THE INTERPLAY BETWEEN RESIDENTIAL LOCATION AND CYCLING CHOICE

Francesco Piras[12], Giovanni Tuveri[1], Eleonora Sottile[1], Italo Meloni[1]

[1]University of Cagliari, Italy

[2]Corresponding author: francesco.piras@unica.it

INTRODUCTION

In recent years sustainable transport and urban pollution have been attracting much attention from practitioners and researchers. Indeed, the transport sector is a primary cause of the observed deterioration in urban air quality (EEA, 2019), road transport having increased significantly. For example, in 2018 in Italy, where the number of cars saw an increase of 4.1% over 2014, air quality worsened, with levels of PM_{10} and $PM_{2.5}$ far higher than the standards set by both the European Union and the World Health Organization (ISFORT, 2018). Transportation also generates several other issues that impact on environment and urban life, including noise pollution, public health and safety.

A key element in the strategies aimed at easing traffic congestion and reducing the environmental impact is to encourage active transportation modes such as walking, biking and bike-sharing. In particular, there has been a surge of interest in cycling (Pucher and Buehler, 2017) as a transport option able to bring benefits at both the individual and the community level, also in view of the technological advances in bicycles in recent years (e-bikes). These benefits include eco-friendliness and enhanced attractiveness of urban areas, a reduction in various diseases such as obesity and diabetes, reduced parking space, low access cost and flexibility in departure time compared to public transport.

An extensive and growing body of literature has investigated the determinants that are likely to encourage people to choose to bike commute (*e.g.* Heinen *et al.*, 2010; Muñoz *et al.*, 2016; Ton *et al.*, 2019). Most of the research has focused on objective factors, such as socioeconomic characteristics, bike environment, trip characteristics and time limitations. One aspect often overlooked in transportation research is how sociodemographic and territorial characteristics factors influence the use of bike for non-commuting purposes (shopping, errands, leisure and sports). Much of the research has focused on bicycle use for any purpose, mixing utilitarian and recreational trips (Oliva *et al.*, 2018). However, the determinants triggering the choice to travel by bike may be different, depending on the reason people cycle. The other issue concerns the existence of a relationship between bike commuting and cycling for other purposes. Some studies (Stinson and Bhat, 2004; Park *et al.*, 2011) found that non-work cycling increases the likelihood to commute by bike, even if the direction of causality may not be very clear (Kroesen and Handy, 2014). Considering this, policy planners have been starting to implement policies and strategies that support cycling for non-work trips (*e.g.* cycleways).

The other aspect given little consideration is the residential self-selection problem. The importance of taking into account the influence of the built environment (population and employment densities, design, street connectivity) has been stressed in different works (see Heinen *et al.* 2010; Wang *et al.*, 2016), but many consider it as an exogenous variable in the decision to cycle, ignoring the possibility of households' residential location choice process (Pinjari *et al.*, 2008). In fact, bicycle travel behaviour may not only be influenced by residential location, but individuals might choose their home because they intend to cycle, preferring to live in areas that allow them to do so easily (Heinen *et al.*, 2010). Although this issue has been largely investigated in studies of walking as well as travel behaviour more generally, little research exists on the role of residential preference specifically influencing bicycle use. Examples include the works of Pinjari *et al.* (2011) and Ettema and Nieuwenhuis (2017).

To fill the gaps identified earlier, the current paper aims to contribute to the literature by investigating the relationships among three behavioural choice variables, namely, residential location choice, commute mode choice and non-commuting cycling frequency. Here, in the attempt to place greater emphasis on the above aspects we used a mixed modelling structure that incorporates common error terms that allows us to control for self-selection and unobserved effects that can simultaneously influence the underlying propensities.

DATA COLLECTION

The data used in this study come from a survey conducted by the Regional Government of Sardinia and the Research Centre for Mobility Models (CRiMM) at the University of Cagliari (Italy) in two mid-size urban areas in Sardinia (Cagliari and Sassari). The survey, called "BIKE I LIKE YOU", was carried out between 2014 and 2016 and targeted local authority employees. In particular, the questionnaire was organised into 4 sections:

- Bicycle use section aimed to identify for what purpose and how frequently people choose to cycle.
- Cycling perceptions section (Likert scale from 1 to 5 (1=Totally disagree to 5 = Totally agree) intended to:
  1. Measure positive and negative perceptions of cycling in general.
  2. Measure the perception of context characteristics, intended as the importance assigned to policies for increasing bike use.
  3. Measure the perception of bikeability and safety of bike lanes and paths.
- Description of home-work commute trip.
- Socio-demographic information section.

A total of 2,128 observations with prerequisites useful for the study at hand were used in our analyses (Table 1). The sample is equally divided between males and females with a slight preponderance of the latter. As the sample is composed predominantly of public sector employees, the majority of respondents have medium-high level of education and are aged between 41 and 60. The majority are married/live with partner in households with on average 3 members.

Table 1. Data collection

Variables	N.	[%]	AVG.
Total sample	2,128		
Gender (male)	1029	48.4%	
Age			48.02
Age 18-30	82	3.9%	
Age 31-40	341	16.0%	
Age 41-60	1559	73.3%	
Age > 60	146	6.9%	
Level of education			
Low (High school and lower)	901	42.3%	
Medium (Graduate)	738	34.7%	
High (Higher than master's degree)	489	23.0%	
Body Mass Index			23.61
Marital status: married	1550	72.8%	
With children	1159	54.5%	
# of members in the household			2.88
Personal car available	1930	90.7%	
# of cars per household			1.72
Personal income per month			
Income 0-1000 €	140	6.6%	
Income 1000-2000 €	1382	64.9%	
Income 2000-3000 €	205	9.6%	
Income >3000 €	301	14.1%	
Residence choice			
Urban high density	1654	77.7%	
Urban low-density	344	16.2%	
Suburban low-density and rural	130	6.1%	
Commute mode choice			
Car	1437	67.5%	
Public transport	210	9.9%	
Walking	313	14.7%	
Bicycle	168	7.9%	
Frequency of cycling for non-commuting trips			
Never	1065	50.0%	
1-10 times per year	328	15.4%	
1-5 times in the past 30 days	328	15.4%	
1-5 days per week	349	16.4%	
Everyday	58	2.7%	

METHODOLOGICAL FRAMEWORK

The behavioural framework in this paper focuses on three key choices of bicycle travel behaviour: residence choice, commute mode choice and propensity to use the bike for non-commuting trips. All the choice variables are estimated simultaneously with a comprehensive modelling framework in which level of service, individual and household characteristics serve as explanatory variables. There are three simultaneous choice models, one for each dependent variable:

- One multinomial choice variable defining the neighbourhood residence choice:

        - High-density urban
        - Low-density urban
        - Low-density suburban and rural.
- One multinomial choice variable representing the commute mode choice:
    - Car
    - Public Transport
    - Walking
    - Cycling.
- One ordered choice variable representing the frequency of cycling for non-commuting trips. We consider five different categories of frequency:
    - I never do
    - 1-10 times per year
    - 1-5 times in the past 30 days
    - 1-5 days per week
    - Every day.

Note that the classification of the neighbourhood residence type is based on the classification made by the Regional Government of Sardinia in its digital land use maps (Agristudio-Geomap, 2007). Another factor to consider is that the level of density is not the only built-environment measure that can be used, but others exist (*e.g.* land use-mix, distance from city centre, street connectivity). However, it has been shown that density is highly correlated with almost all built environment measures and it is the most common measure used in transportation literature (Singh *et al.*, 2019).

The methodological approach taken in this study is a jointly modelling methodology based on the work of Bhat and Guo (2007). In this approach, a series of sub-models are formulated for different choice dimensions—a multinomial logit model of residential location, a multinomial logit model of commute mode choice and an ordered probit model of bicycling frequency for non-commuting purposes. All the models are econometrically joined by the means of the presence of common random coefficients (serial correlations).

MODEL RESULTS

The residential location choice component of the model (first block of table 2) suggests that individuals with children have a greater propensity to reside in low-density urban and suburban areas. This result can be explained by the fact that in Sardinia suburban living spaces tend to have more rooms and more private outdoor space, which are preferred by households with children. Instead, single individuals are more likely to choose to live in high-density urban areas. Lower levels of car ownership are associated with higher-density residential locations, probably because they offer pedestrian-friendly facilities and a denser public transport network that facilitate the use of alternative means of transport.

The second block of table 2 presents the result of model estimation of the commute mode choice. The negative signs of travel times, travel costs, walking time from/to the bus station, walking time from/to the car park and time taken looking for a parking place are consistent with microeconomic theory. The negative effect of the peak hour coefficient in the public transport utility function suggests that public transport passengers are more likely to travel during off-peak times to avoid crowds. In terms of network characteristics, not surprisingly, the existence of bike lanes within 500m of home positively affects the utility of the bicycle mode, suggesting that investments in bicycle infrastructure could have a positive impact on the choice to cycle. On the other hand, hilly terrain has a negative impact on the choice to cycle: among the different specifications we tested, the mean slope of uphill stretches was the most significant. A range of socio-economic variables were found to have a statistically significant influence on mode choice. Males are less likely to travel by car, while, by contrast, individuals with children are more likely to do so. In fact, the presence of children in the household make people less inclined to active commute or use public transport, as they often have to chain trips and do drop offs/pick ups, which is burdensome especially if the drop off/pick-up locations are not close to their commute route. Moreover, as expected, the number of cars per household positively affects the utility to commute to work by car, while the number of bikes positively influences the cycle to work choice.

The third block of table 2 shows the results of the ordered probit model of cycling frequency for non-commuting purposes. Males tend to have a greater propensity to use the bike for recreational purposes and errands/shopping. The results also indicate that younger persons have a much greater predilection for biking than their older counterparts. Interestingly, the Body Mass Index negatively affects the propensity to bike, suggesting that healthier people are more likely to cycle. We found that different household demographics play an important role in cycling frequency for non-commuting purposes: number of cars, number of bicycles, presence of children, and number of household members. As expected, the number of bikes in the household positively affects the utility of using the bike. By contrast, individuals with children are less likely to do so. In fact, individuals with children may have less free time to pursue leisure activities, due to their parental duties. Also, the number of cars in the household has a significant negative impact on bicycle use.

Serial correlations (fourth block of table 2) suggest the existence of unobserved factors among the outcomes. The standard deviation of the error component between the utility to choose to live in high density urban areas and non-commuting bicycle propensity turned out to be positive and significant, indicating the presence of a self-selection effect. A possible interpretation of this finding is that individuals who have a high attitude toward physical activity may locate themselves in urban high-density areas, characterized in Sardinia by the presence of urban parks and recreational/shopping areas, and consequently use the bicycle for non-commuting purposes with a higher level of frequency. Positive correlation was also found between the utility to commute by bike and the non-commuting bicycle propensity. This may be attributable to such unobserved factors as a better perception of bike benefits or a greater perception of bikeability. We also account for observed endogenous effects, and in particular we found that cycling for non-commuting purposes positively influences the choice to cycle for utilitarian purposes. Note that this is a “true” causal effect because of the presence of common error terms in the utility functions of choice dimensions (see Pinjari *et al.*, 2011).

Table 2. Model results

Explanatory variables	Coeff.	R T-stat
Residential location choice model		
Constant urban high density	3.25	15.94
Constant urban low density	0.97	9.45
Urban high-density attributes		
Children (Yes = 1; No = 0)	-0.37	-2.96
# of cars in the household	-0.26	-3.29
Single component household (Yes = 1; No = 0)	0.23	1.14
Commute mode choice model		
Constant public transport	0.53	1.21
Constant walking	1.33	4.26
Constant bicycle	-4.28	-7.79
Car attributes		
Travel time	-0.03	-1.39
Travel cost	-0.46	-4.77
Walking Time from/to parking area	-0.03	-1.39
Time looking for parking area	-0.02	-0.96
Gender (Man=1, Woman=0)	-0.42	-3.56
Children (Yes = 1; No = 0)	0.39	3.24
# of cars in the household	0.43	4.42
Public transport attributes		
Travel time	-0.04	-3.21
Travel cost	-0.28	-2.90
Walking time from/to bus stop	-0.05	-3.55
Waiting time	-0.06	-3.16
# of transfers	-0.21	-0.90
Peak hour (Yes = 1; No = 0)	-0.50	-2.76
Walking attributes		
Travel time	-0.09	-7.28
Bicycle attributes		
Travel time	-0.08	-8.87
AVG Slope	-0.15	-2.21
# of bicycles in the household	0.74	4.88
Presence of bike paths within 500m of home	0.44	1.89
Frequency of bicycling for non-commuting purposes	1.14	8.12
Non-commuting bicycle propensity		
Gender	0.69	9.39
Age	-0.01	-3.26
Body Mass Index	-0.04	-5.61
Bachelor's degree or higher	-0.36	-5.56
# of bikes in the household	0.74	4.88
# of cars in the household	-0.20	-3.55
Presence of children	-0.38	-3.95
# of household components	-0.23	-5.34
Standard deviation of error components		
Standard deviation of the error component between the utility to commute by bike and the non-commuting bicycle propensity	0.68	4.94
Standard deviation of the error component between the utility to choose live in high density urban areas and non-commuting bicycle propensity	0.50	5.56
Measures of fit		
Null loglikelihood	-10,804.10	
Final loglikelihood	-4,902.36	
ρ^2	0.543	

CONCLUSIONS

The paper presents the findings of a study focusing on unrevealing the interplay between the residential location choice, the commute mode choice and the propensity of cycling for non-commuting purposes. We used a jointly modelling structure that incorporates common error terms, so that it was possible to control for self-selection and unobserved effects that can simultaneously influence the underlying propensities. The data used is derived from a survey conducted in Sardinia (Italy), where bicycling is mainly considered as a form of exercise and recreation.

The work contributes in different ways to our understanding of cycling travel behaviour and provides important implications for policy makers aiming to encourage the use of the bike. Regarding the commute mode choice model, our findings mostly support previous research. For instance, travel time and the presence of slopes along the route negatively affect the choice to cycle.

The study also shed light on the propensity of cycling for non-commuting purposes, which is a relatively understudied topic, and whether a relationship exists with the utility to cycle to work. We found that some sociodemographic variables simultaneously influence the two choices. Further, through the inclusion of a common error term we were able to incorporate endogenous effects in our analysis. In particular, we found that cycling for non-commuting purposes influences the choice to commute by bike. From a policy perspective, this last result suggests that investments aimed at supporting the use of the bike for leisure (*e.g.* cycleways and cycle routes) may increase the number of people who choose to use the bike as an alternative means of transport for commuting.

Another important finding of our research concerns the presence of common unobserved factors between the residential location choice and non-work bicycle propensity. In particular we found that we cannot reject the presence of a self-selection effect, suggesting that the only inclusion of traditional sociodemographic variables is no longer sufficient by itself to assess the outcome of a policy intervention, but lifestyles themselves and individuals' attitudes should be included as the target of interventions.

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