Asian British/Asian Scottish (1.9%), Black/African/Caribbean/ Black British/Black Scottish (0.6%), Other ethnic groups (0.2%)
5	**Household income (£)**: 0–10,000 (10.4%), 10,001–20,000 (21.6%), 20,001–30,000 (19.6%), 30,001–40,000 (16.2%), 40,001–50,000 (11.0%), 50,001–60,000 (6.7%), 60,001–70,000 (4.4%), 70,001–80,000 (4.3%), Over 80,000 (5.8%)
6	**Income concern**: Paying bills is a constant struggle and worry (8.7%); Paying bills is tough and on my mind, but I get by (32.7%); My monthly bills are affordable and I don't worry too much about paying them (40.4%); I never worry about my monthly bills (18.2%)
7	**Employment status**: Currently employed, but have been furloughed (10.9%); Currently employed and working from home (22.6%); Currently employed and working outside of home (17.4%); Currently employed and sometimes work from home and sometimes outside the home (3.2%); In full-time education (5.0%); Unemployed (5.4%); Retired (21.3%); Full-time carer (1.7%); Looking after the household (4.7%); Long-term illness or disabled and unable to work (5.9%), Maternity leave (0.8%), Employed other (1.2%)
8	**Future telecommuting**: Yes, intends to telecommute more frequently following COVID-19 (54.0%); Unsure (18.1%); No (27.9%)
9	**Region of Scotland**: Ayrshire and Arran (8.4%); Borders, Dumfries and Galloway (4.5%); Fife (4.7%); Forth Valley (4.5%); Grampian (9.9%); Greater Glasgow and Clyde (23.3%); Highland, Orkney, Shetland, Western Isles (6.6%); Lanarkshire (12.5%); Lothian (17.0%); Tayside (8.6%)
10	**Household car ownership**: no car (21.0%), one car (50.3%), two cars (23.9%), three/more cars (4.7%)
11	**Household size**: More than three occupants (35.8%); Less than three occupants (64.2%)
12	**Household risk**: At least one household occupant has an underlying medical condition, e.g., asthma, heart disease, diabetes (30.3%); No occupant has an underlying condition (69.7%)
13	**COVID-19 risk perceptions (for travelling on public transport modes)**: Low risk (3.0%), Medium risk (36.4%), High risk (60.6%)
14	**Relocation to new residence within 5 years**: Yes (25.1%); Unsure (8.6%); No (66.3%)
15	**Other household types (1 if yes, 0 otherwise)**: Multiple children live in household (26.6%), Multiple elderly occupants (25.0%)
16	**Social norms (1 if perceived to be important, 0 otherwise)**: Work (60.2%), Social life (61.7%), Participating in sports/exercise (36.1%), Going to events/restaurants/pubs (47.8%), Protecting the environment (64.4%), Helping others (70.5%)
17	**Public trust (1 if perceived to be a trustworthy source of COVID-19 information, 0 otherwise)**: Scottish Government (51.3%), UK Government (25.2%), Medical professionals (80.0%), World Health Organization (62.8%)
18	**COVID-19 information channels (1 if used frequently, 0 otherwise)**: Newspapers and magazines (26.2%); Television or radio stations (69.5%); Websites or online news pages (54.6%); Social media, e.g., Facebook, Twitter, WhatsApp (34.1%); Conversations with family, friends or colleagues (47.1%)
19	**COVID-19 mode of travel (1 if used at least 3 days per week, 0 otherwise)** Personal vehicle (car, van) (26.7%), Public transport (bus, train) (5.3%), On-foot (54.7%), Bicycle (6.6%)
20	**Mode of travel used prior to COVID-19 (1 if used at least 3 days per week, 0 otherwise)**: Personal vehicle (car, van) (57.4%), Public transport (bus, train) (19.7%), On-foot (59.7%), Bicycle (5.7%)
21	**General COVID-19 perceptions (1 if likely to contract/spread or is perceived to be dangerous, 0 otherwise)**: Likelihood of contracting COVID-19 (21.7%), Likelihood of spreading COVID-19 (24.4%), Perceived danger of COVID-19 (23.9%)

[2] It should be noted that variables 1–14 in Table 2 contain all outcomes that were available to the respondents, i.e. all subcategories combined = 100%, whereas variables 15–21 are based on more complex survey questions (e.g. using an ordinal scale of response outcomes) so response outcomes were often aggregated, hence they are displayed as dummy variables in Table 2.

Table 3
Descriptive statistics for significant independent variables.

Variable Description	Distribution (%)
Gender (1 if female, 0 otherwise)	48.5%
Age indicator (1 if 18–24, 0 otherwise)	11.5%
Age indicator (1 if over 65, 0 otherwise)	19.3%
Household income (1 if more than £50,000/year, 0 otherwise)	21.6%
Car ownership (1 if no household car, 0 otherwise)	21.6%
Highest education level (1 if postgraduate qualification (e.g., MSc or PhD), 0 otherwise)	13.6%
Public trust (1 if Scottish Government is a trustworthy source of COVID-19 information, 0 otherwise)	52.6%
COVID-19 information channels (1 if frequently uses television or radio, 0 otherwise)	70.9%
COVID-19 information channels (1 if frequently uses online sources, 0 otherwise)	55.8%
COVID-19 mode of travel (1 if personal vehicle used at least 3 days per week, 0 otherwise)	26.5%
Perceived danger of COVID-19 (1 if very dangerous, 0 otherwise)	48.5%
Perceived likelihood of spreading COVID-19 (1 if very likely to pass on to others, 0 otherwise)	51.7%
Perceived importance of protecting the environment (1 if very important, 0 otherwise)	64.2%

algorithm based on Akaike Information Criterion (AIC), was utilised to establish the combination of independent variables that provided the highest explanatory power compared to a baseline model, which contained a constant term only. The stepwise regression was conducted using the R package 'MASS' (Venables and Ripley, 2002).

Table 4 displays the RPOPHM model estimation results and the marginal effects for significant independent variables (t-stats > 1.65 are significant at $> 90\%$ level of confidence (l.o.c.), t-stats > 1.96 are significant at $> 95\%$ l.o.c.). One instance of heterogeneity in the

mean of a random parameter variable was found (denoted by grey fill in Table 4), such that the "COVID-19 information channels (online sources)" variable was affected by an exogenous variable gauging highest education level. In Table 4, models with higher explanatory power are those with log-likelihoods (LL) closer to zero. Table 4 is succeeded by "LRT (I)" the results of which support the allowances made for heterogeneity in the means of random parameters, since the log-likelihood value of the RPOPHM is significantly (>95% l.o.c.) - although not largely - lower than that provided by the RPOP counterpart.

Two independent variables related to "car ownership (no car)" and "COVID-19 information channels (online sources)", resulted in statistically significant random parameters. This finding suggests that levels of compliance with COVID-19 travel restrictions were highly heterogeneous among both of these groups. For the random parameters, model coefficients and marginal effects may not unveil the full extent of the unobserved heterogeneity that they capture, therefore, the distributional effects associated with each of the random parameters are displayed in Fig. 3. The random parameters in Fig. 3 can be interpreted as follows: for the "no car" variable, 48.9% of those with no car are likely to comply fully with restrictions (i.e., increasing the probability of the highest dependent variable outcome), while the remaining 51.1% are likely to be non-compliant or have low compliance (increasing the likelihood of the lowest dependent variable outcome). This relatively even split between positive and negative effects is expected, given the insignificant mean coefficient (-0.017) for the "no car" variable in Table 4, which implies that the mean effect of the specific variable is practically zero. Conversely, 76.7% of those who frequently use online sources for COVID-19 information are likely to comply fully, while the remaining 23.3% of this group are likely to be non-compliant or have low compliance.

5. Discussion of results

As shown in Table 4, a variety of sociodemographic, perceptual and behavioural characteristics of respondents significantly affected levels of compliance with the Scottish Government's COVID-19 travel restrictions. Four sociodemographic characteristics of respondents were found to significantly affect levels of compliance; in addition, the "no car" variable was significant as a random parameter. Two independent variables gauging the age of respondents were influential determinants of compliance with travel

Table 4
RPOPHM model estimation results for compliance with COVID-19 travel and transport regulations and guidance in Scotland[3].

Variable Description	RPOPHM		Marginal Effects		
	Coeff.	*t*-stat	Level 1 – Non- Compliant or Low Compliance	Level 2 –Mostly Compliant	Level 3 – Fully Compliant
Constant	0.749	12.63	–	–	–
Gender (1 if female, 0 otherwise)	0.214	2.083	−0.0504	−0.0171	0.0675
Age indicator (1 if 18–24, 0 otherwise)	−0.448	−2.95	0.1199	0.0109	−0.1308
Age indicator (1 if over 65, 0 otherwise)	0.446	3.30	−0.0944	−0.0544	0.1488
Household income (1 if more than £50,000/year, 0 otherwise)	−0.270	−2.33	0.0677	0.0151	−0.0828
Car ownership (1 if no household car, 0 otherwise)	−0.017	−0.12	0.0051	−0.0013	−0.0038
Standard deviation of parameter density function	*0.625*	*2.08*	–	–	–
Public trust (1 if Scottish Government is a trustworthy source of COVID-19 information, 0 otherwise)	0.242	2.49	−0.0577	−0.0189	0.0766
COVID-19 information channels (1 if frequently uses television or radio, 0 otherwise)	0.321	2.95	−0.0805	−0.0188	0.0992
COVID-19 mode of travel (1 if personal vehicle used at least 3 days per week, 0 otherwise)	−0.304	−2.84	0.0759	0.0178	−0.0936
Perceived danger of COVID-19 (1 if very dangerous, 0 otherwise)	0.254	2.53	−0.0603	−0.0209	0.0811
Perceived likelihood of spreading COVID-19 (1 if very likely to pass on to others, 0 otherwise)	0.178	1.85	−0.0424	−0.0140	0.0564
Perceived importance of protecting the environment (1 if very important, 0 otherwise)	0.431	4.27	−0.1079	−0.0260	0.1339
COVID-19 information channels (1 if frequently uses online sources, 0 otherwise)	0.345	2.79	−0.0691	−0.0279	0.0970
Standard deviation of parameter density function	*0.474*	*1.68*	–	–	–
Heterogeneity in the mean of random parameter COVID-19 information channels (online sources: Highest education level (postgraduate qualification, e.g., MSc or PhD)	−0.332	−1.95	0.0435	0.0164	−0.0599
Threshold 1	1.528	12.63	–	–	–
Number of observations	819		–	–	–
$LL_{CONSTANT}/LL(\beta_{RPOP})$	−720.42/−665.06		–	–	–
$AIC_{CONSTANT}/AIC_{RPOP}$	1444.84/1360.12		–	–	–
$BIC_{CONSTANT}/BIC_{RPOP}$	1447.55/1437. 45		–	–	–
$LL(\beta_{RPOPHM})$	−663.14		–	–	–
AIC_{RPOPHM}	1358.28		–	–	–
BIC_{RPOPHM}	1440.32		–	–	–

LRT (I): RPOPHM > RPOP with > 95.0% l.o.c.

[3] **Abbreviations:** LL = log-likelihood, RPOP = random parameters ordered probit, RPOPHM = random parameters ordered probit with allowances for heterogeneity in the means of random parameters, LRT = likelihood ratio test, l.o.c. = level of confidence.

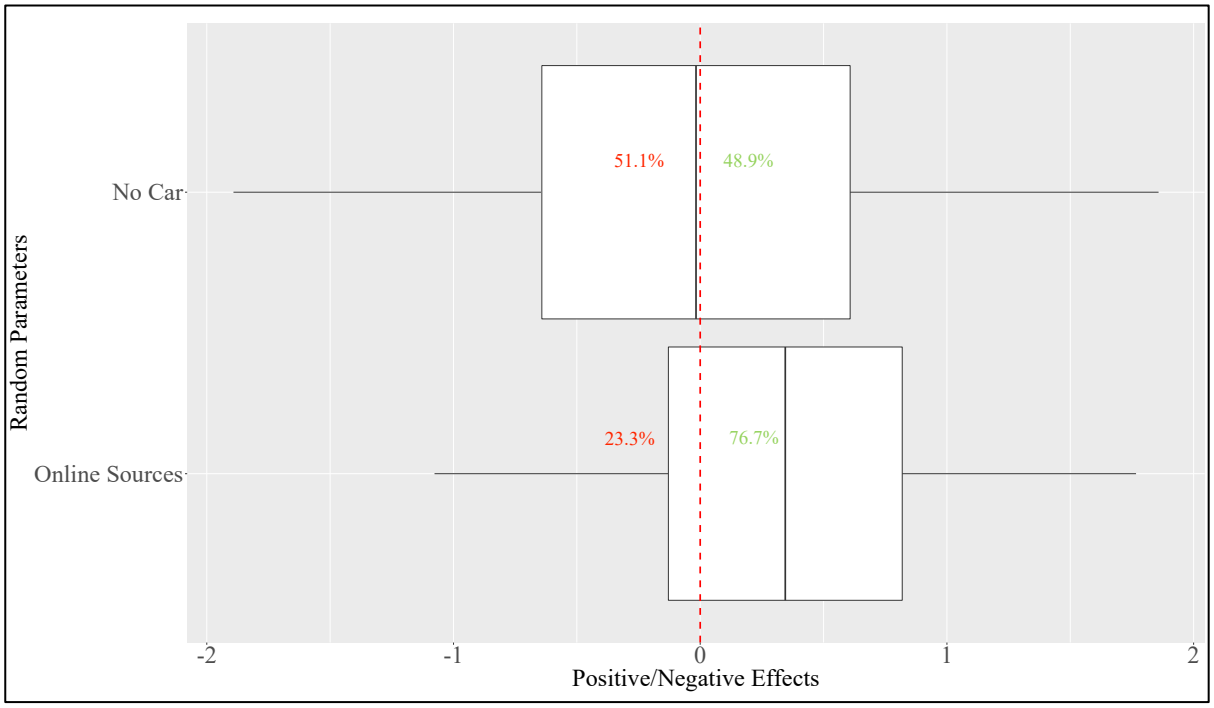

Fig. 3. Distributional effects of independent variables that produced statistically significant random parameters.

restrictions, such that those aged 18–24 were significantly more likely than other age groups to be non-compliant or have low levels of compliance, whereas those aged over 65 were significantly more likely to be fully compliant. The relative potency of the marginal affects associated with the age variables shows that these characteristics had a more pronounced impact on compliance than the other sociodemographic variables. Similar studies across Europe suggested that young individuals' compliance with restrictions was dependent upon trust in the government and "antisocial potential" (e.g., characteristics relating to self-control or association with delinquent peers) (Ceccato et al., 2021; Nivette et al., 2021). The significantly different levels of compliance among younger and older respondents could also be explained by the distinctive mobility requirements of these groups due to their lifestyles. For example, Cui et al. (2017) found that elderly individuals are less likely to travel long trip distances and more likely to be dependent on car travel than younger people. This may have allowed over 65s to comply more easily with COVID-19 travel restrictions, for example, in terms of their ability to avoid frequent public transport use or travelling outside their local neighbourhood.

The model estimation also showed that females were significantly more likely than males to comply fully with COVID-19 travel restrictions. This finding is consistent with past research that shows males are often significantly more likely than females to underestimate health risks (Griffith et al., 2020), which leads to increased non-compliance with government health interventions (Asnakew et al., 2020; Nivette et al., 2021). A variable gauging household income was also influential, such that those who live in households with combined earnings greater than £50,000 per year were significantly more likely than those in lower income households to be non-compliant or have low levels of compliance. Initially, this finding seems counterintuitive, as those in higher income households are more likely to have been able to telecommute throughout the pandemic (Jiao and Azimian, 2021), potentially reducing their trip frequency and distance. Furthermore, high income is often positively correlated with high education level (Statista, 2017), therefore, several recent studies would suggest that these individuals are more likely to have accurate knowledge of COVID-19, resulting in higher compliance with health interventions (Asnakew et al., 2020; Rattay et al., 2021). The effect of this variable may be explained by the fact that individuals of a higher socioeconomic status often have greater freedom of movement as a result of car ownership, therefore, these individuals may have been less likely to comply, especially with restrictions related to travel distance. Furthermore, the financial incentive to comply with restrictions (the Scottish Government enforced on-the-spot fines for restriction contraventions) may be less effective among higher income groups.

One sociodemographic variable, "car ownership (no car)", resulted in a statistically significant random parameter, which suggests significantly heterogeneous levels of compliance among those who do not own a car. As shown previously in Fig. 3, those with no car were approximately evenly split in terms of increasing the likelihood of full compliance (48.9%) or non-compliance/low compliance (51.1%). This heterogeneous effect may capture the varying impact that built environment characteristics have on level of compliance, assuming that car ownership acts as a proxy for people's dependence on built environment features for mobility choices. However, this finding warrants further investigation. It is also worth noting that all independent variables derived from the 'Region of Scotland' variable in Table 2 were insignificant during model estimation. This suggests that the compliance behaviour of different Scottish regions was not significantly dissimilar during the second nationwide lockdown.

Several perceptual characteristics of respondents were also found to significantly influence levels of compliance with travel restrictions. Respondents who perceive the Scottish Government to be a trustworthy source of COVID-19 information were significantly more likely than those who do not trust the Scottish Government to comply fully with restrictions. The explanation for this finding is intuitive, as those who generally trust the Scottish Government are also likely to trust the government's public health advice. This finding reiterates the importance of public trust in governments during public health emergencies (Enria et al., 2021). As shown in Table 3, 52.6% of respondents believe that the Scottish Government is a trustworthy source of COVID-19 information. The Scottish Government may explore ways of regaining the trust of the remaining 47.4% if they wish to increase compliance with COVID-19 restrictions or other health interventions.

Two variables gauging COVID-19 perceptions of respondents significantly affected compliance. Firstly, those who perceive COVID-19 to be a danger to their personal health were significantly more likely to comply fully, in comparison to those who do not believe COVID-19 poses a serious danger. In a similar vein, those who believe that if they were infected with COVID-19 they would spread it to others were also significantly more likely to be compliant. The explanation for the effects of both variables follows a similar rationale. Past research has shown that those with accurate knowledge of COVID-19, particularly in terms of the danger posed to personal health and the necessity of preventative measures to slow viral transmission, comply with restrictions more readily as a result (Dryhurst et al., 2020; Franzen et al., 2021).

A further variable gauging perceived importance of protecting the environment also significantly affected levels of compliance. Respondents who believe protecting the environment is very important were significantly more likely to comply fully with restrictions. Interestingly, the magnitude of the marginal effects associated with the environmental protection variable was greater than the marginal effects associated with the COVID-19 perceptions variables. The environmental importance variable may indirectly capture a sentiment among respondents that is related to the previously discussed perceptual variables. A possible explanation is that those who believe protecting the environment is very important also understand the consequences of climate change for human health (e.g., premature deaths related to extreme weather, food and water shortages, or exposure to air pollutants (World Health Organization, 2018)). Following this logic, it is likely that these individuals are also well informed about COVID-19 health risks making them more likely to be compliant with restrictions. The "perceived importance of protecting the environment" variable may also be interpreted in terms of the short-term climate benefits observed following the introduction of COVID-19 travel restrictions (Monteiro et al., 2021). In fact, a recent study by Kallbekken and Sælen (2020) found that similar factors affected public support for both COVID-19 restrictions and restrictions to reduce the environmental impact of the transport sector. It should be noted that a potential independent variable – "perceived importance of helping others" (see Table 2) – was also trialled in place of the "perceived importance of protecting the environment" variable during model estimation. This variable also produced a significantly positive *t*-stat (these individuals were significantly more likely to comply fully), however, the effect was not as pronounced as the environmental importance variable, i.e., the log-likelihood of the converged model increased with the inclusion of the environmental importance variable. Since both of these variables were moderately correlated (correlation coefficient = 0.46), only the environmental importance variable was included in the final model.

Three behavioural characteristics of respondents were found to significantly influence compliance with COVID-19 travel restrictions. Two of these variables gauged the COVID-19 information channels used by respondents. Both those who frequently use television or radio and those who frequently use online sources were significantly more likely to comply fully with restrictions. For frequent television or radio users, it is likely that COVID-19 information originates from reliable sources (e.g., government sources, academics or medics) and is delivered through trusted information channels (e.g., the British Broadcasting Corporation – a publicly owned television and radio broadcaster). As a result, the COVID-19 information received by these individuals is likely to be factual and aligned with official government advice (broadcasters in the UK are regulated by a government body, *Ofcom*), particularly in comparison to online content (Battineni et al., 2020). The effect of those who frequently use online sources is more unexpected, as past studies have shown that misinformation and disinformation spread more rapidly in online environments, particularly on social media platforms (Battineni et al., 2020; Nsoesie et al., 2020). It should be noted that a potential independent variable for social media as a frequently used COVID-19 information source was trialled in the RPOPHM model but was statistically insignificant. As discussed previously, the "COVID-19 information channels (online sources)" variable was also significant as a random parameter. A possible explanation for this may be due to the variation in quality of public health information found on online platforms. Battineni et al. (2020) found that most public health information found online does not originate from government-aligned or academic sources. As a result, some people who use online sources for COVID-19 information are likely to encounter information that is not aligned with government advice. The concoction of COVID-19 information found in online environments (from official government sources and non-government sources) is likely to have led to public confusion regarding the details of the government's genuine restrictions and guidance. Despite this, the majority (76.7%) of those who frequently use online sources increase the likelihood of compliance with the Scottish Government's COVID-19 travel restrictions, which suggests that, in most cases, Scottish residents are utilising online sources that are aligned with the government's COVID-19 advice.

One instance of heterogeneity in the mean of the "online sources" random parameter was found, such that, among those who frequently use online sources for COVID-19 information, those with postgraduate educational qualifications (e.g., MSc or PhD) were significantly more likely than those with lower qualifications to be non-compliant. Most recent studies have shown the opposite to be true, as lower education levels were found to be associated with lesser knowledge of COVID-19 and greater likelihood of non-compliance (Asnakew et al., 2020; Rattay et al., 2021). However, a further study by Nivette et al. (2021), which focused specifically on young adults' compliance with COVID-19 restrictions, found that highly educated young adults were more likely to be non-compliant, in comparison to young adults with lower education levels (Nivette et al., 2021). In addition, young adults are more likely than older individuals to receive COVID-19 information via online channels (Wang et al., 2020), therefore, it is possible that the

heterogeneity in the mean of the "online sources" random parameter is induced by age-related factors.

The final behavioural factor that significantly influenced compliance gauged respondents' mode usage during the pandemic. It was found that those who frequently used a personal vehicle during the pandemic (at least three times per week) were significantly more likely to be non-compliant or have low levels of compliance with travel restrictions, in comparison to those who did not use a personal vehicle frequently. A possible explanation may be that those who frequently used a personal vehicle during the pandemic did so because they were also frequent personal vehicle users prior to the pandemic. These individuals may have struggled to alter their travel behaviour following the introduction of travel restrictions, therefore, increasing this group's likelihood of non-compliance.

6. Conclusion, policy implications & limitations

This study analyses survey data to show the factors affecting compliance with the Scottish Government's COVID-19 travel restrictions and guidance. The majority of respondents (~57%) were found to have complied fully with restrictions while around 7% were either non-compliant or had low levels of compliance. In addition, upwards of 92% complied somewhat, mostly or fully. Although these results do not provide insights into levels of compliance with specific restrictions, they do suggest that Scottish residents have maintained high levels of compliance with the Scottish Government's COVID-19 travel restrictions and, most likely, other preventative measures. The RPOPHM model unveiled sociodemographic, perceptual and behavioural characteristics of respondents that affected levels of compliance with the Scottish Government's COVID-19 travel restrictions. Males, those aged 18–24 and high income households (more than £50,000 per year) were all significantly more likely to be non-compliant with travel restrictions. Given that the relationship between gender, risk perception and compliance with government health interventions is well-established, the Scottish Government may consider tailoring certain public health information to males. Similar public messaging adjustments should also be considered for young adults, with the ultimate aim of increasing compliance among both demographics. Messages on the importance of compliance, not only for personal and family health, but also for the well-being of communities may be more effective if they are delivered by credible young influencers (Dekoninck and Schmuck, 2022) and showcase how the compliant behaviour of young adults contributes to reduced viral transmission. Gamification can also be particularly useful to affect the behaviour of young adults (Yen et al., 2019). To increase the compliance of members of affluent households, authorities may explore the use of income-based fines (Kantorowicz-Reznichenko, 2018).

Perceptual characteristics of respondents gauging perceived danger, or the likelihood of spreading COVID-19, also significantly affected respondents' level of compliance. Those who perceive the virus to be dangerous to themselves or those around them were more likely to comply with restrictions, which corroborates with past studies. Similarly, those who perceive the Scottish Government's COVID-19 information to be trustworthy were significantly more likely to be compliant. The Scottish Government may consider conducting further research to identify ways of regaining the trust of sceptical residents, whose non-compliance with restrictions is likely to increase their risk of contracting COVID-19. Two behavioural factors relating to COVID-19 information channels also significantly affected levels of compliance. Those who frequently use television or radio and those who frequently use online sources were both significantly more likely to be compliant, however, levels of compliance were highly heterogeneous among those who frequently use online sources. This finding suggests that COVID-19 information broadcasted through television or radio is often aligned with official government advice, resulting in good understanding of COVID-19 travel restrictions and high levels of compliance. Alternatively, the variability of COVID-19 information found online may lead to mixed perceptions of travel restrictions and a comparatively higher likelihood of non-compliance. Despite this, the overall effect of COVID-19 information received through online sources was positive, in terms of generally high levels of compliance with COVID-19 restrictions. As a result, we suggest that the Scottish Government continues to disseminate COVID-19 information through a variety of information channels, particularly, online and through television or radio. These information channels may also be considered by the Scottish Government for communicating other transport-related public messages, such as, the promotion of sustainable transport and enhancing public trust in autonomous technologies. Aside from potential resurgences in COVID-19 infections, the determinants of compliance identified in this study may be used more generally to guide governing strategies in the case of future pandemic or public health crises. There is likely to be significant international variation in some of the variables discussed in this paper, namely, those related to trust in the national government and information channels used for COVID-19 information. As a consequence, the findings associated with these variables may not be transferable to other countries. Perhaps surprisingly, none of the potential independent variables derived from the 'Region of Scotland' variable had a significant effect on compliance. It is possible that more detailed geographical variables that describe the rurality or urbanity of the respondents' area of residence, and thus the associated built environment and infrastructural characteristics, could explain further differences in compliance behaviour. The current survey data lack this type of information; therefore, we suggest that further studies consider this issue in more detail.

Several limitations should be noted. Firstly, survey respondents' compliance with the Scottish Government's COVID-19 travel restrictions was self-reported. This assumes that the survey respondents had accurate knowledge of COVID-19 travel restrictions, thus enabling them to differentiate between behaviours that would constitute compliance or non-compliance. This was partially controlled for, as respondents were able to answer, "don't know". The survey question may also suffer from reporting bias given that non-compliance with COVID-19 restrictions is generally considered to be a socially undesirable act. However, the anonymity of the responses should limit the occurrence of this type of bias. Secondly, given that the survey was active during February 2021, the results should be interpreted with consideration of the political context at that time; in other words, the respondents' compliance was specific to the restrictions that were active during early 2021 in Scotland (see Table 1 for context). Despite this, the survey window coincided with a nationwide lockdown that advised residents to only leave their home for "essential travel", therefore, the data do provide insights into a period where compliance was particularly important for the suppression of COVID-19 infections. Thirdly, the survey

data were collected via the panel response system of Qualtrics, therefore, only complete responses were returned and no information was available regarding the response rate of the questionnaire. Understandability and duration of the survey were checked through the pilot. A further potential limitation concerns the aggregation of the dependent variable, from the original seven-point scale to a three-point scale, which may have induced aggregation bias to a limited extent. This was an unavoidable consequence of the dependent variable's distribution across the original seven levels, as the lowest outcomes contained too few responses for the application of the discrete outcome modelling framework and the extraction of meaningful results. To counteract this, we use an advanced statistical modelling framework with allowances for unobserved heterogeneity to draw granular insights from the independent variables, therefore minimizing the potential effects of aggregation bias. Finally, the survey data lacked granular geographical information to describe the respondents' area of residence. As a result, we were unable to account for the minutiae of respondents' neighbourhoods (e.g., walkability of streets, access to green space or public transport links and availability of active travel links).

CRediT authorship contribution statement

Torran Semple: Formal analysis, Writing – original draft, Writing – review & editing. **Achille Fonzone:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Grigorios Fountas:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Lucy Downey:** Methodology, Data curation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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