



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



ELSEVIER

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Transport disrupted – Substituting public transport by bike or car under Covid 19

Kerstin J. Schaefer^{a,*}, Leonie Tuitjer^a, Meike Levin-Keitel^b

^a Institute of Economic and Cultural Geography, Leibniz University, Schneiderberg 50, 30167 Hannover, Germany

^b Spatial Transformation in the Digital Age, TU Dortmund University, August-Schmidt-Straße 10, 44227 Dortmund, Germany

ARTICLE INFO

Keywords:

Covid 19
Public transport
Transport disruption
Substitutability
Travel behavior
Spatial embeddedness

ABSTRACT

The Covid 19 pandemic has caused dramatic disruptions in the public transport sector that has seen a stark downturn in many cities across the globe, calling into question previous efforts to reduce air pollution and CO₂ emissions by expanding this sector. Especially, the current surge of individual car use is worrying and the question remains which users might be able and willing to substitute public transport by cycling. This effect is interesting to study for the case of Hanover Region, because of the well-developed biking infrastructure that makes biking a viable alternative to individual car use. In this paper, we analyze survey data from June 2020 on the use of transportation modes before and during the pandemic in the Hanover Region. We ask if and how the over 4.000 participants substitute public transport and what characterizes those who chose biking over individual car use. We use multivariate regression models and find evidence that Stadtbahn (local light rail) and bus are substituted by bike, car and working from home, while train use is not significantly replaced by car and seems to be positively related to bike use. The data also shows that women have a higher level of fear of infection than men have during public transport use and therefore reduce public transport use more. Moreover, income displays a positive effect on increased car use while cycling is independent of socio-economic indicators but instead driven by the eco-consciousness of users. Surprisingly, we find that car use was increased in particular by residents of Hanover city, while it was decreased by residents of less densely populated urban areas in the region.

1. Introduction

The public transport sector has seen a drastic decline in demand and revenue during the Covid 19 pandemic (Tirachini and Cats, 2020). Not only did overall mobility decline as many people were sent into home office and social distancing measures led to the cancellation of many leisure activities, but buses and trains suddenly became perceived as places of potential infection. For the first time, many have considered climate friendly public transport from a health perspective. Thus, alternatives to local light rail, buses and trains that provide more isolation are in high demand. In many places, this spurred a (re)surge of car use. While across the globe, cities are involved in finding sustainable transport solutions to curb climate change emissions, reduce air pollution and react to ‘peak oil’ scenarios (Klinger et al., 2013), this development in travel mode choice is opposed to ongoing efforts to reduce CO₂ emissions. In the

* Corresponding author.

E-mail addresses: Schaefer@wigeo.uni-hannover.de (K.J. Schaefer), Tuitjer@kusogeo.uni-hannover.de (L. Tuitjer), Meike.levin-keitel@tu-dortmund.de (M. Levin-Keitel).

<https://doi.org/10.1016/j.tra.2021.09.002>

Received 14 December 2020; Received in revised form 27 August 2021; Accepted 1 September 2021

Available online 7 September 2021

0965-8564/© 2021 Elsevier Ltd. All rights reserved.

light of the current climate emergency, the expansion of the public transport system is one of the main measures to reduce emissions in passenger transport. Our analysis aims to establish how public transport was substituted during the Covid 19 crisis and what factors determined if car use or more climate friendly modes of travel (in particular biking) were chosen.

First international findings show that both car use and active forms of travel were preferred substitutions for public transport during the pandemic. Studies from Greece (Nikiforiadis et al., 2020) and Italy (Moslem et al., 2020) found a rise in active travel and a demand for more infrastructures such as bike sharing offers, bike lanes and parking spaces to sustain this favorable trend in cities like Milan or Thessaloniki. Our study offers a more robust statistical analysis as our sample size is larger and furthermore, we are able to include a wider variety of transport options and substitution effects than the above mentioned studies. A study by Kim & Kwan (2021) who looked at the effect of policy restrictions on people's overall mobility for US counties finds that the general mobility reduction was highest during the early phase of the pandemic in spring 2020 and wore off over time even as infection levels in the US were rising again during summer. Contributions from other regions such as Australia (Beck et al., 2020) and Italy (Moslem et al., 2020) demonstrate the worth of comparing travel behavior during lock down (spring 2020) and when restrictions were gradually eased again (in these regions in summer 2020). This generates actionable policy insights into broader questions of how the pandemic has affected work from home choices and urban travel behaviors. Similarly, we compare reported pre-pandemic levels (January/February 2020) of transport use and with those reported at a later state of the pandemic (late June 2020) when lock down measures were relaxed to report on the behavioral changes of residents.

Specifically, we study travel behavior, socio-economic status and environmental concern by analyzing a survey with over 4.000 respondents in the Hanover Region conducted end of June 2020. We model the effect of the reduction of public transport on bike and car use to gain insights into substitution effects during the pandemic. We also distinguish between the three spatial categories metropolis, medium-sized city and urban area in our research area based on population density and infrastructure availability to differentiate our findings. Such fine-grained socio-spatial analysis of travel behavior is scarce, but needed to generate actionable policy insights that are attentive to the needs of different urban and suburban settlement and mobility types.

The paper is organized as follows. Section 2 takes a closer look at the current situation of public transport during the pandemic. Section 3 reviews the literature on substitution of travel modes after disruptive events (like natural disasters, repair, maintenance, long-distance moves or terrorist attacks). Section 4 presents the case, the data and the methods, and Section 5 presents the results. Sections 6 and 7 go on to discuss the results and provides a conclusion.

2. Public transport during the Covid 19 pandemic

During the 2020 Covid 19 pandemic, government agencies across the globe (e.g. in South Korea (Park, 2020)) warned against public transport use and advocated for other forms of travel, to prevent the spread of the virus. Preliminary reports (Allgemeiner Deutscher Automobil Club, 2020; International Energy Agency, 2020) and few academic papers (Sparke and Anguelov, 2020; Suau-Sanchez et al., 2020) suggest that within the present Covid 19 pandemic the transport sector saw a severe downturn in demand and revenue in various countries. The International Energy Agency for example reports that in March 2020 London underground journeys decreased by 95% (International Energy Agency, 2020). The German Ministry of Transport and Digital Infrastructure commissioned a study in which the mobility patterns of 1000 participants were tracked between January 2020 and May 2020 (Institut für angewandte Sozialwissenschaft and MotionTag, 2020), finding a significant drop of public transport. In this study, however, the drop was explained by travel restrictions, partial shut downs and increasing shares of people in home office. The pandemic thus created a situation in which people both did not want to and furthermore did not need to use public transport as much as before. However, as travel restrictions were eased in summer, the demand for transportation grew again. More robust and local data on the reaction to the pandemic transport disruption in German cities is presently missing.

2.1. Transport disruptions

As there is little literature that systematically deals with disruptive health issues in public transport, we conceptually draw on related research about various causes for travel disruptions.

Whenever public transport is disrupted, daily routines and commutes are threatened and travel must be re-organized, which entails both challenges as well as opportunities for individuals and policy makers alike to re-orient travel behavior (Marsden and Docherty, 2013; Frater et al., 2020). Disruptions to public transport can take a variety of forms. Strikes (van Exel and Rietveld, 2009), mega events (Parkes et al., 2016) or maintenance (Marsden et al., 2020) are well-known and frequently experienced reasons for transport disruptions policy makers can plan for. Moreover, the literature on travel behavior research discusses the effect of residential neighborhood change and long-distance moves as disruptive events that trigger transport mode changes (De Vos et al., 2018; Klinger, 2017; Klinger and Lanzendorf, 2016; Scheiner, 2006; Scheiner and Holz-Rau, 2013; Verplanken et al., 2008).

Such diverse transport disruptions can take different temporal intervals (short term to long term), they can be planned (e.g. when maintenance is announced prior to its beginning) or unplanned (sudden technical difficulties) (Marsden et al., 2020). Attending to these parameters is crucial, as announced and short-term travel disruptions like pre-announced strikes usually only trigger a short-term modal shift in transport. For a one-day strike in the Netherlands, van Exel and Rietveld (2009) found, that 24 % of respondents switched to car use that day, however, "Despite high levels of perceived behavioral control and satisfaction with the chosen alternative, permanent modal shift as result of this strike is not expected" (ibid, p. 526). In contrast to such short term and pre-announced disruptions, a change of residential context poses a more permanent change to established travel choices. New routes as well as the physical infrastructure offered to the resident have the power to induce a break with existing travel patterns (Klinger and Lanzendorf,

2016; Klinger 2017). Similarly, the on-going nature of the Covid 19 pandemic and the uncertainties attached to the timing of its end may lead to a situation where new travel modes are not only tested but also become more permanent. Thus, there is a particular need for policy makers to build on the experiences made by a change of mode choice in order to use this as experimental field for a more sustainable mobility system (e.g. the Berlin pop-up bike lanes, Götting and Becker, 2020).

There is also a strand of literature on more sudden and destructive disruptions. Natural disasters disrupt both long distance travel as well as local public transport services (Sheller, 2013; Tuitjer, 2019; Adey and Anderson, 2011), demonstrating the vulnerability of urban and regional transport systems and the need for policy and planning to protect critical infrastructures (Zanni and Ryley, 2015) and to accommodate for sudden long term transport mode changes of big parts of society. Terrorist attacks and threats of attacks can equally disrupt public transport (Potoglou et al., 2010; Elias et al., 2013; Mattsson and Jenelius, 2015) and shake people's trust in its safety. Attacks on the London underground (2005) and Madrid commuter trains (2004) put the vulnerability of mass transport into sharp relief (Potoglou et al., 2010). Within previous health crises such as the SARS epidemic in 2003 (Wang and Thiel, 2014) or during the Swine Flu outbreak in 2009 (Rubin et al., 2009) people reduced their public transport use in Taipei City and the UK respectively, due to the fear of catching the disease. Transport policy makers and urban planners must thus address multiple sources of vulnerability within their urban transportation concepts to enhance their resilience.

2.2. Socio-economic factors influencing public transport substitution during disruptions

In light of the above mentioned disruptions, the literature on travel behavior discusses the concept of substitutability (van Wee et al., 2019), which is particularly designed to investigate travel alternatives during transport disruptions. Van Wee et al. (2019) dissect substitutability into change of activities, modes, routes and time. Such a perspective is useful for thinking through the disruptions and substitutions during the Covid 19 pandemic. When viewing the current decline in public transport use under the aspect of substitutability, we hypothesize that in general trips are being partially substituted by a change of activities, such as working at home instead of the office using digital means, whereas public transport trips in particular are additionally substituted by other modes of transportation. Therefore, public transport might experience a reduction driven by two different kinds of substitution: the avoidance of transport altogether through working from home and a change of transportation mode away from public transport.

During disruptive events, fear can be a powerful reason to avoid public transport (Potoglou et al., 2010). Goodwin et al. (2020) find that the Covid 19 outbreak led to a high degree of general anxiety in their Thai research sample and triggered a reduction of public transport use in Bangkok. Elias et al. (2013)'s research find that women are more likely than men to substitute public transport with private car travel in the case of terrorist attacks. The rich tradition of risk research (Finucane et al., 2000) as well as research on travel behavior and transport choices of women (García-Jiménez et al., 2020) confirms the correlation between gender and risk perception. It thus seems likely that female gender correlates positively with fear of the catching the virus and thus shapes travel behaviors during the current pandemic. We therefore expect women to avoid using public transport more frequently than men due to fear of catching the virus.

A key predictor for substitution of public transport with other means of travel apart from fear and gender is disposable income. Car use, as an alternative to public transport, is especially dependent on income and access to a car, which is confirmed by research looking at such wide ranging forms of disruptions like natural disasters, household moves or terrorist threats. Klinger and Lanzendorf (2016) study long distance moves between selected German cities and confirm that besides spatial characteristics car use is especially dependent on socio-economic factors. Socio-economic aspects influence which alternative modes of transport are available to people in times of crisis. Therefore, it is crucial for policy development to understand how far socio-economic factors shaped transport substitution options during the Covid 19 pandemic.

A more active and particularly cheap alternative to using public transport during the pandemic is cycling. Yet, whether people switch to biking is dependent on various factors. Research focusing on student mobility has found that cycling is especially popular among students as it is such a cheap transport option (Cadima et al., 2020; Mohammadzadeh, 2020; Nash and Mitra, 2019). De Vos (2020) adds that active forms of travel also enhance subjective feelings of well-being, which is important in the current pandemic as social distancing rules can increase feelings of anxiety, stress, isolation and depression. Thus, promoting active travel during the pandemic might address extended policy goals (e.g. public health) which go beyond the aim of increasing sustainable urban transport. However, active modes of travel might be less viable for people with handicaps, young children or elderly people.

2.3. Environmental concern and travel mode choice

Travel choices are not only determined by objective factors of a person's life situation but also by subjective factors such as personal attitudes, preferences and lifestyle (Mokhtarian and Salomon, 1997; Scheiner and Holz-Rau, 2007; Hunecke, 2015). Research has found that people who report high eco-consciousness are more likely to switch to active modes of travel such as biking when confronted with the need of behavioral change in transport situations through relocation (Klinger and Lanzendorf, 2016). Yet, classic work in environmental behavior that is interested in the discrepancy between attitudes and actual environmental practices, foregrounds the low-cost strategy, which makes actual environmental behavior more likely, if people perceive the costs of doing so as low (Diekmann and Preisendörfer, 1998).

As argued before, within moments of disruption may also lie chances for behavioral change, in particular if such changes are sustained by attitudes and values of people (Frater et al., 2020). Moreover, by studying relocation effects within the city of Ghent, De Vos et al. (2018) conclude that residents might also change their attitude towards new transportation modes fit to their new environment gradually over time. A longer period of Covid 19 related disruption could thus serve as the type of disruption that encourages

people to switch to biking. In short, travel modes are determined by a complex interplay between choices and constraint that individuals need to navigate (Schwanen et al., 2012) and environmental concern seems an important subjective factor that influences substitution practices during the Covid 19 pandemic.

2.4. Spatial embeddedness

It is common ground in the literature that mobility and transport modes are place-specific (e.g. Stead and Marshall, 2001; Holz-Rau et al., 2014; Naess, 2011; Cao, 2009), and so is the mode choice change and the substitutability of transport – experience shows that it increases with the intensity of the use of space including not only a high population density as potential public transport users but also the mix of land uses such as housing, shopping facilities, job vacancies (UBA (Hrsg.), 2020). Scheiner and Holz-Rau (2007) even identify spatial factors as the most salient factor that determines travel mode choices. Apparently, the substitutability of transport is particularly high in dense metropolitan areas and particularly low in small towns and villages in rural regions, as the accessibility of public transport varies fundamentally. Others (Schwanen and Mokhtarian, 2005; Handy et al., 2005) have shown in their studies about the relation between built environment and travel behaviour that even if the latter is largely explained by attitudes, changes in travel behaviour and changes in the built environment show significant associations (Schwanen and Mokhtarian, 2005).

From a policy perspective, the spatial embeddedness of mode choice allows a closer look in local-specific contexts and in how far the changes of mode choice are affected by different spatial arrangements (Levin-Keitel et al., 2018). For example, the opportunities to avoid crowds of people in public transport differs in urban neighbourhoods, in small towns or rural villages without a direct connection to the regional rail or bus network. This local-specific potential depends crucially on the overall network of cities in the Hanover Region, how work and life are spatially organised, which infrastructures are located where and which traffic this induces - in short the organization of the region in terms of infrastructure and accessibility (along the logic of central-places). Therefore, we assume differences in how public transport can be substituted between the dense urban area and the differently classified suburban areas, between medium and basic centres in a metropolitan region.

3. Research questions

Stemming from the insights of the literature, we arrive at a set of research questions about the reduction and substitution of public transport use during the COVID-19 pandemic. First, we have to ask if we can observe a decrease in public transport and an increase in bike and car use during the pandemic in the observed region. The second question following the literature on what shapes travel mode choices is how socio-economic factors affect the avoidance of public transport and how these factors affect the substitution by bike and car. In order to account for the literature discussion, we also ask which role these socio-economic factors plays for explaining fear of infection during public transport use. We further ask how eco-consciousness affects the substitution of public transport by bike or car during the pandemic in order to better understand its effect on travel mode changes during the pandemic. The last question we pose here is the role of the spatial environment, in particular density and infrastructure, in how these effects play out.

4. Case study and method

4.1. Case study site: Hanover Region

Hanover is the capital city of the northern German federal state Lower Saxony. The city has a population of 521,000 inhabitants and more than 1 million inhabitants within the urban region. Since the 1990s, Hanover has been particularly active within various climate change initiatives, thus raising its international profile as a green city. For example, Hanover is a founding member of Local Governments for Sustainability, a global network committed to sustainable urban development (Emelianoff, 2014). Moreover, the green party has been strong in city politics since the late 1990s and succeeded in winning the mayor election in 2019. The Green Party mayor Belit Onay is further fostering the development of public transport, bike paths and car-free zones within the city (Landeshauptstadt Hannover, 2011). Within Hanover Region, transport can be organized via bus and rail, car, or local light rail, the so-called Stadtbahn that operates partially on the street and underground, as well as active modes of travel such as cycling or walking. Investment into the well-developed public transport sector plays an important role for reducing CO₂-emissions contributing to the city's green profile (Emelianoff, 2014). In Hanover, increasing shares of public transport (underground systems, bus services using e-buses) is an important element to achieve these goals. Therefore, it is important to monitor how the pandemic affects travel behavior within the city as a potential increase in car use directly conflicts with the declared aim to reduce traffic emissions to combat climate change (Landeshauptstadt Hannover, 2011).

4.2. Method

In order to investigate the change in public transport use in Hanover Region during the pandemic, we are using online survey data obtained between June 15th and June 30th 2020 in a survey on the future of mobility in Hanover. At the time of the survey, many restrictions that had been in place during the peak of the first wave of the Covid 19 pandemic in Germany (such as social distancing measures as well as closing schools, kindergartens, retail and leisure spaces) were lifted, as curbing the spread of the virus in spring had been successful. Shops, restaurants and museums were open again, more than two households were allowed to meet and childcare as well as schools had partially reopened.

The main population, from which a sample of 4,359 questionnaires was generated, are people who are regularly using public transport in Hanover Region and hence defined as people either living or working in the region. Only 273 participants did report to live but not work in Hanover Region and 91 participants reported to work but not live in Hanover Region. We therefore were able to record 3,271 respondents living and working in Hanover Region while 673 respondents only reported their place of residence or work and 118 respondents preferred not to report either in detail. Every participant is counted once, independently of whether they live, work or live and work in the study area. The survey had a maximum of 201 questions if no filters applied and completion took on average 22 min with an overall completion rate of over 70 %. The Institute of Economic and Cultural Geography at Leibniz University Hanover conducted the survey in cooperation with the *Region Hannover*, the administration of Hanover Region. It was advertised explicitly calling upon people living or/and working in the region through various platforms such as the ticketing website of the GVH (Großraum-Verkehr Hannover), which is the public transport association for Hanover Region, social media and the Leibniz University.

Even if the overall case study region is a dense urban environment, its spatial structure is nevertheless heterogeneous. For the analyses including spatial dimensions, the respondents were grouped by place of residence according to the RegioStaR17 categorization for spatial transport research provided by the German federal ministry of transport and digital infrastructure (BMVI, 2018). We omitted the 91 respondents not residing in the Hanover Region for the analysis for consistency. This hierarchical spatial categorization is based on spatial settlement patterns, supply facilities, infrastructure and accessibility (BMVI, 2018). For our case, the metropolitan categories indicating a metropolis with more than 100.000 inhabitants and a catchment area over 25% commuter within a travel time of at least 35 min, are used. In the region of Hanover the metropolis (111) with the federal capital Hanover, medium-sized cities (113) and urban areas (114) were used to distinguish spatial categories according to their population density, accessibility and regional interrelations such as employment facilities, commuting activities or infrastructural services, as shown in Fig. 1. The map shows that this categorization does not represent how far the area is located from the city center but its structural endowment. We had to omit category 115 because it is not sufficiently represented in Hanover Region in terms of population.

RegioStaR spatial categories for Hanover Region

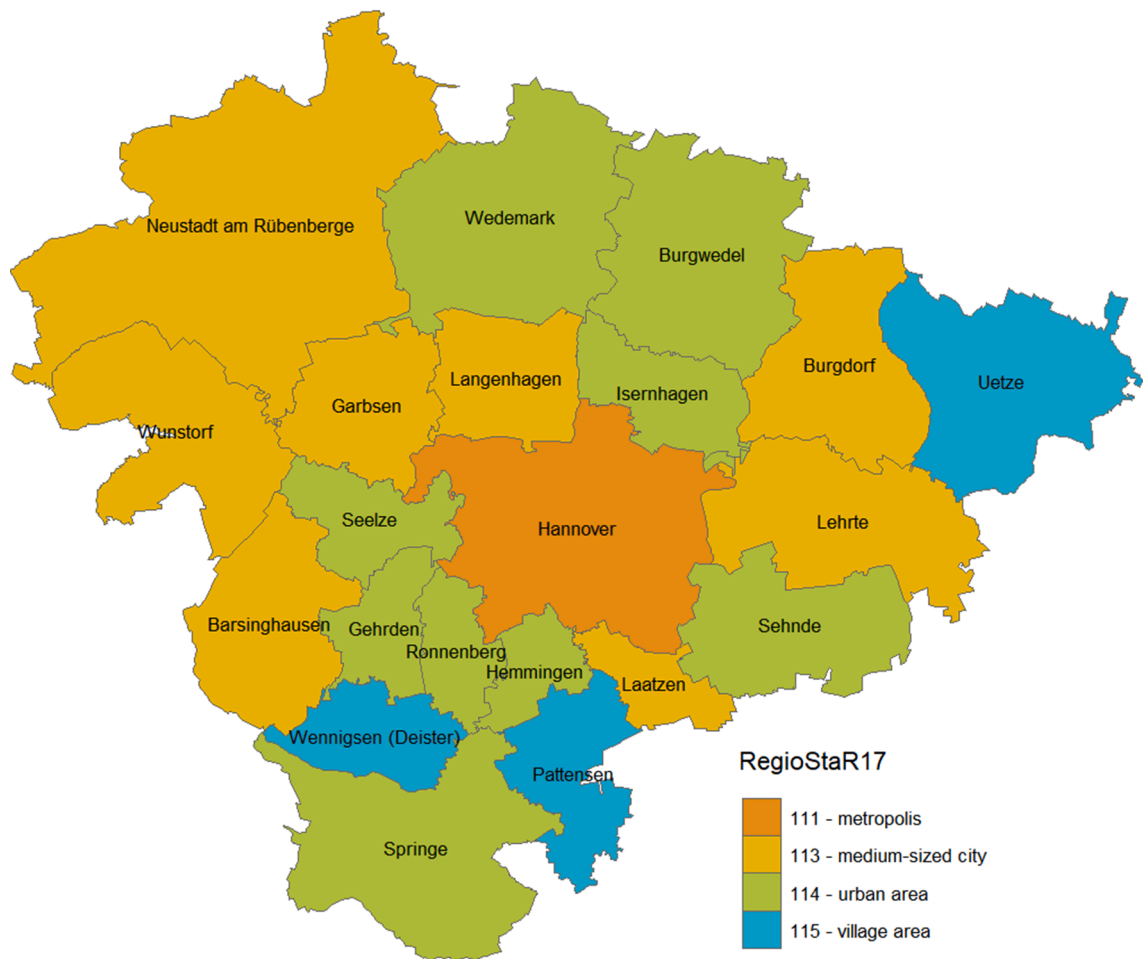


Fig. 1. Location of spatial categories in Hanover Region.

Table 1 shows the socio-economic characteristics of the overall sample and the spatial categories. The gender balance between men and women is even, but only few participants identified as diverse. What seems surprising, is the lower number of women compared to men for the medium-sized city and urban area categories. The sample includes 74 % of participants living directly in the city while 26 % come from the surrounding region. In terms of age, we find that the sample has only few participants over 65, which is a common bias in online surveys due to digital barriers for this age group. The age group of under 30 is over represented coinciding with the large proportion of university students in the sample. This group mainly drives the 40 % of participants in the lowest income group. This might be because respondents with permanently low-incomes did chose not to report their income category in the questionnaire. People without a job and with a permanently low income seem to be under represented. As the main population cannot be quantified exactly as there is no detailed information on age or gender of people working in the region but residing outside, we cannot determine exactly how representative the sample is of our main population. However, given the form of the survey as an online survey without random selection and the afore mentioned underrepresentation of certain groups that stems from it, we understand that our sample is not statistically representative of the main population. This needs to be taken into account when interpreting the results of the inference statistical analyses.

In order to answer the first research question about the change in transport behavior during the pandemic, we use a one-sample t-test to establish which modes of transport are used differently. This gives us a first impression of how transportation use has actually changed. The change is measured as the difference between the use of the three public transport modes Stadtbahn, bus and train in number of days per month before and during the pandemic (*stbh_diff*, *bus_diff* and *train_diff*).

For the second research questions about the impact of socio-economic factors, we used linear regression to estimate the before mentioned change in the three public transport modes (models 1–3). The variables used to assess the socio-economic status of participants are *income* and *age* as well as a dummy for gender (*female*) and one for higher education (*univ_deg*). We also control for fear from infection during public transport use (*fear*), the length of commute in kilometers (*commute*), whether the respondent worked from home (*home_off*) and how often the transport mode was used before the pandemic (*stbh_bf*, *bus_bf* and *train_bf*).

$$\begin{aligned}
 stbh_diff_i &= \beta_0 + \beta_1 income_i + \beta_2 age_i + \beta_3 female_i + \beta_4 univ_deg_i + \beta_5 fear_i + \beta_6 commute_i + \beta_7 home_off_i + \beta_8 stbh_bf_i \\
 bus_diff_i &= \beta_0 + \beta_1 income_i + \beta_2 age_i + \beta_3 female_i + \beta_4 univ_deg_i + \beta_5 fear_i + \beta_6 commute_i + \beta_7 home_off_i + \beta_8 stbh_bf_i \\
 train_diff_i &= \beta_0 + \beta_1 income_i + \beta_2 age_i + \beta_3 female_i + \beta_4 univ_deg_i + \beta_5 fear_i + \beta_6 commute_i + \beta_7 home_off_i + \beta_8 stbh_bf_i
 \end{aligned}$$

Because we find that the level of fear from infection during public transport use (*fear*) is a mediator between socio-economic variables and the change in public transport use (*stbh_diff*, *bus_diff* and *train_diff*) and therefore might mask their effect, we include models 4–7 that analyze a potential mediator effect. Models 4–6 show models 1–3 without the mediator variable *fear* and model seven shows the effect of the socio-economic variables on *fear* in order to assess the mediator effect.

$$\begin{aligned}
 stbh_diff_i &= \beta_0 + \beta_1 income_i + \beta_2 age_i + \beta_3 female_i + \beta_4 univ_deg_i + \beta_5 commute_i + \beta_6 home_off_i + \beta_7 stbh_bf_i \\
 bus_diff_i &= \beta_0 + \beta_1 income_i + \beta_2 age_i + \beta_3 female_i + \beta_4 univ_deg_i + \beta_5 commute_i + \beta_6 home_off_i + \beta_7 bus_bf_i
 \end{aligned}$$

Table 1
Socio-economic characteristics of respondents.

Variable	Value	Overall sample (%)	Sample metropolis (111) (%)	Sample Medium-sized city (113) (%)	Sample Urban area (114) (%)
Age	< 30	52,21	56,39	41,3	39,51
	30–44	20,53	20,27	23,69	18,27
	45–65	24,75	21,5	29,14	38,77
	>65	2,51	1,84	5,87	3,46
	Gender	Female	49,14	49,93	45,51
	Male	50,31	49,48	53,85	52,12
	Diverse	0,54	0,59	0,64	0,25
Income	<= 1.000 €	38,3	40,40	31,82	32,24
	>1.000–1.500 €	11,43	12,84	8,02	6,58
	>1.500–2000 €	10,68	10,15	10,7	12,83
	>2.000–2.500 €	14,36	14,40	17,38	11,84
	>2.500–3.000 €	10,83	10,36	13,90	10,53
	>3.000 €	14,39	11,84	18,18	25,99
Education	University degree	54,24	56,77	43,35	50,25
Job status	School student	1,68	1,1	2,88	3,36
	University student	46,2	50,06	36,95	34,37
	Employed	49,14	46,35	54,65	58,4
	Unemployed	0,36	0,42	0,44	0
	Retired	2,61	2,08	5,09	3,88
Place of residence	Hanover city	74	100	0	0
	Hanover Region (except Hanover city)	25,97	0	100	100
	Outside Hanover Region	0,03	0	0	0
Mobility needs	People with reduced mobility	7,43	6,1	9,9	12,43

$$\begin{aligned} \text{train_diff}_i &= \beta_0 + \beta_1 \text{income}_i + \beta_2 \text{age}_i + \beta_3 \text{female}_i + \beta_4 \text{univ_deg}_i + \beta_5 \text{commute}_i + \beta_6 \text{home_off}_i + \beta_7 \text{train_bf}_i \\ \text{fear}_i &= \beta_0 + \beta_1 \text{income}_i + \beta_2 \text{age}_i + \beta_3 \text{female}_i + \beta_4 \text{univ_deg}_i + \beta_5 \text{commute}_i + \beta_6 \text{home_off}_i \end{aligned}$$

In order to dive further into the question how socio-economic factors affects the substitution of public transport during the pandemic, we analyze how the change in public transport use leads to a change in biking or car use and subsequently separate the models by spatial categories. The model also takes into account the third research question on eco-consciousness. We use ordinary least square regression to model the following two dependent variables and compare the effects:

$$\begin{aligned} \text{bike_diff}_i &= \beta_0 + \beta_1 \text{stbh_diff}_i + \beta_2 \text{bus_diff}_i + \beta_3 \text{train_diff}_i + \beta_4 \text{income}_i + \beta_5 \text{age}_i + \beta_6 \text{female}_i + \\ &\beta_7 \text{univ_deg}_i + \beta_8 \text{eco_con}_i + \beta_9 \text{fear}_i + \beta_{10} \text{commute}_i + \beta_{11} \text{home_off}_i + \beta_{12} \text{car_acc}_i + \beta_{13} \text{bike_bf}_i + \beta_{14} \text{car_bf}_i \\ \text{car_diff}_i &= \beta_0 + \beta_1 \text{stbh_diff}_i + \beta_2 \text{bus_diff}_i + \beta_3 \text{train_diff}_i + \beta_4 \text{income}_i + \beta_5 \text{age}_i + \beta_6 \text{female}_i + \\ &\beta_7 \text{univ_deg}_i + \beta_8 \text{eco_con}_i + \beta_9 \text{fear}_i + \beta_{10} \text{commute}_i + \beta_{11} \text{home_off}_i + \beta_{12} \text{car_acc}_i + \beta_{13} \text{bike_bf}_i + \beta_{14} \text{car_bf}_i \end{aligned}$$

Our statistical models 8 and 9 explain the change in bike (*bike_diff*) and car (*car_diff*) use during the pandemic by the change in public transport use, socio-economic characteristics and eco-consciousness. The models contain three types of independent variables. The first type are the changes in public transport use as used in models 1–3. The second type of independent variables are the socio-economic factors that were also used in the first three models. The third type of variables is the respondent’s eco-consciousness (*eco_con*) as well as fear from infection during public transport use (*fear*). We control for commuting distance (*commute*) as part of people’s daily transportation, how much people currently work from home (*home_off*), if they have access to a car (*car_acc*) and how much they used bike (*bike_bf*) or car (*car_bf*) as transportation before the pandemic. In order to analyze the spatial variations of the model effects, the sample then is split along the three spatial categories metropolis, medium-sized cities and urban area as discussed above, producing models 10 to 15.

5. Results

In order to investigate if public transport was reduced and bike or car use increased during the pandemic, we analyze the change in transportation mode use in days per month during the pandemic with a one-sample *t*-test against a change of zero. Fig. 2 visualizes the estimated change for each transport mode and the respective confidence intervals while Table 2 displays the values accordingly. As expected, we see an increase in the use of bikes and cars. We see that the mean for bike use is slightly higher but has also a larger confidence interval compared to car use. In contrast, public transport such as Stadtbahn, buses and trains are clearly being used less frequently during the pandemic. The strongest change is apparent for the Stadtbahn, which is on average used almost seven days less during the pandemic. The use of buses and trains decreased by around two and three days per month respectively. These numbers still

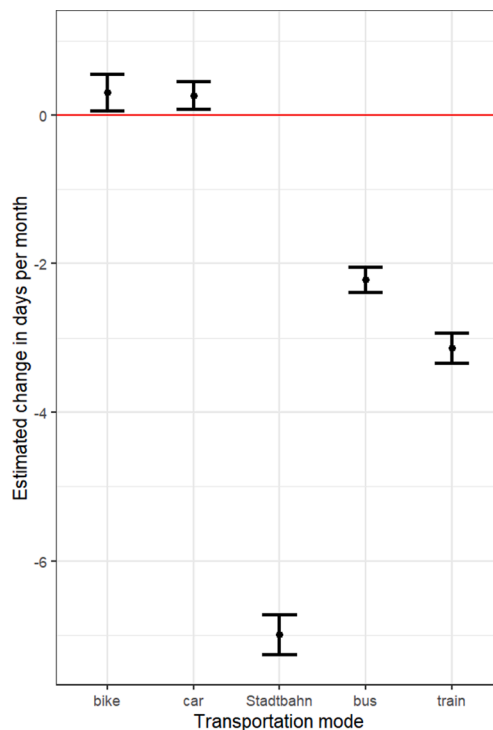


Fig. 2. Estimated change and confidence intervals of transport mode choice.

Table 2
One sample *t*-test against zero.

Mode	mean	p-value	95%-CI	t	df
bike	0.30	0.0178	0.05–0.55	2.37	4127
car	0.26	0.0053	0.08–0.45	2.79	4100
Stadtbahn	−6.99	<0.00	−7.26 to −6.72	−51.0	4039
bus	−2.22	<0.00	−2.39 to −2.05	−25.8	3878
train	−3.14	<0.00	−3.34 to −2.94	−30.3	3942

include the effect of generally reduced mobility during the pandemic because of an increase in people working from home and is therefore not suited for a long-term prognosis of transport use. However, they provide a good overview of the change in transportation mode use after the first wave of the pandemic receded.

5.1. Multivariate regression analysis

The following models in Table 3 show how socio-economic factors affected the change in public transport use. Income seems to decrease the use of public transport, in particular for buses and trains, while a small positive effect size for age seems to suggest that elder people reduce public transport use less. The variables being female and having a university degree do not show any significant effects while fear has a strong effect on public transport use in particular for Stadtbahn. As expected, the control variables commuting distance, working from home and how often the transport mode was used before the pandemic have a negative impact on using public transport (except for commute on bus use).

Overall, models 1–3 show that income and fear seem to play a decisive role. However, we find from robustness checks that fear seems to play a mediating role masking the effect of some socio-economic variables on public transport use. We therefore analyze this effect in models 4–6 by leaving out fear as a variable and using it as a dependent variable in model 7. The results in Table 4 show that fear is a mediator for the strong effect of being female on Stadtbahn use as well a smaller effect on train use. The mediator masks the effect of being female in model 1 and 3, as shown by the significant effect of this independent variable in model 4 as well as the strong effect of being female on fear in model 7. Other effect sizes change only slightly between models 1–3 and models 4–6 and we can

Table 3
Linear regression models 1–3.

Dependent variable:	Dependent variable:		
	stbh_diff (1)	bus_diff (2)	train_diff (3)
<i>Socio-economic variables:</i>			
income	−0.111 (0.075)	−0.110** (0.047)	−0.113** (0.056)
age	0.021* (0.011)	0.013* (0.007)	0.014* (0.008)
female	−0.004 (0.182)	0.001 (0.116)	0.017 (0.138)
univ_deg	0.209 (0.194)	0.202* (0.123)	0.079 (0.146)
fear	−1.094*** (0.055)	−0.421*** (0.035)	−0.499*** (0.042)
<i>Control variables:</i>			
commute	−0.034*** (0.008)	0.0003 (0.005)	−0.039*** (0.007)
home_off	−0.492*** (0.055)	−0.239*** (0.035)	−0.435*** (0.042)
stbh_bf	−0.695*** (0.010)		
bus_bf		−0.653*** (0.009)	
train_bf			−0.622*** (0.011)
Constant	5.743*** (0.487)	2.274*** (0.297)	3.901*** (0.351)
Observations	2,758	2,648	2,692
R ²	0.708	0.697	0.679
Adjusted R ²	0.707	0.696	0.678
Residual Std. Error	4.679 (df = 2749)	2.907 (df = 2639)	3.494 (df = 2683)
F Statistic	831.497*** (df = 8; 2749)	759.565*** (df = 8; 2639)	710.211*** (df = 8; 2683)

Note: **p* < 0.1; ***p* < 0.05; ****p* < 0.01.

Table 4
Linear regression models 4–7.

	<i>Dependent variable:</i>			
	<u>stbh_diff</u>	<u>bus_diff</u>	<u>train_diff</u>	<u>fear</u>
	(4)	(5)	(6)	(7)
<i>Socio-economic variables:</i>				
income	–0.143* (0.079)	–0.121** (0.048)	–0.133** (0.057)	0.046* (0.025)
age	0.015 (0.011)	0.010 (0.007)	0.011 (0.008)	0.007** (0.003)
female	–0.507*** (0.191)	–0.188 (0.116)	–0.233* (0.138)	0.474*** (0.061)
univ_deg	0.180 (0.204)	0.183 (0.124)	0.085 (0.148)	0.013 (0.066)
<i>Control variables:</i>				
commute	–0.030*** (0.008)	0.003 (0.005)	–0.040*** (0.007)	–0.006** (0.003)
home_off	–0.597*** (0.058)	–0.279*** (0.035)	–0.485*** (0.042)	0.104*** (0.019)
stbh_bf	–0.684*** (0.010)			
bus_bf		–0.651*** (0.009)		
train_bf			–0.609*** (0.011)	
Constant	2.793*** (0.490)	1.181*** (0.287)	2.596*** (0.338)	2.461*** (0.148)
Observations	2,804	2,694	2,738	2,918
R2	0.667	0.684	0.663	0.032
Adjusted R2	0.667	0.683	0.662	0.030
Residual Std. Error	4.983 (df = 2796)	2.970 (df = 2686)	3.564 (df = 2730)	1.636 (df = 2911)
F Statistic	801.310*** (df = 7; 2796)	829.421*** (df = 7; 2686)	767.617*** (df = 7; 2730)	16.112*** (df = 6; 2911)

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

therefore rule out additional mediator effects. In addition to proving the mediating effect of fear, model 7 provides further insights on the determinants behind the fear of catching the virus while using public transport. We can clearly see that in addition to being female, age and income both influence the level of fear reported. We therefore find that income predicts the reduction of public transport directly while gender predicts it through the mediator fear, while the fear of using it itself is driven by gender, age and income.

The ordinary least squares models in Table 5 show the two dependent variables *bike_diff* and *car_diff*. The first section of variables includes the change in public transport use as a predictor for the change in bike and car use, which states that public transport is at least partially substituted by bike and car use during the pandemic. The results of models 8 and 9 indicate that a decrease in the use of Stadtbahn and buses increases the use of biking and car driving. The effect of Stadtbahn use on bike use is higher than for cars while the effect of bus use is similar for both substitutes. This implicates that Stadtbahn is replaced mostly by biking, whereas buses which are more broadly available are replaced by bikes and cars alike. The use of trains however is positively associated with biking while it is negatively but not significantly associated with car use, indicating that they are mostly used in combination with bikes but not as a substitute. This might be due to the longer distances people travel by train compared to bus, Stadtbahn and bike. This result points out that train rides are not substitutable by bike but both modes are rather used in combination.

The second section of variables relates to socio-economic factors determining the increase of bike and car use. The results show that income categories do not systematically influence bike use but predict the change in car use. This finding is in line with Klinger and Lanzendorf (2016) who find that the use of cars can be explained by socio-economic factors more than the use of other transport modes. In our case, this implies that people who are in a higher income category tend to use cars more often to fulfill their mobility needs during the pandemic than before. The age of the participants seems to play a minor role for determining who is biking during the pandemic while it has a statistically significant negative impact on car use. This means the older the participants the less they are using a car during the pandemic, possibly pointing towards a higher reduction of travel activity altogether. The influence of the dummy variables for being female and a university degree varies too much to have a systematic influence on the dependent variable. A robustness check without including fear in the model shows that there is no strong moderating effect of fear for being female in these models. However, in the alternative model 9 being female has a significant impact of 0.392 with a significance on the 0.1 level on the increase in car use. Overall, we can see that the socio-economic variables are more differentiated between bike and car use, but have less explanatory power than the change in public transport use.

The third section of variables includes eco-consciousness and fear to see if environmental conscious people increased biking during the pandemic and how fear impacts substitution. We can see from models 8 and 9 that eco-consciousness is one of the strongest

Table 5
Linear regression models 8 and 9.

<i>Dependent variable:</i>		
	BK_diff	CR_diff
	(8)	(9)
<i>Change in public transport use:</i>		
stbh_diff	−0.197*** (0.021)	−0.076*** (0.016)
bus_diff	−0.085*** (0.030)	−0.080*** (0.022)
train_diff	0.146*** (0.029)	−0.028 (0.021)
<i>Socio-economic variables:</i>		
income	0.076 (0.121)	0.182** (0.088)
age	0.019 (0.018)	−0.050*** (0.013)
female	0.305 (0.291)	0.269 (0.213)
univ_deg	0.527* (0.313)	−0.310 (0.229)
<i>Eco-consciousness and fear</i>		
eco_con	0.503*** (0.116)	−0.571*** (0.085)
fear	0.333*** (0.090)	0.321*** (0.066)
<i>Controls</i>		
commute	−0.031** (0.015)	−0.042*** (0.011)
home_off	−1.040*** (0.090)	−0.456*** (0.066)
car_acc	−0.965*** (0.350)	2.483*** (0.256)
bike_bf	−0.290*** (0.016)	−0.016 (0.011)
car_bf	−0.001 (0.023)	−0.358*** (0.017)
Constant	3.456*** (0.922)	5.431*** (0.676)
Observations	2,507	2,502
R ²	0.273	0.240
Adjusted R ²	0.269	0.235
Residual Std. Error	7.106 (df = 2492)	5.199 (df = 2487)
F Statistic	66.756*** (df = 14; 2492)	55.988*** (df = 14; 2487)

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

predictors for bike and against car use during the pandemic. Moreover, we find that eco-consciousness is a stronger predictor for an increase in bike or car use than socio-economic variables, which display a higher variation in predicting change in bike and car use. However, there might be a recursive effect of people using their bike or car more often during the pandemic for other reasons than eco-consciousness but reporting a higher or lower preference for sustainable mobility decisions for the sake of being consistent with their behavior. Therefore, it is difficult to claim causality for this relation. Fear also seems to be a strong predictor, driving the increase in bike and car use with similar effect strength.

Next, we turn to the research question on the spatial differentiation of the substitution effects. As a first step, we get an overview of the change in transport use separated by the three spatial categories we obtained from the RegioStaR17 categorization (metropolis (1 1 1), medium-sized city (1 1 3) and urban area (1 1 4)) in Fig. 3. We clearly see that the difference between the transport modes is for the most part larger than between the spatial categories of the same transport mode. The largest difference between spatial categories can be seen for train use, where residents of the metropolis category had a much lower reduction compared to the other two categories. The most surprising finding here is the difference in car use. In contrast to what we would expect, we find that residents of the metropolis increase car use the most, while the least densely populated urban area category shows even a significant decrease in car use.

Turning to our regression models, Fig. 4 gives an overview of the difference in standardized estimates while Table 6 provides the original coefficients. When interpreting the significance of the coefficients, we need to keep in mind that the sample contains a much larger number of respondents living in the metropolis than in the other two categories.

Comparing the coefficients shows that the use of Stadtbahn and buses increased bike use significantly only for residents in the

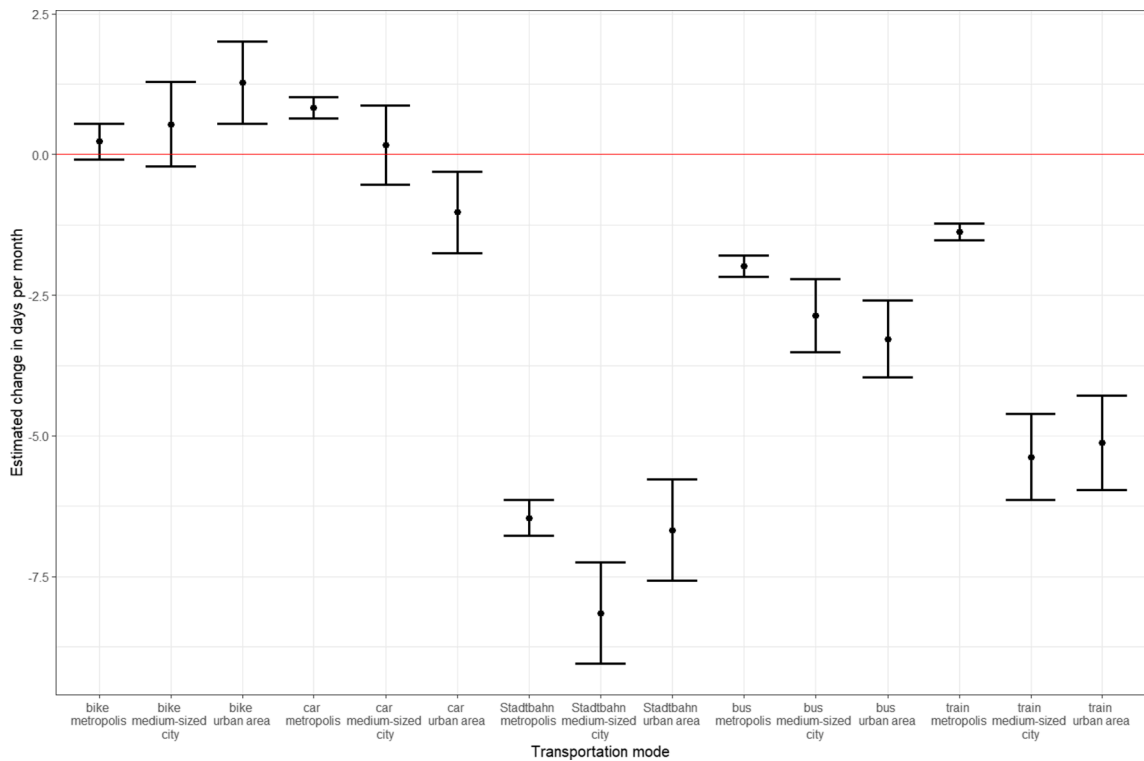


Fig. 3. Estimated change of transport mode choice by spatial category.

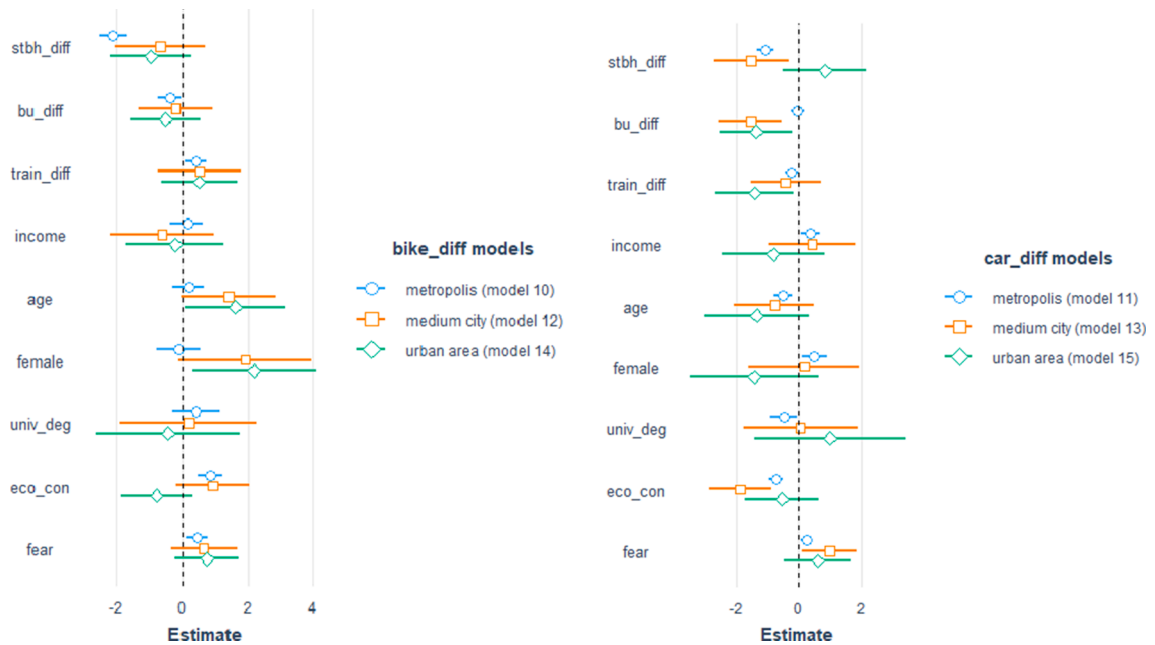


Fig. 4. Comparison of standardized model coefficients.

metropolis, while the other spatial categories show a non-significant reduction. The symbiotic relationship between public transport and biking has been explored elsewhere (Kager et al. 2016; Nello-Deakin and te Brömmelstroet, 2021) and our research seems to confirm that there is indeed an interaction between these two transport modes. Further, reduced bus use increases car use particularly for residents of the medium-sized cities and urban areas. Income seems to increase car use in particular for metropolis residents while

Table 6
Linear regression models 10–15.

<i>Dependent variable:</i>						
	<u>bike_diff</u> <u>metropolis</u>	<u>car_diff</u> <u>metropolis</u>	<u>bike_diff</u> <u>medium-sized city</u>	<u>car_diff</u> <u>medium-sized city</u>	<u>bike_diff</u> <u>urban area</u>	<u>car_diff</u> <u>urban area</u>
	(10)	(11)	(12)	(13)	(14)	(15)
<i>Change in public transport use:</i>						
stbh_diff	−0.257*** (0.026)	−0.132*** (0.016)	−0.071 (0.073)	−0.162** (0.065)	−0.107 (0.069)	0.091 (0.076)
bus_diff	−0.081** (0.037)	−0.008 (0.023)	−0.035 (0.101)	−0.268*** (0.089)	−0.075 (0.080)	−0.204** (0.087)
train_diff	0.112** (0.049)	−0.066** (0.030)	0.065 (0.083)	−0.054 (0.073)	0.063 (0.072)	−0.175** (0.078)
<i>Socio-economic variables:</i>						
income	0.076 (0.144)	0.206** (0.087)	−0.324 (0.423)	0.220 (0.373)	−0.106 (0.366)	−0.395 (0.399)
age	0.015 (0.021)	−0.043*** (0.013)	0.102* (0.052)	−0.057 (0.046)	0.109** (0.053)	−0.092 (0.057)
female	−0.122 (0.342)	0.495** (0.208)	1.917* (1.025)	0.161 (0.906)	2.194** (0.958)	−1.437 (1.048)
univ_deg	0.420 (0.369)	−0.493** (0.225)	0.182 (1.056)	0.043 (0.932)	−0.446 (1.120)	0.993 (1.224)
<i>Eco-consciousness and fear:</i>						
eco_con	0.630*** (0.137)	−0.555*** (0.083)	0.656 (0.402)	−1.336*** (0.360)	−0.591 (0.413)	−0.413 (0.454)
fear	0.279** (0.110)	0.158** (0.067)	0.363 (0.284)	0.541** (0.251)	0.428 (0.276)	0.339 (0.304)
<i>Controls:</i>						
commute	0.0001 (0.025)	−0.036** (0.015)	−0.027 (0.074)	0.092 (0.065)	0.017 (0.061)	−0.033 (0.067)
home_off	−1.281*** (0.106)	−0.139** (0.064)	−0.254 (0.296)	−1.548*** (0.261)	−0.234 (0.294)	−1.533*** (0.320)
car_acc	−0.869** (0.410)	2.443*** (0.249)	−1.333 (1.340)	2.876** (1.186)	−0.686 (1.243)	2.494* (1.361)
bike_bf	−0.277*** (0.019)	0.013 (0.011)	−0.384*** (0.059)	−0.013 (0.052)	−0.234*** (0.052)	−0.074 (0.056)
car_bf	−0.013 (0.036)	−0.295*** (0.022)	0.066 (0.062)	−0.386*** (0.055)	−0.082 (0.058)	−0.295*** (0.064)
Constant	3.831*** (1.110)	3.331*** (0.674)	−2.505 (3.012)	9.503*** (2.674)	1.258 (2.868)	11.776*** (3.143)
Observations	1,833	1,830	237	236	194	193
R ²	0.308	0.201	0.262	0.391	0.245	0.293
Adjusted R ²	0.303	0.195	0.216	0.352	0.186	0.237
Residual Std. Error	7.136 (df = 1818)	4.331 (df = 1815)	7.442 (df = 222)	6.562 (df = 221)	6.167 (df = 179)	6.719 (df = 178)
F Statistic	57.883*** (df = 14; 1818)	32.658*** (df = 14; 1815)	5.643*** (df = 14; 222)	10.116*** (df = 14; 221)	4.156*** (df = 14; 179)	5.271*** (df = 14; 178)

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

the effect is not significant for residents of the other spatial categories. The effect of income is still insignificant for predicting bike use in all spatial categories. Age has a negative impact on car use for metropolis respondents while it plays no role for predicting the change in bike use. However, bike use increases with age for the other spatial categories.

We also observe that being female has a positive impact on bike use for the least densely populated category. This effect expands to the medium-sized city in a robustness check for the models without the variable fear. However, including fear has only a small impact on the effect of being female in the models. In the metropolis, the variable being female has a positive impact on car use. Having a university degree decreases car use for metropolis residents while it has no significant effect for the other spatial categories. Eco-consciousness reduces car use significantly for metropolis residents. What is very interesting is that this effect is even stronger for residents in medium-sized cities, while it is not significant for urban areas. This could be explained by a stronger dependency on cars in medium-sized cities that needs a higher level of eco-consciousness to be overcome. Fear seems to be a positive driver of substitution in all spatial categories, although not a significant one in some cases.

Due to a smaller sample size in the two less densely populated spatial categories, some interesting differences in effects such as an increasingly positive effect of university degree or a decreasingly negative effect of age on car use with reduced population density are not significant but might yield interesting insights in further investigations. Moreover, we find no evidence for a stronger increase of car use in less densely populated areas. In contrast, we find that car use even increased in the most dense metropolis category while it decreased in absolute terms in the urban area category.

6. Discussion

Our results clearly show a drastic reduction in public transport use in Hanover during the pandemic. The reasons are twofold, first public health measures like social distancing and an unprecedented rise of people working from home lead to a drop in demand. Second, there seems to be a loss of trust into public transport, as high numbers of people in our sample reported to worry about virus transmission in buses and trains.

Our research allows us to confirm that this effect is gendered, as women report a much higher reduction of public transport use due to a higher degree of fear of virus transmission in public transport facilities. The pandemic therefore has altered in particular women's perspectives on public transport which is now increasingly associated with disease and unhealthy conditions. Women's fear of public transport spaces have long received academic attention (for an overview see: [García-Jiménez et al., 2020](#)), however the emphasis was usually on security issues such as gender based violence or violent urban crimes and recommendations predominantly referred to improvements of the urban form of transport sites (lightning etc.) ([Valentine, 1989](#); [Law, 1999](#); [Strandbygaard et al., 2020](#)). Little is known about gender-specific perceptions of fear in the context of a public health crisis like the Covid 19 pandemic.

This constitutes an unprecedented challenge for public transport providers. In order to win back trust into public transport as a safe, affordable and sustainable way of travelling, authorities should start to foster knowledge exchange between transport planners and public health specialists. Enhancing the hygiene in buses and trains through the regular disinfection of surface areas, improving the air circulation in carriages, enhancing the frequency of services to allow spreading out of passengers and continuously promoting the use of facemasks could all be viable first steps to win back customers ([De Vos, 2020](#); [Tirachini and Cats, 2020](#)). Furthermore, good public communication seems necessary to win back sceptical public transport users. Given the utmost importance to curb CO2 emissions and the vital role public transport plays in this effort, the loss of trust and associated reduction in public transport demand must be addressed.

We want to discuss one more important finding here, that might support progressive transport policy formulations. Environmental consciousness is an important predictor within our sample that explains why people refrain from increasing their car use. Interestingly, this effect is not only pronounced within the metropolis (where arguably alternatives like biking or walking are easier), but also in the medium-sized cities. Therefore, even in areas where alternatives to car use might be less available, environmental consciousness triggers pro-environmental substitution practices. Specifically, our result matches insights from other scholars ([Cadima et al., 2020](#); [Klinger et al., 2013](#); [Mohammadzadeh, 2020](#); [van Acker et al., 2011](#)) who found that biking and eco-consciousness are closely connected. There could be other mechanisms at work here as well, however. For example, we could observe a situation where people are responding to a particular social norm (avoiding public transport in pandemic times) or we are potentially witnessing a moment in which a latent eco-consciousness is translated into actual behaviour by an external force (the pandemic). To determine which forces are at work in this case, further research is required.

Our finding is also significant, as established literature in the field of environmental behavior has found that people are more ready to change their behavior when costs of doing so are low ([Diekmann and Preisendörfer, 1998](#)). Our sample however rather indicates that eco-consciousness extends from the metropolis to the medium-sized cities and sustains ecological transport choices in times of disruption there as well. Here "costs" of switching to alternatives (in terms of time needed for transport due to longer distances etc.) are arguably higher than in the metropolis, however. Hence, our assumption about the spatial setting of where costs are perceived as "high" or "low" are not confirmed within the study. Only in the relatively least densely populated spatial category of our sample, the urban areas, this effect wears off. Moreover, we find that the negative relation between environmental consciousness and change in car use is stronger for residents in medium-sized cities, implying that already a smaller level can yield a higher reduction of car use compared to metropolis residents.

Viewing the findings from the perspective of substitutability, which insists that substitution always depends on having choices and alternatives ([van Wee et al., 2019](#); [Klinger et al., 2013](#)), our findings are somewhat surprising. Contrary to expectations, it is not within the less densely populated medium-sized cities and urban areas where car use increases, but in the metropolis. This seems to suggest that infrastructures and other spatial characteristics are neither the only nor the most salient factors that influence mode choices in times of disruptions. This is supported by our finding that eco-consciousness plays an even more important role for predicting car use in medium-sized cities than for the metropolis or urban areas. We find it important to also relate our findings to wider debates about transport justice that advocate for flexible transport solutions for remote areas ([Velaga et al., 2012](#)). Public transport from such a perspective is more than just a way to bring people from place A to place B, but rather serves an important democratic goal, namely to provide cheap and reliable transport options for all members of society ([Martens, 2016](#)). As [Arellana et al. \(2020\)](#), highlight, the Corona crisis thus reveals the need to rethink urban transport infrastructures and increase the availability of space for active travel in addition to hygienic public transport infrastructures.

While it is encouraging to see that the increase of biking as a substitution for public transport slightly surpassed the increase of car use, however, it seems that during the crisis predominantly people who were already eco-conscious turned to biking. Thus, contrary to [Frater et al.'s \(2020\)](#) findings, the crisis might have not opened a window of opportunity for behavioral change for all. Research on climate change communication confirms that it is much easier to motivate eco-conscious people to switch their behavior to more sustainable options, whereas the real challenge lies in fostering awareness and efficacy beliefs in populations who are more skeptical ([Duffy et al., 2019](#); [Hestres, 2014](#); [McNeal et al., 2014](#)).

6.1. Further research

As mentioned before, elder people and people in the lowest income group are difficult to capture adequately in an online survey.

However, this particularly vulnerable group should receive more attention in researching mobility behavior. Therefore, we propose other methods such as qualitative inquiries to study the travel behavior of these groups during the pandemic. As we have pointed out before, the survey only gives us a temporary glimpse on the change of transportation mode choice at this point during the pandemic. As the situation is particularly volatile with fear of more infection waves to come, it is difficult to make predictions how people's transport behavior will change in the months to come. In addition, biking usually becomes a less attractive alternative in winter even for people determined to support the environment. This effect is not only driven by the level of comfort but also by safety concerns, as biking in the dark hours of the day or on slippery or icy bike-paths poses safety risks. Therefore, many people who substituted public transport with biking during the time of the survey might decide between giving in to the comfort of a private car if available to them, or warily putting on their facemasks and returning to public transport as their main means of transportation.

7. Conclusion and policy implications

In this paper, we survey over 4000 respondents from Hanover Region to investigate how their travel behavior changed during the first wave of the Covid 19 pandemic (March-June 2020). Our data set gives important novel insights for a large metropolitan area with other 1 million inhabitants during the pandemic. Hence, we contribute to growing research on how the public health crisis affected the transport sector.

We found a significant reduction in public transport use and an increase in car use and biking. Women were more likely to report that they reduced their public transport use due to the fear of catching the virus in transport facilities. The reduction behavior was hence gendered. We moreover found that income had a significant effect on substitution choices, as higher income correlated significantly with an increase of car use. Encouragingly, environmental concern is a strong predictor in our sample as well, showing that people who are eco-conscious switch to bike rather than car use. This is a trend that needs to see encouragement from policy makers to foster green urban transport in the city and region of Hanover. Especially, because this effect was even more pronounced in the surveyed medium-sized cities, demonstrating that people are willing use their car less in times of disruptions even if they do not live in the metropolis. Regarding policy-making this is an interesting result to built upon: The differences of a change towards more sustainable mobility behavior only lays in parts in questions of density, but much more in local-specific spatial contexts. Policies then have to take into account small-scale possibilities and arrangements like safe bike lanes to access the train station or the number of commuters and how to solve the first or the last mile. Small-scale solutions to increase the quality of travels seem to be the means of choice of experiments in an "out-of-the-normal" situation as a pandemic to lead to more sustainable mobility behavior.

Although biking is clearly the advantageous substitution practice in terms of environmental impact, bike and car use might not be a viable solution for all, as it requires a certain physical constitution. In particular, they exclude more vulnerable groups such as elderly people and people with reduced physical mobility. Thus, substitutability of public transport has its limits. The challenge for policy-makers remains to make public transport as safe as possible for all those dependent on it in times of this unprecedented health crisis to sustain environmental goals as well as social cohesion.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRedit authorship contribution statement

Kerstin J. Schaefer: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization. **Leonie Tuitjer:** Conceptualization, Validation, Writing – original draft. **Meike Levin-Keitel:** Conceptualization, 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.

Acknowledgements

Foremost, we would like to thank the participants of the study project *mobility of the future* 2020 for their excellent work on the survey. We would also like to thank three anonymous reviewers for their constructive comments that helped improve the manuscript. We also would like to thank Lennart Schott and Louis Kneupling for their feedback on the paper and Lukas Arndt for contributing to the cleaning of spatial data. Moreover, we would like to thank Klaus Geschwinder from *Region Hannover* for his support in distributing the survey.

References

Adey, P., Anderson, B., 2011. Anticipation, materiality, event: the Icelandic ash cloud disruption and the security of mobility. *Mobilities* 6 (1), 11–20. <https://doi.org/10.1080/17450101.2011.532919>.

- Allgemeiner Deutscher Automobil Club, 2020. Corona und Mobilität: Mehr Homeoffice, weniger Berufsverkehr. <https://www.adac.de/verkehr/standpunkte-studien/mobilitaets-trends/corona-mobilitaet/> [Accessed 10.09.2020].
- Arellana, J., Márquez, L., Cantillo, V., 2020. COVID-19 Outbreak in Colombia: An Analysis of Its Impacts on Transport Systems. *J. Adv. Transport.* 2020 (4), 1–16. <https://doi.org/10.1155/2020/8867316>.
- Beck, M.J., Hensher, D.A., Wei, E., 2020. Slowly coming out of COVID-19 restrictions in Australia: Implications for working from home and commuting trips by car and public transport. *J. Transp. Geogr.* 88, 102846. <https://doi.org/10.1016/j.jtrangeo.2020.102846>.
- BMVI, 2018. Regionalistische Raumtypologie (RegioStaR) des BMVI für Mobilitäts- und Verkehrsforschung. V1.1. Unter Mitarbeit von Markus Sigismund. Hg. v. Bundesministerium für Verkehr und digitale Infrastruktur. Online verfügbar unter https://www.bmvi.de/SharedDocs/DE/Anlage/G/regiostar-arbeitspapier.pdf?__blob=publicationFile.
- Cadima, C., Silva, C., Pinho, P., 2020. Changing student mobility behaviour under financial crisis: Lessons from a case study in the Oporto University. *J. Transp. Geogr.* 87, 1–10. <https://doi.org/10.1016/j.jtrangeo.2020.102800>.
- Cao, X., 2009. Disentangling the influence of neighborhood type and self-selection on driving behavior: an application of sample selection model. *Transportation* 36 (2), 207–222. <https://doi.org/10.1007/s11116-009-9189-9>.
- De Vos, J., 2020. The effect of COVID-19 and subsequent social distancing on travel behavior. *Transport. Res. Interdisciplinary Perspectives* 5, 1–3. <https://doi.org/10.1016/j.trip.2020.100121>.
- De Vos, J., Ettema, D., Witlox, F., 2018. Changing travel behaviour and attitudes following a residential relocation. *J. Transp. Geogr.* 73, 131–147. <https://doi.org/10.1016/j.jtrangeo.2018.10.013>.
- Diekmann, A., Preisendörfer, P., 1998. Environmental Behavior: Discrepancies between aspirations and reality. *Rationality Soc.* 10 (1), 79–102. <https://doi.org/10.1177/104346398010001004>.
- Duffy, M.A., Hammond, J.W., Cheng, S.J., 2019. Preaching to the choir or composing new verses? Toward a writerly climate literacy in introductory undergraduate biology. *Ecol. Evol.* 9 (22), 12360–12373. <https://doi.org/10.1002/ece3.v9.2210.1002/ece3.5736>.
- Elias, W., Albert, G., Shifftan, Y., 2013. Travel behavior in the face of surface transportation terror threats. *Transp. Policy* 28, 114–122. <https://doi.org/10.1016/j.tranpol.2012.08.005>.
- Emelianoff, C., 2014. Local Energy Transition and Multilevel Climate Governance: The Contrasted Experiences of Two Pioneer Cities (Hanover, Germany, and Växjö, Sweden). *Urban Studies* 51 (7), 1378–1393. <https://doi.org/10.1177/0042098013500087>.
- Finucane, M.L., Slovic, P., Mertz, C.K., Flynn, J., Satterfield, T.A., 2000. Gender, race, and perceived risk: the 'white male' effect. *Health, Risk & Society* 2 (2), 159–172. <https://doi.org/10.1080/713670162>.
- Frater, J., Vallance, S., Young, J., Moreham, R., 2020. Disaster and unplanned disruption: Personal travel planning and workplace relocation in Christchurch, New Zealand. *Case Stud. Transport Policy* 8 (2), 500–507. <https://doi.org/10.1016/j.cstp.2019.11.003>.
- García-Jiménez, E., Poveda-Reyes, S., Molero, G.D., Santarremigia, F.E., Gorrini, A., Hail, Y., Ababio-Donkor, A., Leva, M.C., Mauriello, F., 2020. Methodology for gender analysis in transport: factors with influence in women's inclusion as professionals and users of transport infrastructures. *Sustainability* 12 (9), 3656. <https://doi.org/10.3390/su12093656>.
- Götting, K., Becker, S., 2020. Reaktionen auf die Pop-Up-Radwege in Berlin. Ergebnisse einer explorativen Umfrage zur temporären Radinfrastruktur im Kontext der Covid-19 Pandemie. Institute for Advanced Sustainability Studies (IASS), IASS STUDY. https://publications.iass-potsdam.de/rest/items/item_6000142_4/component/file_6000157/content [Accessed 08.12.2020].
- Goodwin, R., Wiwattanapantuwong, J., Tuicomepee, A., Suttiwan, P., Watakakosol, R., 2020. Anxiety and public responses to covid-19: Early data from Thailand. *J. Psychiatr. Res.* 129, 118–121. <https://doi.org/10.1016/j.jpsychires.2020.06.026>.
- Handy, S., Cao, X., Mokhtarian, P., 2005. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transport. Res. Part D: Trans. Environ.* 10 (6), 427–444. <https://doi.org/10.1016/j.trd.2005.05.002>.
- Hestres, L.E., 2014. Preaching to the choir: Internet-mediated advocacy, issue public mobilization, and climate change. *New Media Soc.* 16 (2), 323–339. <https://doi.org/10.1177/1461444813480361>.
- Holz-Rau, C., Scheiner, J., Sicks, K., 2014. Travel distances in daily travel and long-distance travel: what role is played by urban form? *Environ. Plann. A: Econ. Space* 46 (2), 488–507. <https://doi.org/10.1068/a4640>.
- Hunecke, M., 2015. Mobilitätsverhalten verstehen und verändern. Springer Fachmedien Wiesbaden. <https://doi.org/10.1007/978-3-658-08825-5>.
- Institut für angewandte Sozialwissenschaft, MotionTag, 2020. Alles anders oder nicht? Unsere Alltagsmobilität in der Zeit von Ausgangsbeschränkung oder Quarantäne. https://www.infas.de/fileadmin/user_upload/infas_mobility_CoronaTracking_Nr.02_20200421.pdf [Accessed 10.07.2020].
- International Energy Agency, 2020. Changes in transport behaviour during the Covid-19 crisis. <https://www.iea.org/articles/changes-in-transport-behaviour-during-the-covid-19-crisis> [Accessed 15.07.2020].
- Kager, R., Bertolini, L., Te Brömmelstroet, M., 2016. Characterisation of and reflections on the synergy of bicycles and public transport. *Transport. Res. Part A: Policy Practice* 85, 208–219. <https://doi.org/10.1016/j.tra.2016.01.015>.
- Kim, J., Kwan, M.-P., 2021. The impact of the COVID-19 pandemic on people's mobility: A longitudinal study of the U.S. from March to September of 2020. *J. Transp. Geogr.* 93, 103039. <https://doi.org/10.1016/j.jtrangeo.2021.103039>.
- Klinger, T., Kenworthy, J.R., Lanzendorf, M., 2013. Dimensions of urban mobility cultures – a comparison of German cities. *J. Transp. Geogr.* 31, 18–29. <https://doi.org/10.1016/j.jtrangeo.2013.05.002>.
- Klinger, T., Lanzendorf, M., 2016. Moving between mobility cultures: what affects the travel behavior of new residents? *Transportation* 43 (2), 243–271. <https://doi.org/10.1007/s11116-014-9574-x>.
- Klinger, T., 2017. Moving from monomodality to multimodality? Changes in mode choice of new residents. *Transport. Res. Part A: Policy Practice* 104, 221–237. <https://doi.org/10.1016/j.tra.2017.01.008>.
- Landeshauptstadt Hannover, 2011. Masterplan Mobilität 2025. <https://www.hannover.de/content/download/221157/3494065/file/Brosch%C3%BCre-Masterplan-Mobilit%C3%A4t-2025.pdf> [Accessed 13.09.2020].
- Law, R., 1999. Beyond 'women and transport': towards new geographies of gender and daily mobility. *Prog. Hum. Geogr.* 23 (4), 567–588. <https://doi.org/10.1191/030913299666161864>.
- Levin-Keitel, M., Mölders, T., Othengrafen, F., Ibendorf, J., 2018. Sustainability Transitions and the Spatial Interface: Developing Conceptual Perspectives. *Sustainability* 10 (6), 1880. <https://doi.org/10.3390/su10061880>.
- Marsden, G., Docherty, I., 2013. Insights on disruptions as opportunities for transport policy change. *Transport. Res. Part A: Policy Practice* 51, 46–55. <https://doi.org/10.1016/j.tra.2013.03.004>.
- Marsden, G., Anable, J., Chatterton, T., Docherty, I., Faulconbridge, J., Murray, L., Roby, H., Shires, J., 2020. Studying disruptive events: Innovations in behaviour, opportunities for lower carbon transport policy? *Transp. Policy* 94, 89–101. <https://doi.org/10.1016/j.tranpol.2020.04.008>.
- Martens, K., 2016. *Transport Justice*, 1st ed. Routledge, New York, NY.
- Mattsson, L.-G., Jenelius, E., 2015. Vulnerability and resilience of transport systems – A discussion of recent research. *Transport. Res. Part A: Policy Practice* 81, 16–34. <https://doi.org/10.1016/j.tra.2015.06.002>.
- McNeal, K.S., Hammerman, J.K.L., Christiansen, J.A., Carroll, F.J., 2014. Climate Change Education in the Southeastern U.S. Through Public Dialogue: Not Just Preaching to the Choir. *J. Geosci. Educ.* 62 (4), 631–644. <https://doi.org/10.5408/13-061.1>.
- Mohammadzadeh, M., 2020. Exploring tertiary students' travel mode choices in Auckland: Insights and policy implications. *J. Transp. Geogr.* 87, 1–8. <https://doi.org/10.1016/j.jtrangeo.2020.102788>.
- Mokhtarian, P., Salomon, I., 1997. Modeling the desire to telecommute: The importance of attitudinal factors in behavioral models. *Transport. Res. Part A: Policy Practice* 31, 35–50. [https://doi.org/10.1016/S0965-8564\(96\)00010-9](https://doi.org/10.1016/S0965-8564(96)00010-9).
- Moslem, S., Campisi, T., Szmelter-Jarosz, A., Duleba, S., Nahiduzzaman, K.M., Tesoriere, G., 2020. Best-Worst Method for Modelling Mobility Choice after COVID-19: Evidence from Italy. *Sustainability* 12 (17), 6824. <https://doi.org/10.3390/su12176824>.

- Naess, P., 2011. 'New urbanism' or metropolitan-level centralization? A comparison of the influences of metropolitan-level and neighborhood-level urban form characteristics on travel behavior. *J. Trans. Land Use* 4 (1), 25–44. <https://doi.org/10.5198/jtlu.v4i1.170>.
- Nash, S., Mitra, R., 2019. University students' transportation patterns, and the role of neighbourhood types and attitudes. *J. Transp. Geogr.* 76, 200–211. <https://doi.org/10.1016/j.jtrangeo.2019.03.013>.
- Nello-Deakin, S., te Brömmelstroet, M., 2021. Scaling up cycling or replacing driving? Triggers and trajectories of bike-train uptake in the Randstad area. *Transportation* 1–29. <https://doi.org/10.1007/s11116-021-10165-9>.
- Nikiforiadis, A., Ayfantopoulou, G., Stamelou, A., 2020. Assessing the impact of COVID-19 on Bike-Sharing Usage: The Case of Thessaloniki, Greece. *Sustainability* 12 (19), 8215. <https://doi.org/10.3390/su12198215>.
- Park, J., 2020. Changes in Subway Ridership in Response to COVID-19 in Seoul, South Korea: Implications for Social Distancing. *Cureus* 12 (4), e7668. <https://doi.org/10.7759/cureus.7668>.
- Parkes, S.D., Jopson, A., Marsden, G., 2016. Understanding travel behaviour change during mega-events: Lessons from the London 2012 Games. *Transport. Res. Part A: Policy Practice* 92, 104–119. <https://doi.org/10.1016/j.tra.2016.07.006>.
- Potoglou, D., Robinson, N., Kim, C.W., Burge, P., Warnes, R., 2010. Quantifying individuals' trade-offs between privacy, liberty and security: The case of rail travel in UK. *Transport. Res. Part A: Policy Practice* 44 (3), 169–181. <https://doi.org/10.1016/j.tra.2009.12.006>.
- Rubin, G.J., Amlot, R., Page, L., Wessely, S., 2009. Public perceptions, anxiety, and behaviour change in relation to the swine flu outbreak: cross sectional telephone survey. *BMJ* 339 (jul02 3), b2651. <https://doi.org/10.1136/bmj.b2651>.
- Scheiner, J., 2006. Housing mobility and travel behaviour: A process-oriented approach to spatial mobility: Evidence from a new research field in Germany. *J. Transp. Geogr.* 14 (4), 287–298. <https://doi.org/10.1016/j.jtrangeo.2005.06.007>.
- Scheiner, J., Holz-Rau, C., 2007. Travel mode choice: affected by objective or subjective determinants? *Transportation* 34 (4), 487–511. <https://doi.org/10.1007/s11116-007-9112-1>.
- Scheiner, J., Holz-Rau, C., 2013. Changes in travel mode use after residential relocation: a contribution to mobility biographies. *Transportation* 40 (2), 431–458. <https://doi.org/10.1007/s11116-012-9417-6>.
- Schwanen, T., Mokhtarian, P.L., 2005. What affects commute mode choice: neighborhood physical structure or preferences toward neighborhoods? *J. Transp. Geogr.* 13 (1), 83–99. <https://doi.org/10.1016/j.jtrangeo.2004.11.001>.
- Schwanen, T., Banister, D., Anable, J., 2012. Rethinking habits and their role in behaviour change: the case of low-carbon mobility. *J. Transp. Geogr.* 24, 522–532. <https://doi.org/10.1016/j.jtrangeo.2012.06.003>.
- Sheller, M., 2013. The islanding effect: post-disaster mobility systems and humanitarian logistics in Haiti. *Cultural geographies* 20 (2), 185–204. <https://doi.org/10.1177/1474474012438828>.
- Sparke, M., Angelou, D., 2020. Contextualising coronavirus geographically. *Trans. Instit. Br. Geograph.* 45 (3), 498–508. <https://doi.org/10.1111/tran.v45.310.1111/tran.12389>.
- Stead, D., Marshall, S., 2001. The relationships between urban form and travel patterns: an international review and evaluation. *Eur. J. Trans. Infrastruct. Res.* 1 (2), 113–141. <https://doi.org/10.18757/ejtr.2001.1.2.3497>.
- Strandbygaard, S.K., Spence Jones, A.K., Jensen, L.M.B., Nielsen, O.A., Grönlund, B., 2020. Fear follows form: A study of the relationship between neighborhood type, income and fear of crime at train stations. *J. Transport Land Use* 13 (1), 585–603. <https://doi.org/10.5198/jtlu.2020.1675>.
- Suau-Sanchez, P., Voltés-Dorta, A., Cugueró-Escofet, N., 2020. An early assessment of the impact of COVID-19 on air transport: Just another crisis or the end of aviation as we know it? *J. Transp. Geogr.* 86, 1–8. <https://doi.org/10.1016/j.jtrangeo.2020.102749>.
- Tirachini, A., Cats, O., 2020. COVID-19 and Public Transportation: Current Assessment, Prospects, and Research Needs. *J. Public Transport.* 22, 1–21. <https://doi.org/10.5038/2375-0901.22.1.1>.
- Tuitjer, L., 2019. Bangkok flooded: re(assembling) disaster mobility. *Mobilities* 14 (5), 648–664. <https://doi.org/10.1080/17450101.2019.1586097>.
- UBA (Hrsg.), 2020. Grundlagen für ein umweltorientiertes Recht der Personenbeförderung. Teilerbericht 2. Texte | 213/2020, Umweltbundesamt. <https://www.umweltbundesamt.de/publikationen/grundlagen-recht-personenbefoerderung>.
- Valentine, G., 1989. The geography of women's fear. *Area* 21 (4), 385–390.
- van Acker, V., Mokhtarian, P., Witlox, F., 2011. Going soft: on how subjective variables explain modal choices for leisure travel. *Eur. J. Trans. Infrastruct. Res.* 11, 115–146. <https://doi.org/10.18757/ejtr.2011.11.2.2919>.
- van Exel, N.J.A., Rietveld, P., 2009. When strike comes to town... anticipated and actual behavioural reactions to a one-day, pre-announced, complete rail strike in the Netherlands. *Transport. Res. Part A: Policy Practice* 43 (5), 526–535. <https://doi.org/10.1016/j.tra.2009.01.003>.
- van Wee, B., van Cranenburgh, S., Maat, K., 2019. Substitutability as a spatial concept to evaluate travel alternatives. *J. Transp. Geogr.* 79, 1–12. <https://doi.org/10.1016/j.jtrangeo.2019.102469>.
- Velaga, N.R., Beecroft, M., Nelson, J.D., Corsar, D., Edwards, P., 2012. Transport poverty meets the digital divide: accessibility and connectivity in rural communities. *J. Transp. Geogr.* 21, 102–112. <https://doi.org/10.1016/j.jtrangeo.2011.12.005>.
- Verplanken, B., Walker, I., Davis, A., Jurasek, M., 2008. Context change and travel mode choice: Combining the habit discontinuity and self-activation hypotheses. *J. Environ. Psychol.* 28 (2), 121–127. <https://doi.org/10.1016/j.jenvp.2007.10.005>.
- Wang, K.-Y., Thiel, V., 2014. How Change of Public Transportation Usage Reveals Fear of the SARS Virus in a City. *PLoS ONE* 9 (3), e89405. <https://doi.org/10.1371/journal.pone.0089405>.
- Zanni, A.M., Ryley, T.J., 2015. The impact of extreme weather conditions on long distance travel behaviour. *Transport. Res. Part A: Policy Practice* 77, 305–319. <https://doi.org/10.1016/j.tra.2015.04.025>.