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Interest-adoption discrepancies, mechanisms of mediation and socio-spatial inclusiveness in bike-sharing: The case of nine urban regions in Norway

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ABSTRACT

Bike sharing systems are increasingly promoted as a quick, accessible, affordable, and healthy transport alternative in a less car-dependent urban mobility system. The objective of this article is to elucidate the social and spatial inclusiveness of bike sharing, by exploring its intersectionality with user backgrounds and residential contexts, and its mechanisms of mediation by attitudes, mobility resources and daily mobility patterns. Hereto, the paper examines and cross-compares the discrepancies between stated bike sharing interest and reported bike sharing membership, amongst a sample of 3672 residents of urban regions in Norway in structural equation models (SEM). Our results indicate that interest is positively influenced by early adopter characteristics, such as young age, full-time work, environmental consciousness, urban outlook, urban residential locations, and the current adoption of combined bicycle and public transport use. In contrast, reported bike sharing membership is explained more typically as a travel behaviour: with reduced effects of attitudes; enhanced effects of residential urban form and bicycle-public transport use; and additional negative effects of car and bike ownership. The paper concludes by discussing these and other interest-adoption discrepancies across social and spatial categories, to derive policy and research directions for inclusive bike sharing.

1. Introduction

Around the world, bike sharing systems are increasingly put forward to provide people with a fast, accessible, convenient, healthy and climate-friendly form of mobility as a key alternative for car use in cities, although in reality also mainly as a substitute for walking, private bike use and public transport (e.g. Fishman et al., 2015; Hosford and Winters, 2018). Meanwhile, the micro-mobility landscape in cities has rapidly evolved from the bike-sharing boom of the early 2010s, as exemplified by the diversification of bike-sharing systems (e.g. free-floating systems, e-bike fleets) and the introduction of new privately owned as well as shared forms of mobility (e.g. e-scooters, e-kick-scooters).

With the worldwide popularity of bike sharing systems, the changing micro-mobility landscape, and the increasing public availability of big bike-sharing data, the number of bike-sharing studies is rapidly rising. Previous studies identify that a majority of bike-sharing users tend to have the same early adopter characteristics, such as young age, male, western decent, higher income and

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education, and urban places of residence (e.g. Shaheen et al., 2011; Ricci, 2015; Fishman, 2016). Other social groups use bike sharing much less, often due to poor geographic access or other bike sharing service characteristics ill-fitted to their user needs. These mismatches are striking as such groups often face harsh intersecting mobility inequalities, with fewer financial and transport resources, higher dependencies on public or other transport alternatives, yet when typically residing in less-accessible locations (Hosford and Winters, 2018). Despite recent insights, deeper empirical investigations into the mechanisms of bike sharing adoption are urgently required, especially as questions are being raised on its social and spatial inclusiveness. In our literature review, presented in the following section, we identify four knowledge needs that require particular attention: i) understanding interest-adoption discrepancies in bike-sharing; ii) examining the effect of understudied socio-economic and socio-cultural factors like work status and ethnicity; iii) examining the role of mediation by personality traits and attitudes; and iv) a need to expand dominant adoption and sharing economy perspectives on bike-sharing with insights from transport studies on urban form effects, accessibility and the role of transport resources/habits.

In order to address these knowledge needs, this paper aims to elucidate the social and spatial inclusiveness of bike sharing by exploring its interest-adoption discrepancies and intersectionality with socio-demographic, socio-economic and residential urban form attributes, directly as well as mediated by attitudes, mobility resources and the daily uses of other transport modes. Hereto, the paper examines and cross-compares stated interest in the use of shared bikes as a general concept and the reported adoption of membership required to use station-based non-electric bike sharing systems in Norwegian cities, based on a survey amongst 3672 residents of nine urban regions in Norway. Drawing on a conceptual travel behaviour model by Van Acker et al. (2010) and a Norwegian study on car sharing (Hjorteset and Böcker, 2020), we use structural equation modelling (SEM) to unite spatial, socio-economic, mobility and attitudinal components of bike sharing within the same model. After this introduction follows a literature review; a description of our data, study areas and statistical modelling techniques; a presentation and discussion of descriptive and multivariate results; and concluding remarks and discussions.

2. Literature review

This section provides a review of existing literature findings and knowledge needs with regard to the relationship of bike sharing with three sets of indicators that will form the basis for our multivariate analyses: user (and non-user) profiles, attitudes, and transport resources and habits.

2.1. Bike sharing user and non-user profiles

A first body of literature focuses on the user profiles of bike-sharing users. Despite different national contexts, studies typically find that the majority of bike-sharing users have similar user profiles: the majority of users are generally highly educated urban dwellers, male, young, and often in higher income groups (Hosford and Winters, 2018; Fishman et al., 2015; Ricci, 2015). The similarities between a typical bike share member and the characteristics of early adopters are clear (Shaheen et al. 2011). While innovation adoption literature generally attributes such profiles to the preferences, skills, networks or resources of early adopters, comparison studies in the case of bike sharing, for example from Canada (Hosford and Winters, 2018) and the USA (Ursaki and Aultman-Hall, 2015), highlight uneven geographic access as the main exclusionary mechanism. Similar results on the relevance of geographic access were found in Glasgow, Scotland by Clark and Curl (2016). However, this particular study also reveals the existence of other exclusionary mechanisms, for example that a majority of non-western groups are not adopting the use of bike sharing systems, despite living in close proximity to bike sharing stations. McNeil et al. (2018) find additional barriers intersecting with poor bike sharing access, such as lack of cycling infrastructures, excluding payment methods and unfamiliarity. The study which surveyed neighbourhoods in Philadelphia, Chicago and Brooklyn, NY, concluded that it was not a lack of interest among people of colour and/or lower income groups that kept them from enrolling in a program, but rather the economic and geographical barriers they were facing.

Other studies focus on the unequal proportions of male and female bike-sharing users. In line with lower cycling shares and cultures amongst women generally, they often link gender inequalities in bike sharing to cycling unsafety, particularly in low cycling contexts (e.g. Vogel et al., 2014; Fishman, 2016; Beecham and Wood, 2014). Fishman (2016) reviews that women's concerns for safety and their reliance on bike-friendly infrastructures can explain why, in most cities, fewer women participate in bike sharing. Findings from bike sharing surveys in Oslo, Norway, indicate that women also have different bike sharing needs (e.g. for longer maximum rental durations), as they conduct different types of trips, such as more leisure trips, fewer short-distance trips, and fewer public transport access-egress strips (Priya Uteng et al., 2019; Böcker et al., 2020). Another detrimental factor for cycling generally and the (stated interest in the) adoption of bike sharing in particular, is older age (Efthymiou et al., 2013; Fishman et al., 2015). Although age is often acknowledged as an important predictor, few studies seek to find explanations as to why disproportionate amounts of bike-sharing users are younger – usually even under the age of 35. To answer this question, Wang et al. (2018) investigated different age-categories' ridership level in New York City, using data from Citi Bike. Findings suggest that the early adoption of other forms of shared mobility amongst youngsters, as well as their common inner-city employments, are part of the reason.

2.2. Attitudes

It is argued that bike sharing is affordable and beneficial to the environment and attractiveness of cities, by reducing car dependency, congestion and emissions, and by contributing to the lifelines of city streetscapes and the freeing up of valuable urban space to repurpose away from asphalted usages (e.g. Meyer and Shaheen, 2017; Fishman, 2016). Underlying mechanisms of visions, attitudes or personality traits that reconcile with such economic, environmental and urban attractiveness narratives may motivate membership enrolment. Yet, the mediating roles of such traits are currently understudied and will be further explored in this paper.

Efthymiou et al. (2013) investigated personality factors affecting the intention to adopt bike sharing in Greece. *Environmentally conscious* individuals were more likely to show interest in membership enrolment in the near future. Affordability was also a motivator for membership, which could indicate that *financially aware* individuals are more likely to do bike sharing – a result contradicting the overrepresentation of high-income early adopters among bike-sharing users. Possible explanations for this could be that bike-sharing users are amongst those living voluntarily without a vehicle, or that financial situations and financial awareness not necessarily overlap. In contrast, Fishman et al. (2014) in Melbourne and Brisbane, find convenience to be the primary motivator for membership, whereas environmental concerns and financial savings had limited effects. Financial savings were however a motivating factor for low-income members of Capital bike share in Washington DC (LDA Consulting, 2013). Others find increased bike sharing ridership in densely built downtown areas compared to suburban neighbourhoods, and with proximity to restaurants, commercial enterprises and universities (Bachand-Marleau and El-Geneidy, 2012; Fishman et al., 2014; Noland et al., 2016). Bike-sharing users are often young urban dwellers, drawn towards more urban lifestyles and leaning towards urban identities. Yet, explicit linkages between bike sharing and attitudes related to urban lifestyles or outlooks are currently lacking. The mediating role of *urban outlook* will be further explored in this paper as an attempt to differentiate in the explanation for the 'urbanness' of bike sharing, between mechanisms of exclusionary urban bike sharing access and urban outlook-oriented self-selection.

2.3. Transport resources and habits

One factor often overshadowed by the aforementioned early-adoption perspectives on bike sharing, is that its adoption is first and foremost a choice of transport mode, and part of people's complex daily travel behavioural patterns. Most studies in this respect focus on the transport modes the bike sharing substitutes. Evidences suggest that this is not limited to car use, but that bike sharing especially substitutes private bike use, walking and public transport use (e.g. Fishman, 2016; Munkácsy and Monzón, 2017). A limited number of studies also point to the importance of ownership of and access to different means of transport (Bachand-Marleau and El-Geneidy, 2012; Fishman, 2016). Owning a car decreases the probability of bike sharing (Buck et al., 2013; Fishman, 2016). Fishman et al. (2014) identify the car's convenience as the main obstacle for bike sharing in Brisbane and Melbourne. People who own a bike are also less inclined to use bike sharing. A study from Washington D.C. finds this is the case especially for dedicated cyclists (Buck et al. 2013). In Montreal, Bachand-Marleau and El-Geneidy (2012) find that previous habits of combining cycling and transit significantly increase bike sharing membership. Individuals who own a bike are more likely to be enrolled in the bike sharing program, while user frequency is negatively correlated with owning a bike. Bike sharing membership and public transport usage were also correlated. However, higher levels of public transport connectivity at the residential location significantly reduced the chance of using bike sharing frequently. Jäppinen et al. (2013) show that bike sharing combined with public transport could enhance accessibility and reduce overall travel times by more than 10%. Other survey-based studies confirm connections between public transport and bike sharing. In Beijing and Hangzhou, over half of the respondents of the bike sharing programs claimed to be combining these transportation modes (Fishman et al., 2013). Mobike Global estimated that a majority of bike sharing trips were undertaken to link with buses and trains (Ding et al., 2018).

2.4. Literature gaps and knowledge needs

Despite these valuable insights four knowledge needs require particular attention: First, most studies look at either the revealed user characteristics in samples of bike sharing members, or the stated interest in bike sharing amongst current non-users. Yet, integrated comparisons of interest and membership that could help reveal unmatched potentials or mismatching of needs across societal groups, are scarce (McNeil et al., 2018). Second, while recent studies on bike sharing user profiles vastly increased our knowledge on the effects of classic socio-demographic and socio-economic attributes like age, gender, income and education, other factors like work status and especially ethnicity remain largely understudied. Third, although some studies highlight the importance of personality traits or attitudes for bike sharing adoption, integrated analyses are currently lacking on the mediating roles that such factors could play. Fourth, bike sharing has been primarily studied from a sustainability innovation or sharing economy adoption perspective. Studies complementing such knowledge with transport research perspectives on the phenomenon – i.e. studying it first and foremost as a travel behaviour, in conjunction to urban form attributes, accessibility measures, individual or household transport resources, and other daily travel behaviours – could greatly improve our understanding of bike sharing adoption generally and its inclusiveness in particular.

3. Research design

3.1. Study area

Norwegian cities make an interesting case to study bike sharing for two important reasons. First, a northern European study complements the current literature on bike sharing that is largely confined to empirical studies from cities in the USA, Western Europe, Australia and China (Fishman, 2016). Northern European cities offer unique bike sharing conditions, such as compact land uses, at least in inner-city areas, well-functioning public transport, and modal splits that supplement car use with substantial shares of other transport modes. This includes large shares of walking and increasing shares of private and shared bicycle use, despite colder climate conditions in winter. Second, Norwegian cities offer a favourable political landscape to test out and upscale new mobility solutions such as bike sharing. With the Norwegian land-based power sector being 100% renewable, emission reduction efforts are more than in other countries focused on the transport sector. As a result, Norwegian city regions are subjected to ambitious local, regional and national climate, environmental and urban development strategies, including the implementation of car free zones in city centres, the allocation of road tolls to public transport and bicycle investments, and the decoupling of car traffic growth from population growth (Norwegian Ministry of Transport and Communications, 2017).

This study draws on a 2017 survey on shared mobility conducted across nine Norwegian urban areas. This dataset is part of a larger Norwegian Research Council-funded project titled “Shared mobility for inclusive green cities (Sharming cities)”, and has been verified, utilised and described in detail in one earlier publication (Hjorteset and Böcker, 2020). Fig. 1 describes the geographic situation of the nine regions. The rationale for selecting specifically these nine regions is threefold. First, these are the largest urban areas in Norway and, as such, offer levels of density, urbanity, public transport provision and bicycle infrastructure required to adopt bike sharing. Second, in addition to basic levels of urbanity, the regions in this study show also significant variation in built environments both across and within regions, to analyse the effects of urban form. Third, most urban regions in this study have had unmanned station-based non-electric bike sharing systems operational at the time of survey and/or in previous years. Two exceptions are Skien/Porsgrunn and Fredrikstad/Sarpsborg, both of which had ongoing plans to implement such systems at the time of survey. Currently, Oslo/Bærum has the largest installed system with 245 stations, followed by Bergen (100 stations) and Trondheim (55 stations). Drammen has the smallest system in operation (15 stations). The Stavanger/Sandness and Skien/Porsgrunn regions have recently installed new electric bike sharing system, although these were not available at the time of survey.

3.2. Data

The empirical basis for this study is a web-based self-administered stated adaptation and participation survey on shared mobility, amongst a non-stratified random sample of 3672 respondents, aged 18 and older, from the general population inhabiting the nine aforementioned Norwegian city regions. Respondents were recruited via email from a register provided by the Norwegian postal service consisting of users of its services. The full response rate was 13.19% of those who opened emails, which is in line with web survey response rates generally (Fan and Yan, 2010), but which does require consideration regarding representativeness and potential non-response bias. Comparison of our sample composition to population statistics for the respective Norwegian urban regions, reveals that our sample is relatively well balanced on key demographics like age, gender and employment, yet with a notable underrepresentation of non-western ethnicities and lower educated (see Table 1). Underrepresentation of these two groups is quite common in (web-based) transport surveys (Arentze et al., 2005), yet requires caution when interpreting and generalising our results. To account for the fact that some groups are better represented than others, socio-demographics are added as control variables in the multivariate models. We decided against applying sample weights to not introduce additional bias, as we do not know to what extent non-western and lower-educated respondents in our sample are representative for the respective social groups. For a more detailed description and discussion of the dataset, see Hjorteset and Böcker (2020).

Besides these sociodemographic attributes, the dataset contains two key dependent variables on bike sharing: (i) general *interest* in the phenomenon should it be available in one’s neighbourhood (measured on a 7-point Likert scale); and (ii) whether or not people report actual current adoption of *membership* into a scheme. The dataset also contains information on transport resources, daily mobility patterns and attitudes regarding the environment, financial awareness and urban outlook, all of which will be used to elucidate mediating mechanism for bike sharing adoption (see multivariate modelling techniques). The dataset is further enriched with urban form attributes linked to respondents’ geolocated residential addresses, using geographic information systems (GIS). Population density (# inhabitants/ha) and building use diversity (Shannon Index[1]) are summarised over the area comprised of 250 × 250 m grid cells (supplied by Statistics Norway) that intersect with a 300 m buffer around each respondent’s residential location. Public transport proximity is calculated based on the inverted distance of the residential location to the nearest public transport stop with at least 240 weekly departures, using shortest path analysis on the OpenStreetMap network. Finally, a binary variable is calculated to distinguish between Oslo inhabitants and inhabitants from other areas. Such effect may be expected as this capital is the largest and primary city in Norway with the lowest car ownership and usage (Hjorthol et al., 2014) and the most extensive public transport, car and bike sharing systems. Table 1 provides a descriptive overview of all variables in our analyses.

3.3. Statistical modelling techniques

The multivariate analyses in this paper are based on Structural Equation Modelling (SEM) through the software package Mplus. SEM offers the opportunity to integrate attitude factor models for environmental consciousness, financial awareness and urban outlook as constructs into our analyses, each consisting of multiple items measured on 7-point Likert scales. Prior to being integrated into SEM, the three attitude constructs were first established through confirmatory factor analysis (see Table 2). *Environmental consciousness* is based on a shortened 5-item version of the revised (Dunlap, 2008) New Environmental Paradigm scale (Dunlap and

[1] The Shannon Diversity Index ranges from 0, when all buildings have the same function, to maximum diversity when dwellings, stores, offices and/or industrial building functions are maximally mixed.

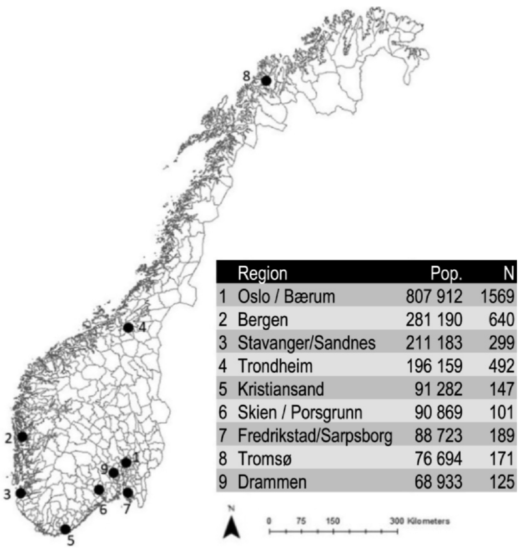

Fig. 1. Study area.
Adapted from Hjorteset & Böcker, 2020.

Table 1
Descriptive statistics of all variables.

	sample statistics (N = 3672)			population statistics [a]
	min/max	mean/%	s.d.	Mean/%
Age in years	19/80	39.1	(14.2)	39.4
Female	0/1	48,7%		50,4%
Non-western ethnicity [b]	0/1	4.6%		8.2% [c]
Fulltime employment	0/1	66.0%		74,5%
BA/MA degree or higher	0/1	67,8%		36,6%
Lower gross househ. income (< 0.5 M NOK)	0/1	33.0%		*median gross household income is 711,000 NOK*
Middle gross househ. income (0.5–1 M NOK)	0/1	36.3%		
Higher gross househ. income (≥1 M NOK)	0/1	21.5%		
Car access in the household	0/1	68,7%		88.0% [d]
Individual bicycle ownership	0/1	73.5%		75.0% [d]
Residential address in Oslo	0/1	35.6%		34,7%
Population density (inhabitants/ha)	0/249	55.3	(50.3)	
Building diversity (Shannon Index)	0/2.58	0.67	(0.55)	
Distance to public transport in km	0/82.3	0.43	(1.73)	
Environmental consc. (average over 5 items)	1/7	5.02	(1.40)	
Financial awareness (average over 3 items)	1/7	5.39	(1.11)	
Urban outlook (average over 3 items)	1/7	4.95	(1.46)	
Bike sharing interest	1/7	3.86	(2.23)	
Bike sharing adoption	0/1	7,0%		

[a] 2017 averages across our study regions based on the Norwegian Bureau for Statistics, unless indicated otherwise.
[b] Respondent, or at least one of his/her parents is born in Asia, Africa or Latin America.
[c] 2017 national average based on the Norwegian Bureau for Statistics.
[d] 2013/2014 national averages based on the Norwegian National Travel Survey.

Van Liere, 1978). With a Cronbach's Alpha score of 0.912, this latent construct has very strong internal consistency in the dataset. *Urban outlook* is based on three items related to one's attitude towards city life in terms of how much one values a varied sports and cultural offer, diversity and liveliness, and a broad retail/service offer in cities. A Cronbach's alpha score of 0.820 indicates fair internal consistency for this latent construct. *Financial awareness* is based on three items on one's relation to money, in terms of degree of financial control, awareness of the price of goods, and the strive to cut unnecessary costs. A Cronbach's alpha score of 0.707 indicates a somewhat poorer internal consistency for this latent construct, although still within the realm of what is considered acceptable and in alignment with common internal consistency values in behavioural research (Peterson, 1994). Moreover, the scale does not compromise the total structural equation model fit (see modelling techniques), i.e., including or omitting the scale does not change model outcomes for the other variables. Nevertheless, the reader should be cautious with interpreting and generalising the financial awareness results. Besides the items listed in Table 2, there were other questions of this type in the survey, but these have not been included in this particular study on bike sharing as they map on constructs (e.g. trust and sociability) that are more relevant

Table 2
Factor analysis for attitude constructs.

Item	Survey statements on the extent to which the respondent (on a 7-point Likert scale from fully disagree to fully agree)…	constructs, crombach's α, and factor loadings		
		environmental consciousness (α = 0.912)	Financial awareness (α = 0.707)	Urban outlook (α = 0.820)
E1	…views environmental protection as an important social policy task	0.905		
E2	…is willing to reduce consumption for the sake of the environment	0.879		
E3	…is worried about climate change	0.859		
E4	…views protecting nature and biodiversity as important	0.849		
E5	…prefers protecting the environment over economic growth	0.818		
F1	…is aware of the price of goods, and what pays of		0.904	
F2	…has control over his/her finances		0.787	
F3	…strives to cut unnecessary costs		0.697	
U1	…values highly the diversity and liveliness in cities			0.879
U2	…values highly a varied sports and cultural offer in cities			0.857
U3	…values highly a broad retail and service offer in cities			0.838

for shared mobilities that involve peer-to-peer interaction.

The environmental consciousness and financial awareness scales have been successfully tested in a parallel study on the adoption of car sharing (Hjorteset and Böcker, 2020). Urban outlook was added in this bike sharing paper, to test to what extent the interest in and adoption of bike sharing are urban lifestyle related and to distinguish such potential lifestyle effect from the effects of urban residential built environment factors. With mean scores of respectively 5.02, 5.39, and 4.95 out of 7 (Table 1), respondents score relatively high on all three constructs (Table 2).

Another reason for using SEM is that it allows for the simultaneous inclusion of multiple dependent variables and an investigation of the paths of mediation via attitudes, transport resources and daily mobility patterns, through which socio-demographics and urban form attributes affect bike sharing outcomes. Hereto, we theoretically defined causality between independent, mediating and dependent variables as follows: Sociodemographic/economic and urban form attributes are included as independent variables, whilst bike sharing interest and adoption form the ultimate dependent variables at the other end. In between, a first set of mediators is formed by the attitude constructs. One of these attitudes, environmental consciousness, is subsequently modelled to affect (along with the independent variables) a second set of mediators consisting of transport resources. This link is theoretically founded on the well-documented negative and positive effects of environmental consciousness on respectively car (e.g. Anowar et al., 2014) and bicycle ownership (e.g. Handy et al., 2010). The relationships between the other two attitudes and transport resources were also tested but ultimately omitted due to non-significant effects and deterioration of overall model fit. Daily mobility patterns, influenced by attitudes and transport resources, make up a third and final mediator set. After testing out various configurations descriptively, in SEM, as well as in more conventional ordered logit (for interest) and binary logit models (for adoption), an interaction between public transport and bicycle usage reported by the respondent for the last week of travel, proved to be the most influential factor for bike sharing. Hence, we chose to include the complementary usage of these two transport modes as a binary mediating variable. These causalities result in two final SEM model configurations (one for interest; one for adoption) presented in Fig. 2.

4. Results and discussion

4.1. Descriptive results

Table 3 describes the distribution of stated bike sharing interest and reported bike sharing adoption shares across different social and spatial categories. For our full sample, mean bike sharing interest is 3.86 on a 7-point scale, with 42% stating an interest (score of 5 or higher) into the phenomenon should it be available in the neighbourhood. Despite this considerable interest, reported bike sharing adoption is quite a bit lower (7%). There may be various reasons for this. It could be that real interest is simply lower than stated interest. It could also be that a time lag exists before interest is concretised into actual adoption, for instance through life-

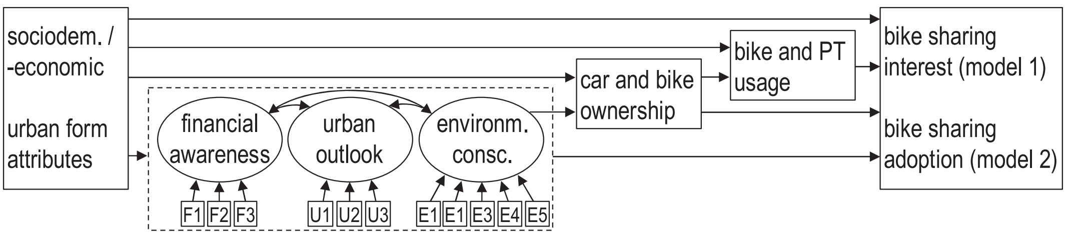

Fig. 2. SEM model structure.

Table 3
Distribution of reported bike sharing adoption and stated bike sharing interest across categories.

category	distribution of stated interest and mean (1 2 3 4 5 6 7)	adoption share	category	distribution of stated interest and mean (1 2 3 4 5 6 7)	adoption share
age u30	4.36	11.1%	env. consc. ≥5	4.21	8.4%
age 30-49	3.89	6.7%	env. consc. <5	3.44	5.2%
age 50+	3.12	2.1%	fin. awaren. ≥5	3.83	6.4%
female	4.01	7.4%	fin. awaren. <5	3.92	8.4%
male	3.72	6.6%	urban outl. ≥5	4.15	9.4%
western ethn.	3.77	7.0%	urban outl. <5	3.46	3.6%
non-west. ethn.	3.83	8.1%			
			owns car	3.64	3.5%
work full-time	3.91	7.9%	no car	4.35	14.6%
part-time/ other	3.77	5.3%	owns bike	3.90	5.1%
income highest	3.70	5.7%	no bike	3.73	12.2%
income lower	3.90	7.3%	bike & PT use	4.67	17.5%
educ. BA/MA	3.91	7.9%	bike use	4.31	13.1%
educ. lower	3.75	5.1%	PT use	4.12	9.5%
			car use	3.75	5.1%
Oslo	4.24	16.4%			
outside Oslo	3.65	1.8%	**full sample**	3.86	**7.0%**
	0 % – 100 %			0 % – 100 %	

course triggers (e.g. a residential/workplace relocation; a change in household composition) or active policies, as previously investigated in the case of car sharing (Kent et al., 2017). Or it may indicate that barriers exist with regard to today's geographies or functioning of bike sharing systems (see Böcker et al., 2020) that prevent people to actually enrol in a bike sharing scheme, let alone integrating bike sharing on a regular basis into their daily mobility practices.

When looked at sociodemographic factors, there is a clear and seemingly linear negative age effect on interest and adoption. The adoption share in particular is relatively high amongst younger (11.1%) compared to middle (6.7%) and older age groups (2.1%). In contrast to existing findings (e.g. Fishman et al., 2015), women may be slightly more interested and likely to adopt bike sharing than men, but this gender effect is weaker than that of age and will need to be verified multivariately. The descriptives indicate that non-western groups could be more interested in bike sharing and have higher adoption shares. However, such effects need to be verified multivariately by controlling for factors like residential location that are likely to interfere. For example when tested within a subsample for Oslo, a city where bike sharing interest and especially adoption shares appear much higher than in other study areas, groups with a non-western ethnicity show slightly lower bike sharing membership (14.3%) compared to groups with a western background (16.6%).

Full time work, higher education and lower income seem to have positive effects on both interest and adoption, but these effects need to be untangled from each other, as well as from that of attitudes in multivariate models. In line with early adopter rhetoric, of the attitudes environmental consciousness and urban outlook seem to have clear positive effects on both interest and adoption. Finally, transport resources and travel patterns seem to play a key role, especially when looked at the adoption shares. Car ownership seems to have some negative effect on interest, but a much stronger negative effect on adoption shares (3.5%, compared to 14.6% for those not owning a car). Bicycle ownership is also negatively linked to adoption shares, indicating that some probably use the bike sharing system as a substitute for owning a bicycle. Car use has a minor negative effect on bike sharing interest and adoption, whilst public transport and bicycle use have somewhat stronger positive effects. Yet, it is the combination of cycling and public transport use that has the clearest positive effect on both interest (mean = 4,67) and adoption (17.5%). Hence, we will test the effect of this combination multivariately.

4.2. Multivariate analysis of stated bike sharing interest

Table 4 presents our multivariate SEM results regarding the effects of travel behaviour, transport resources, attitudes and sociodemographics on stated bike sharing interest. The table presents the direct effects for each set of these factors, as well as the total effects, which include also the indirect effects via travel behaviour, transport resources and attitudes, if applicable (see Fig. 2). A final column indicates notes on the significant paths of mediation (with 95% confidence) within these total effects. All parameter estimates are standardised to ease comparing their relative impacts on the dependent variable. The model is well-fitted with an RMSEA value of 0.041, below the critical 0.05 level, and a CFI value of 0.988, well above the critical 0.95 level. It explains 15.1% of the variance in bike sharing interest.

Confirming our descriptive results, combined bicycle and public transport use (B&PT) has a positive effect on bike sharing interest, more so than alternative model configurations where bicycle use or public transport use are tested separately. Those who only use public transport, may have reservations to cycle, a lack of familiarity, and/or lack the necessity to do so. On the other hand, those who cycle without using public transport, use their own bicycle possibly on a regular basis and mainly as a stand-alone mode. It is likely the ones that combine use of and familiarities with both cycling and public transport that are most appealed to the idea of bike sharing. Either as a stand-alone mode to replace some public transport trips, or as an access or egress mode directly integrated

Table 4
Results of SEM model 1 on stated bike sharing interest.

	direct effect		total effect		notes on total effect with regard to significant paths of mediation ($p \leq 0.05$)
bicycle & PT user (ref. not)	0.132	***	n/a		n/a
car ownership (ref. not)	0.010		−0.001		non-sig., despite negative path via B&PT
bike ownership (ref. not)	0.030	*	0.061	***	enhanced by higher B&PT
environmental consc.	0.168	***	0.190	***	positive effect enhanced by higher bicycle & PT usage (B&PT)
urban outlook	0.096	***	n/a		n/a
financial awareness	0.002		n/a		n/a
age	−0.195	***	−0.205	***	negative effect enhanced by lower B&PT and urban outlook
female (ref. male)	0.014		0.043		non-sig., due to mixed effects via higher env. consc. and lower B&PT
non-west. ethn. (ref. west.)	0.183	**	0.201	***	enhanced by higher urban outlook despite lower B&PT
full-time work (ref. part-time)	0.062	*	0.041		non-sig., due to mixed effects via env. consc. and B&PT (through bike/car o.)
higher income (ref. lower)	−0.030		−0.009		non-sig. due to mixed effects via B&PT (through bike/car o.)
higher education (ref. lower)	−0.004		0.087	**	positive, thanks to higher env. consc., urban outlook and B&PT
population density	0.081	***	0.117	***	enhanced by higher env. consc., urban outlook and B&PT
building use diversity	0.041	**	0.047	***	enhanced by higher B&PT (through lower car o.)
proximity (log) to PT	−0.025		−0.015		non-sig., despite positive path via higher urban outlook
Oslo (ref. not)	0.062		0.074	*	positive, thanks to higher B&PT

Model fit: $Chi^2(df) = 1094(150)^{***}$ RMSEA = 0.041 CFI = 0.988 R^2 bike sharing interest = 0.151.
Significance: $*p \leq 0.1$; $**p \leq 0.05$; $***p \leq 0.01$.

into public transport trips. Besides the effect of B&PT use, we also identify a positive effect of bicycle ownership on bike sharing interest. Also here, it may be some form of cycling familiarity that bicycle ownership brings, which positively influences bike sharing interest. Car ownership is not found to have an effect.

Besides being related to the mobility factors discussed above, bike sharing interest is also, and in some cases even more so, connected the attitudinal factors environmental consciousness and urban outlook typically linked to the early adoption of sustainability and sharing economy innovations (e.g. Piscicelli et al., 2015; Hamari et al., 2016; Botsman and Rogers, 2011). Environmental consciousness has a particularly strong positive effect. Moreover, the effect is further enhanced by an indirect positive path of mediation via higher B&PT use amongst environmentally conscious people. The effect supports asserted positive associations of shared mobility with more environmentally-friendly future transport systems (Burkhardt and Millard-Ball, 2006, Efthymiou et al., 2013). Besides environmental consciousness, urban outlook also has a strong positive effect, indicating that bike sharing may be a phenomenon of interest connected to urban lifestyles. Our third attitude, financial awareness, appears to have no effect.

Also when looked at socio-demographic backgrounds, we find indications that link bike sharing interest to the characteristics of early adopters (Shaheen et al. 2011), but we also find some surprising contradictions. In line with results on bike sharing intentions in Greece (Efthymiou et al., 2013) and bike sharing uses in New York City (Wang et al., 2018)), we find that age has a particularly strong direct negative effect, which is further enhanced by the lower urban outlook and the lower B&PT use of older aged people. Other factors like full time work (only directly, due to various opposing indirect effects) and higher education (not directly, but only indirectly via higher urban outlook, environmental consciousness and B&PT use) are also positively linked to bike sharing interest, albeit less prominently. On the other hand, we observe neither direct, nor indirect effects of gender or income on bike sharing interest, contrary to the general consensus that bike sharing is typically dominated by men and higher income groups (e.g. Fishman et al., 2015; Wang and Akar, 2019). Moreover, we find that non-western groups, not a typical early adopter category, show considerably higher bike sharing interest than people with a Norwegian or other western background. The total effect is even further enhanced thanks to a stronger positive path of mediation via higher urban outlook, outweighing the negative effect of lower B&PT use amongst non-western groups.

Finally, bike sharing interest is related to urban form attributes in the residential vicinity. Higher population density leads to more bike sharing interest, a positive effect further enhanced by higher B&PT usage in such areas, and by the residential self-selection of more environmentally conscious people. Higher building use diversity also leads to higher interest, an effect slightly enhanced via higher B&PT usage related to lower car ownership in such areas. Public transport proximity at the residential location is not found to affect bike sharing interest: neither directly, nor in total, despite a positive path via higher urban outlook amongst those living closer to public transport. The clear descriptive difference in bike sharing interest between Oslo residents and those outside the capital observed earlier (see Table 3), appears to be captured by other factors when tested multivariatly: No direct capital city effect is detected, and only a minor total effect thanks to higher B&PT usage amongst Oslo residents.

4.3. Multivariate analysis of bike sharing membership

Table 5 presents our structural equation modelling results with regard to bike sharing membership, with a similar structure and layout as Table 4. The model is well-fitted with an RMSEA value of 0.041, a CFI value of 0.988, and explains 19.2% of the variance in bike sharing membership. Even more strongly than its effect on bike sharing interest, combined bicycle and public transport use (B&PT) has a positive effect on the adoption of bike sharing membership. This result is in line with existing findings from Montreal (Bachand-Marleau and El-Geneidy, 2012), indicating that people who combine cycling and public transport are the ones most likely to use the bike sharing system. Whilst car ownership was not found to affect bike sharing interest, it does have a direct negative effect

Table 5
Results of SEM model 2 on bike sharing membership.

	direct effect		total effect		notes on the total effect with regard to significant (p ≤ 0.05) paths of mediation
bicycle & PT user (ref. not)	0.190	***	n/a		
car ownership (ref. not)	−0.046	***	−0.062	***	negative effect enhanced by lower B&PT
bike ownership (ref. not)	−0.123	***	−0.078	***	negative effect despite being weakened by higher B&PT
environmental consc.	0.028		0.054	***	positive, thanks to lower car o., despite negative path via higher bike o.
urban outlook	0.061	***	n/a		
financial awareness	−0.016		n/a		
age	−0.061	***	−0.094	***	negative effect enhanced by lower B&PT usage and higher car o.
female (ref. male)	−0.023		−0.042		non-sig., due to mixed effects via B&PT and bike/car o. (through env. consc.)
non-west. ethn. (ref. west.)	−0.111	*	−0.064		non-sig., as lower bike o. and higher urban outlook oppose the direct neg. effect
full-time work (ref. part-time)	0.102	***	0.056		non-sig., due to mixed effects via B&PT and bike/car o (direct/via env. consc.)
higher income (ref. lower)	0.030		−0.017		non-sig., due to mixed effects via bike o., car o. and B&PT
higher education (ref. lower)	0.041		0.071	*	positive, thanks to higher B&PT, urb. outl. and lower car o. (through env. consc.)
population density	0.209	***	0.260	***	enhanced by higher B&PT, urb. outl. and lower car o., despite higher bike o.
building use diversity	0.040	**	0.056	***	enhanced by higher B&PT, despite higher bike o. weakening the effect
proximity (log) to PT	−0.018		−0.007		remains non-sig.
Oslo (ref. not)	0.188	***	0.215	***	enhanced by higher B&PT

Model fit: $Chi^2(df) = 1073(150)^{***}$ RMSEA = 0.041 CFI = 0.988 R^2 bike sharing membership = .192.
Significance: *p ≤ 0.1; **p ≤ 0.05; ***p ≤ 0.01.

on bike sharing adoption (congruent to Washington DC findings by Buck et al., 2013), further enhanced by its negative effect on B&PT use. This discrepancy between car ownership effects on interest versus adoption is something we also found in a parallel study in the context of car sharing (Hjorteset and Böcker, 2020). Compared to car ownership, bicycle ownership has an even stronger direct negative effect on bike sharing use, even though its total effect is somewhat weakened by its negative effect on B&PT use. The negative relation between bicycle ownership and bike sharing is in line with the aforementioned Montreal and Washington DC studies (ibid.), as well as with findings from Greece (Efthymiou et al., 2013). So, whilst bicycle ownership stimulates bike sharing interest, its negative effect on adoption confirms the descriptive indication that some may use bike sharing as a substitute for owning a bicycle.

Where some attitudes exerted strong effects on bike sharing interest, their respective effects on actual adoption appear to be more modest, an observation also in line with the aforementioned car sharing findings (Hjorteset and Böcker, 2020). Urban outlook has a positive effect on adoption, although not as strong as on interest. Environmental consciousness has no direct effect on the likeliness of having a bike sharing membership. Nevertheless, a positive total effect is detected, thanks mainly to a strong positive effect of lower car ownership amongst environmentally conscious people, outweighing the negative adoption effect of higher bike ownership for this group. Urban outlook does have a positive direct effect. Similarly, to what we found for interest, financial awareness appears to have no effect on membership. This contrasts with studies from Brisbane and Melbourne (Fishman et al., 2015) and Washington (LDA Consulting, 2013) that find financial savings motivations for bike sharing. Although in the first study its role was relatively modest and in the second it was only found amongst low income members. It also rejects our hypothesis that bike sharing systems may appeal to or be used by financially conscious people to replace more expensive travel alternatives. A possible explanation could be that in Norwegian cities public transport, the most logically substituted mode, is often paid for by periodic subscriptions rather than costly single tickets, which makes it hard for regular public transport users to save money unless substituting use drastically.

Considering socio-demographics, in line with earlier studies (e.g. Fishman et al., 2015), age has a prominent negative effect on bike sharing membership, though less strong than on interest. We detect neither direct nor total significant effect of gender on bike sharing adoption, due to mixed paths of mediation (see Table 5). This contrasts with earlier studies (e.g. Fishman et al., 2015; Vogel et al., 2014), including from Norway (albeit exclusive to Oslo – Böcker et al., 2020), that indicate lower uses amongst women. An interesting finding is that of non-western ethnicity. Whilst being more interested in bike sharing (Table 4), non-western groups are less likely to be a bike sharing member when looked at the direct effect. Even though issues of ethnicity or race are rarely studied in the context of bike sharing or shared mobility generally, this finding is somewhat in line with earlier USA and Glasgow studies (McNeil et al., 2018; Clark and Curl, 2016). It detects that people of colour have significantly lower user rates than white or western people, despite being just as interested in bike sharing. It seems that barriers prohibit such groups to concretise their interest into actual adoption, possibly resulting from geographical or other mismatches between bike sharing offers and their specific user needs (e.g. Hosford and Winters, 2018).

Regarding socio-economic status, we find income to have neither direct, nor total effect, in contrast to e.g. USA studies (Ursaki and Aultman-Hall, 2015; McNeil et al., 2018) that indicate negative income effects, albeit in a less egalitarian context than Norway. Yet, our other employment-related factor indicates that not having a full-time job has a negative direct effect on bike sharing, in line with previous research from Canada (Hosford and Winters, 2018). Its total effect is not significant though, due to a complex of mixed effects via B&PT use, bike/car ownership and environmental consciousness. Congruent to existing studies (e.g. Ricci, 2015, Fishman, 2016; McNeil et al., 2018), education is found to have a positive total effect. The effect is not direct though, but is because higher educated more often use B&PT, have a more urban outlook, and own fewer cars as they are more likely to be environmentally conscious.

When looked at urban form, its effects on bike sharing adoption appear even stronger than on interest. In line with studies pointing at the heavier use of bike sharing in urban centres (e.g. Bachand-Marleau and El-Geneidy, 2012; Fishman et al., 2014; Noland et al., 2016) and the logic that bike sharing systems are usually primarily installed in inner-city areas (which is also the case in our study areas), we find that population density has a clear positive effect, in fact strongest in magnitude of all estimated parameters. Its total effect is further enhanced by higher B&PT use, a more urban outlook, and lower car ownership in densely populated areas, despite being also somewhat weakened by higher bike ownership. Diversely-built neighbourhoods also add to higher bike sharing membership, a relationship strengthened by higher B&PT usages in such areas, despite that higher bicycle ownership makes fewer people use bike sharing as a substitute. Whilst earlier studies indicate the importance of public transport proximity at the residential location for bike sharing (e.g. Bachand-Marleau and El-Geneidy, 2012; Fishman et al., 2014, McNeil et al., 2018), we find neither untransformed nor log-transformed public transport proximity effects. An explanation could be that, unlike in the aforementioned North American and Australian studies, the close proximity to public transport in our study areas (430 m proximity on higher-frequency public transport stops, see Table 1) makes this factor less of an issue. Rather than proximity, it may be the suitability of using public transport in everyday life, which we capture partly by the inclusion of B&PT-usage. Additional variance across our sample with regard to the relative competitiveness of public transport relevant to bike sharing, may be captured by distinguishing between people living outside and inside Oslo: a city where public transport shares far exceeds that of any other large Norwegian city (Hjorthol et al., 2014). Where we detected no direct and only a marginal total "Oslo-effect" on bike sharing interest, living in this capital city does exert a very strong positive effect on bike sharing adoption, an effect further enhanced by higher B&PT usage.

5. Conclusion

Amidst increasing popularity of bike sharing and research on the topic, the objective of this paper is to elucidate its social and spatial inclusiveness. To this end, the paper compares *stated interest* in bike sharing and *reported membership*, and explores the intersectionality with socio-demographic, socio-economic and residential urban form attributes, directly as well as mediated by attitudes, car and bike ownership, and daily mobility patterns. The paper draws on a web-based survey amongst 3672 residents of urban regions in Norway. As with web-surveys generally, caution with regard to non-response bias is required when interpreting the results, despite controlling for socio-demographics in multivariate models.

This paper complements existing bike sharing studies by exploring *interest-adoption discrepancies*. Our results indicate that stated bike sharing interest is positively influenced by early adopter characteristics such as young age, full-time work, environmental consciousness, urban outlook, urban residential locations, and the current adoption of combined bicycle and public transport use. In contrast, reported bike sharing membership is explained more typically as a travel behaviour: with significant yet weaker effects of attitudes; enhanced effects of residential urban form and bicycle-public transport use; and an additional negative effect of car ownership. This pattern is similar to what we observed in an earlier Norwegian study comparing interest and adoption for car sharing (Hjorteset and Böcker, 2020). Interestingly, bike ownership stimulates bike sharing interest, possibly as a proxy for the cycling familiarity and skills required to bike share, whilst negatively effecting membership. The latter may indicate that some use bike sharing to substitute owning a bike. Another notable interest-adoption discrepancy is observed with regard to the understudied effect of ethnicity. Against early adopter logic, non-western groups are found to have higher bike sharing interest, but their likeliness of adopting membership turns out to be lower, in line with findings from the USA (McNeil et al., 2018). Besides revealing new insights into bike sharing adoption and inclusiveness, such interest-adoption discrepancies shed new light on differences between stated and revealed bike sharing outcomes, which can help better contextualise and compare existing studies.

This paper makes a second important contribution to the field by uniting spatial, socio-demographic/economic, attitudinal and mobility-related components of bike sharing into one analysis. Through use of Structural Equation Modelling we reveal the *complex interrelations* of above-mentioned components and distinguish between *direct* and *mediated* effects, even though causalities defined in this paper could be debated and explored in further research. It shows us that many of the effects on bike sharing outcomes usually attributed to user backgrounds or residential contexts, are actually partially (e.g. for age, ethnicity and most urban form attributes) or entirely (e.g. for education level) mediated by attitudes, transport resources, daily transport mode uses, or combinations thereof. This gives a deeper understanding of the mechanisms at play, including that of potential negative rebound effects, such as the negative paths of mediation that run via increased bicycle ownership to decreased bike sharing outcomes.

Our results have important implications for policy aimed at improving the effectiveness of bike sharing in *combatting car dependency*, and its *socio-spatial inclusiveness*, as well as for further research supporting such policies. First, the integration of mobility factors in our analyses reveals that bike sharing has strong potential to reduce vehicle ownership, synergise with public transport and private bicycle usages, and enhance their combined relative competitiveness against the car, even though some people may just use it to substitute walking, private bike use and public transport. This provides an important policy argument to further invest in bike-sharing generally, and its seamless integration with public transport particularly. Practical examples to advance seamless integration may include the direct placement of bike sharing docks at station entrances; integrated public-transport-bike-sharing ticketing systems for periodic subscriptions as well as single rides; and better bike sharing demand-balancing to match supply with demand peaks at stations. To further support such integration policies, new pre/post-adoption studies are recommended on the precise spatio-temporal interweaving of bike sharing into daily mobilities, including on access-egress uses in different types of multimodal public transport systems (e.g. Böcker et al., 2020).

Second, interest-adoption discrepancies reveal important policy implications to target bike sharing adoption challenges for certain groups. For example, for groups that are not full time employed as well as for non-western ethnicities, it becomes clear that it is not so much a lack of awareness, willingness or preference, but rather more structural barriers that prohibit these groups from adopting bike sharing. The implications of this for policy are that information and communication campaigns alone are not enough to stimulate inclusive adoption, but that more structural measures are required to tackle uneven bike sharing access and improve services to cater a wider range of user needs. Such structural measures may include wider geographic expansion into neighbourhoods of lower socio-economic status or the removal of barriers to better match bike sharing services with the specific user needs of marginalised groups. For example, policy makers and bike sharing operators may want to trial a removal of ride time barriers, subscription registrations, subscription fees, the requirement of credit card access to rent bikes, and/or provide better guidance/coaching to those who are less familiar with the (bike) sharing technologies and platforms. To support such structural measures, two important tasks for further research are to pinpoint the heterogenous user needs of marginalised groups, and to unravel the individual and neighbourhood effects on bike sharing adoption rates, preferably with multilevel analyses.

Third, our findings have implications for policy targeting bike sharing in lower density regions. People living in less diversely built, lower density areas, and/or those living outside the capital city Oslo, have much lower membership rates, even though their interests into bike sharing are only marginally lower. This demonstrates that also here there is an unmet potential for using (shared) bicycles as an integrated part of daily mobility, with possibly even higher significance for combatting car dependence than in inner-city areas. While geographic expansion of bike sharing systems into more peripheral lower density areas may not be as resource and cost-effective, policy makers may rather meet this potential by trialling alternative solutions to integrate (electric) cycling with public transport. Examples of such solutions could be the integration of systems of (e-)bike lending and/or lease within periodic public transport subscriptions, combined with secure bicycle parking services at stations and/or bike and ride systems.

CRediT authorship contribution statement

Lars Böcker: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Ellinor Anderson:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing.

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