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Effect of Environmental Awareness on Electric Bicycle Users' Mode Choices

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ABSTRACT: Travellers' environmental awareness can affect their mode choices. The primary objective of this study is to identify the effect of electric bicycle (e-bike) users' environmental awareness on their mode choice when the use of e-bikes is prohibited in urban areas in China. The data were collected via a questionnaire survey administered at ten locations in Nanjing, China. Using mixed multinomial logit (MMNL) models, we examined the relationship between the e-bike users' mode choice and their environmental awareness, combined with socioeconomic and demographic characteristics and trip attributes. The results show that the level of environmental awareness, gender, age, education, income, the ownership of car and conventional bike, and trip distance affect e-bike users' choices significantly. Those with a high level of environmental awareness are more likely to choose zero-emission transport modes. A stratified analysis reveals that the effect of environmental awareness is association with their original transport mode choice prior to their use of the e-bike. With a high level of environmental awareness, original car users tend to opt for moderate- or zero-emission modes; original bus and metro users incline to choose a zero-emission mode or their original mode; and few original cyclists and walkers favour moderate- or high-emission modes. The results of the current study provide transport authorities with insights to establish sustainable urban transportation management policies and strategies to increase the share of zero- and low-emission transport modes.

KEYWORDS: electric bicycle, mode choice, zero-emission, transport mode, environmental awareness

1. INTRODUCTION

Electric bicycles (e-bikes) are important components of the urban transportation system in China. E-bikes are bicycles equipped with batteries and electric motors, and they provide convenient, flexible, and affordable mobility to their users. E-bikes are also an environmentally friendly transport mode. From the perspective of life cycle assessment, in China, e-bikes consume 90% less energy and generate 86%-95% fewer pollutants than do private cars. The carbon dioxide emission rate of e-bikes is 60%-93% lower than that of private cars and comparable to that of public transit, and with respect to PM2.5 emissions, they outperform private cars and buses (Cherry et al., 2009; Ji et al., 2012).

Despite these advantages, e-bike use has raised safety concerns nationwide. Compared to conventional cyclists, e-bike users have a higher propensity to commit risk-taking behaviours (Bai et al., 2013, 2015; Guo et al., 2014; Hu et al., 2014; Ma et al., 2019; Pai and Jou, 2014; van der Horst et al., 2014). The illegal occupation of motor vehicle lanes, over-speed cycling, red-light running, and illegal manned and reverse cycling are the main risk-taking behaviours associated with e-bikes (Ma et al., 2019). The rate of traffic incidents involving e-bikes was twice that of conventional bikes at signalized intersections, particularly when the e-bike users were at fault (Bai et al., 2013). Considering these safety concerns, several Chinese cities have restricted the use of e-bikes in urban areas. Some cities, such as Beijing, Shenzhen, Xiamen and Zhuhai, have prohibited the use of e-bikes in central urban areas and on major arterial roads. The local authority of Guangzhou has banned the use of e-bikes throughout the city since 2016.

Prohibiting or restricting the use of e-bikes can have significant impacts on urban travel mode choices because it forces current e-bike users to switch to public transit, cars, conventional bikes or walking (Cherry and Cervero, 2007; Montgomery, 2010). The mode share of e-bikes is considerably high (reaching 34% in some cities); thus, it is essential to understand the mode choice behaviours of e-bike users when major Chinese cities are increasingly prohibiting the use of e-bikes.

Several researchers have studied the relationship between demographic and socioeconomic characteristics and the choice behaviours of e-bike users (He et al., 2019; Montgomery, 2010; Weinert et al., 2007). Cherry and Cervero (2007) developed a ~~binomial~~ binary logit model to investigate the factors that influenced the transition from the conventional bicycle to the e-bike. They found that travel time savings, e-bike ownership, endorsement of the e-bike, ~~attitudes about~~preference for reduced cycling effort, older ~~age~~ people and younger females had a positive influence on the e-bike use. Cherry et al. (2016) developed choice models to investigate the e-bike use pattern over time. Income and car ownership strongly influenced the probability of the transition from the e-bike to the car. Additionally, younger and female e-bike users had high propensity to switch to the car. Cheng et al. (2019) applied a random forest ~~method~~ approach to model travel mode choice behaviours. ~~The d~~Distances to the nearest metro and bus station, school and shopping trips, older ~~age~~people, holding driving license and e-bike ownership had a positive influence on the propensity of choosing ~~the~~ e-bike. In contrast, land use pattern, road network density, bus network density, the number of bus stops and car ownership had a negative influence. In addition, the use of ~~the~~ shared e-bike ~~was~~ could be affected by temperature and wind speed. Weekends, summer months, high population density, proximity to public transit centres, recreational centres, and bike trails also positively ~~affected~~ correlated to the increase in the demand for e-bikes (He et al., 2019).

Although several research studied influencing factors, little research focused on the effect of the environmental awareness of road users on their travel mode choice behaviours. Based on the choice of an alternative transport mode, its environmental impact on the sustainable urban transport system will vary accordingly (Cherry et al., 2009). Previous studies point out that environmental awareness and travellers' knowledge of carbon emissions have the potential to moderate travel choices (Cao and Yang, 2017; Jia et al., 2018; Liu et al., 2017). Low-carbon knowledge and travel habits are closely correlated with the use of low-emission transport modes. Therefore, the environmental awareness of e-bike users may influence their mode choice behaviours.

In this paper, we attempt to identify the influence of the environmental awareness of e-bike users, combined with socioeconomic and demographic characteristics and trip attributes, on mode choice behaviours if the use of e-bikes is prohibited or restricted. We conduct a stratified analysis to reveal the effect of environmental awareness in association with the original transport mode on mode choice behaviours. Figure 1 presents an outline of the study. The results can provide transport authorities and public transport operators with insights to modify transport planning policies and encourage a greater use of sustainable transportation in the long run.

2. SURVEY

This research is a case study of Nanjing, China. In the urban area of Nanjing, there is an extensive public transportation system composed of buses, the metro and taxis. High registration fees and reduced license quotas discourage the use of motorcycles. Additionally, Nanjing requires licensing for e-bikes. In 2013, e-bikes account for 26% of the mode share (the highest among all transport modes). The mode share of walking, conventional bike, public transit and private ~~vehicles~~ car is 19%, 15%, 17% and 23%, respectively (Cheng et al., 2019). Therefore, prohibiting e-bike use would have a significant impact on travel behaviour in Nanjing.

We conducted a questionnaire survey from early March to late April 2017. Commuters who commute by e-bike were the target population. The purpose of the survey was to investigate the alternative mode choice of e-bike users in the absence of their e-bikes. Walking, conventional bikes, buses, ~~the~~ metro, traditional taxis and private cars are the alternative transport modes. Note that e-bikes refer to both bicycles that are solely electric-powered and those that require pedalling, while conventional bikes refer to those that require pedalling only. ~~The p~~Private cars refer to ~~are~~ fossil-fuel~~led~~ vehicles only. We define an e-bike user as a rider who rides an e-bike, a conventional bike user as a cyclist and, a car user refers to ~~as~~ a car driver ~~of the car~~. We categorize the transport modes in accordance with their life cycle emission levels: zero emission (0 g carbon emissions per passenger kilometre, i.e., walking, cycling), moderate emission (less than 100 g carbon emissions per passenger kilometre, i.e., buses, the metro and e-bikes), and high emission (more than 100 g carbon emissions per passenger kilometre, i.e., cars and taxis) (Cherry et al, 2009).

The surveyors conducted the surveys at ten large parking lots dedicated to both conventional bikes and e-bikes during both peak (between 7:00 and 9:00 in the morning and between 5:00 and 7:00 in the afternoon) and non-peak (between 9:00 in the morning and 5:00 in the afternoon) periods on non-rainy weekdays. Such parking lots were considered well distributed both geographically and functionally, for example, in commercial, residential, industrial and school areas. The surveyors selected the respondents randomly. Before the face-to-face questionnaire surveys started, the surveyors explained the background and purpose of the survey to the respondents. They also explained the rights of respondents and the meaning of the key terminology in the survey for the respondents (shown in Table 1). Informed consent was obtained before the survey.

The questionnaire consists of four parts: (i) the demographics and socioeconomic characteristics of the respondents: gender, age, education, income, and car and conventional bike ownership; (ii) trip attributes: the distance from home to the workplace, the total distance from the home/workplace to a bus stop, and the total distance from the home/workplace to a metro exit, (iii) the preferences of transport modes: the mode used for the trip before e-bikes were ~~available~~introduced, and the alternative transport mode to be used for the same trip if e-bikes were ~~restricted~~not available; and (iv) environmental awareness. In this study, the knowledge of carbon emission and ~~the~~ preferred~~ence of~~ transport modes were used to measure the environmental awareness of the respondents. There are three questions in this part: Q~~q~~uestion O~~o~~ne ~~asks~~, “Do you know the approximate carbon emission rates of buses, ~~the~~ metro, taxis, cars, cycling and walking?” If the answer is “Yes”, then Q~~q~~uestion T~~t~~wo is~~, asked:~~ “Can you rank the emission rates in ascending order of (a) buses and ~~the~~ metro, (b) taxis and cars, and (c) cycling and walking?” If the answer is correct, then Q~~q~~uestion T~~t~~hree is~~, asked:~~ “Suppose that it is a sunny day, temperature is 20ºC and ~~the~~ air quality is good. ~~The b~~Bicycle lane and ~~the~~ bicycle are available. You also own a ~~The~~ private car and have a valid~~your~~ driving license ~~plate are also available~~. All the ~~trip~~ out-of-pocket costs such as the fares for ~~the~~ bus, ~~the~~ metro and ~~the~~ taxi, and the expenses for the petrol and parking, are affordable. Suppose that ~~the~~ travel time and degree of~~the~~ convenience are comparable among ~~is similar for~~ all ~~the~~ transport modes. Given these conditions, would you prefer a lower-carbon mode when you make a trip?” The purpose of ~~the q~~Question T~~t~~hree is to control for~~avoid of the~~ i~~nterference of~~ the factors including~~of the~~ weather, out-of-pocket~~the trip~~ cost, ~~the~~ travel time and degree of~~the~~ convenience on mode choice~~of the transport modes~~. If the answer is “Yes”, then the respondent is considered to have a high level of environmental awareness. Otherwise, the respondent is considered to have a low level of environmental awareness. If the answer to Q~~q~~uestion O~~o~~ne is “No” or the answer to Q~~q~~uestion T~~t~~wo is incorrect, then the respondent is considered to have ~~no~~ zero environmental awareness. Figure 2 presents the procedure for identifying the level of environmental awareness.

A total of 1,729 respondents completed the survey. Table 1 presents a summary of the sample. The majority of the respondents were young adults, i.e., younger than 39 years old. More than 80% of the respondents had a university degree or above. Over 70% of the respondents had a monthly income of CNY 5,000 or below. More than 70% of the respondents were aware of environmental issues to a certain degree, although more than half of them did not prefer to use a low-carbon transport mode for commuting. Table 2 presents the distribution of the respondents by ~~the~~ environmental awareness and ~~the~~ monthly income. ~~The r~~Respondents with a high level of environmental awareness accounted for 10%, 14%, 17% and 35% of the respondents in four different categories of monthly income, respectively.

3. MIXED MULTINOMIAL LOGIT MODEL

In this study, we develop mixed multinomial logit (MMNL) models to identify the factors and to assess their impacts on e-bike users' alternative mode choice preferences. Compared to traditional multinomial logit models, MMNL models accommodate unobserved heterogeneity across observations by adding a random effect to the parameters of the utility function. The specification of the MMNL model is as follows. The index n represents the individual e-bike user ($n = 1,2, \ldots, N$), the index i represents the alternative mode ($i = 1,2, \ldots, I$), and the index k represents the parking lot ($k = 1,2, \ldots, K$). The utility U_{kin} that individual e-bike user n will choose alternative mode i at parking lot k is as follows:

$$U_{kin} = \beta_k X_{kin} + \varepsilon_{kin} \quad (1)$$

where X_{kin} is a vector of candidate variables that affect the valuation of individual e-bike user n choosing alternative mode i at parking lot k. β_k is the corresponding vector of the coefficients of X_{kin}, which varies across the parking lots. ε_{kin} represents a location-specific random error term assumed to be independently and identically extreme value Type I distributed.

At a specific parking lot k, the probability P_{kin} that individual e-bike user n will choose alternative mode i is as follows:

$$P_{kin}\left|\beta_k\right. = \frac{\exp\left(\beta_k X_{kin}\right)}{\sum_{j=1}^{I}\exp(\beta_k X_{kjn})} \tag{2}$$

Let $q(\beta_k|\varphi)$ denote the probability density distribution of β_k and φ represent a vector of parameters describing the probability density distribution. Therefore, the unconditional probability is as follows:

$$P_{kin} = \int \frac{\exp\left(\beta_k X_{kin}\right)}{\sum_{j=1}^{I}\exp(\beta_k X_{kjn})} q\left(\beta_k\left|\varphi\right.\right) d\varphi \tag{3}$$

The likelihood function $L(\beta_k)$ for the alternative mode choice set of e-bike users at parking lot k is as follows:

$$L\left(\beta_k\right) = \prod_{n=1}^{N}\prod_{i=1}^{I}\left(P_{kin}\left|\beta_k\right.\right)^{y_{kin}} \tag{4}$$

where y_{kin} equals the value of 1 if individual e-bike user n chooses alternative mode i at parking lot k and 0 otherwise. The unconditional likelihood function $L(\varphi)$ for the alternative mode choice set of e-bike users is as follows:

$$L(\varphi) = \int L\left(\beta_k\right) q\left(\beta_k\left|\varphi\right.\right) d\varphi \tag{5}$$

The log-likelihood function is as follows:

$$LL\left(\varphi\right) = \sum_{k} \ln L(\varphi) \tag{6}$$

where $LL(\varphi)$ is the log-likelihood function. Simulation techniques can be used to estimate the MMNL model. We assumed that the parameter probability density function was a normal distribution. For the details of the estimation methods of the MMNL model, please refer to Bhat (2001, 2003) and McFadden and Train (2000).

4. RESULTS

We group the respondents' alternative mode choices according to their original transport modes before the availability of e-bikes. Discrete choice models are developed to measure the effects of possible factors on the respondents' alternative mode choice preferences. We conduct stratified analysis on the original transport mode of e-bike users to evaluate the variations in the effects of the independent variables (IVs) on the respondents' alternative mode choice preference. The following sub-sections present these results in detail.

4.1 Description of the alternative mode choices

Figure 3 illustrates the respondents' alternative mode choices if the use of e-bikes was not possible. If e-bikes were unavailable, the most likely choice would be conventional bikes, accounting for more than 30% of all respondents. More than 35% of the respondents would switch to public transit, with 23.1% choosing buses and 15.8% choosing the metro. Additionally, 17.8% and 9.7% of the respondents would switch to a car and walking, respectively. Taxis are the least preferred alternative mode, accounting for only 2.8%. Figure 4 illustrates the alternative modes grouped by the original transport modes of the respondents. The alternative mode choice preferences of the respondents vary with their original modes. There is a high likelihood that the respondents would revert to their original mode if e-bikes were unavailable (46.9% for walking, 59.1% for cycling, 44.9% for buses, 47.2% for the metro, 66.7% for taxis, and 39.2% for private cars).

4.2 Alternative mode choice model

The dependent variable of the alternative mode choice model has six levels, including walking, cycling, buses, the metro, taxis and private cars, where the base level is cycling. The possible factors considered are demographic and socioeconomic characteristics, travel habits and environmental awareness, which are presented in Table 1. We conduct stepwise variable selection to select the IVs that need to be included in the alternative mode choice model, and we consider the model with the highest log-likelihood at convergence to be the best. Table 3 presents the results of the alternative mode choice model. The model has fourteen explanatory variables, of which the parameters of two variables significantly varied across locations. This result indicates that unobserved heterogeneity is possible.

As shown in Table 3, the demographics of e-bike users affect their alternative mode choice preferences significantly at the 10% level. The coefficients of the variable "male" are significant and negative for all alternative modes, which indicate that as opposed to cycling, male e-bike users have a lower likelihood of choosing a bus, the metro, a taxi, a car and walking than do female users. The coefficient of the variable "age 25-39" is negative for walking, and the coefficients of the variable "age 40-59" are positive for walking, buses, the metro and cars. These findings suggest that young people have a lower likelihood of choosing walking and that middle-aged users have a higher likelihood of choosing walking, a bus, the metro and a car.

Additionally, the coefficients of the variable "university degree" are positive for buses and the metro. This result indicates that users holding a university degree have a higher likelihood of switching to public transit. The coefficient of the variable "income < 3,000 CNY/month" is positive for buses; the coefficients of the variable "income 5,000-8,000 CNY/month" are negative for buses but positive for taxis and private cars. These findings indicate that users with lower incomes have a higher likelihood of choosing a bus. In contrast, those with higher incomes have a lower likelihood of choosing a bus and a higher likelihood of choosing a taxi and a private car. These findings are consistent with those of a previous study (Cherry et al., 2016).

The level of environmental awareness significantly affects the choice behaviour of e-bike users. The coefficients of the variable "high level of environmental awareness" are positive for buses and the metro and negative for taxis and private cars. These results indicate that those with a higher level of environmental awareness have a higher likelihood of choosing public transit and a lower likelihood of choosing a taxi and a private car. However, the coefficients of the variable "low level of environmental awareness" are not significant for all the modes listed. Additionally, the coefficients of the variable "car ownership" are negative for walking, buses, the metro and taxis and positive for private cars. Furthermore, the coefficients of the variable "bicycle ownership" are negative for all alternative modes. These findings indicate that those who own a car have a higher likelihood of choosing a private car and a lower likelihood of choosing walking, a bus, the metro or a taxi. In addition, those having a conventional bike at home have a lower likelihood of choosing walking, a bus, the metro, a taxi and a private car.

Finally, trip attributes significantly affect the choice behaviour of e-bike users. For trips longer than 5 kilometres, the likelihood of choosing walking decreases dramatically, while that of choosing a taxi increases. E-bike users have a lower likelihood of choosing the metro for a trip between 5 and 10 kilometres and a higher likelihood of choosing a bus for a trip longer than 10 kilometres. E-bike users have a lower likelihood of choosing a bus if home or the workplace is slightly far from a bus stop. Similarly, they have a lower likelihood of choosing the metro if home or the workplace is slightly far from a metro exit. The likelihood of choosing a bus increases if home or the workplace is far from a metro exit. E-bike users have a higher likelihood of choosing a taxi if home or the workplace is far from a bus stop or metro exit.

4.3 Stratified analyses by original modes

During the survey, six transport modes are initially considered in the choice set. Since the sample size of original taxi users is not sufficient for a meaningful analysis, we exclude "taxi" from the stratified analysis. Hence, we conduct five stratified analyses. As shown in Figure 5, not all transport modes are considered in the choice set in every stratified analysis due to the small sample sizes. For example, the metro is not considered in the original walker group, and walking is excluded from the original bus user, metro user, and car user groups. Regarding the respondents' original transport modes, we use five MMNL models to evaluate the effects of the IVs on their alternative mode choice preferences under the condition that the use of e-bikes is prohibited. The base modes in the original walker, conventional bike user, bus user, metro user and car user models are walking, cycling, buses, the metro and cars, respectively. Table 4, 5, 6, 7 and 8 separately present the results of the models for the original mode choice groups, and significance is measured at the 10% level.

4.3.1 Original walker and cyclist models

Regarding original walkers (Table 4), male respondents have a higher likelihood of choosing a conventional bike as their alternative mode. Those aged between 25 and 39 years have a higher likelihood of choosing a conventional bike, bus and private car. Those with an income lower than 3,000 CNY/month have a lower likelihood of choosing a car. Those with a higher level of environmental awareness have a lower likelihood of choosing a bus and a car. Those with a car at home have a higher likelihood of choosing to drive and a lower likelihood of choosing to cycle. Additionally, the respondents are less likely to choose a bus and more likely to choose a conventional bike if home or the workplace is slightly far from a stop. Furthermore, they are more likely to choose a conventional bike and a bus if home or the workplace is slightly far from a metro exit.

Among original cyclists (Table 5), those aged between 40 and 59 years have a higher likelihood of choosing a car. Those with a higher level of environmental awareness have a lower likelihood of choosing a bus and a car as alternative modes, while those with a lower level of environmental awareness have a higher likelihood of choosing a car. Those who own a car at home have a lower likelihood of choosing a bus, and those who own a conventional bike have a lower likelihood of choosing to drive. The respondents have a higher likelihood of choosing a bus and a lower likelihood of choosing to drive if the trip distance is shorter than 5 kilometres.

4.3.2 Original bus and metro user models

Regarding original bus users (Table 6), those aged between 40 and 59 have a higher likelihood of choosing the metro and a car, while a lower likelihood of choosing a conventional bike. Those with a university degree and high school diploma have a higher likelihood of choosing a conventional bike. Those with a moderate income (between 3,000 and 5,000 CNY/month) have a higher likelihood of choosing the metro and a conventional bike and a lower likelihood of choosing a car. Those with a higher level of environmental awareness have a higher likelihood of choosing the metro and a conventional bike. As expected, those who own a conventional bike have a higher likelihood of reverting to cycling, while those who own a car have a higher likelihood of reverting to driving. The respondents tend to choose a conventional bike instead of the metro for trips between 5 and 10 km. Additionally, they have a higher likelihood of choosing to cycle if home or the workplace is far from a bus stop or metro exit.

For original metro users (Table 7), male respondents have a higher likelihood of choosing a conventional bike than do female respondents. Those who have lower education levels have a higher likelihood of choosing a conventional bike. The respondents with a high level of environmental awareness also have a higher likelihood of choosing to cycle. Those who own a conventional bike are more likely to choose to cycle. However, those with moderate-to-high incomes (between 3,000 and 8,000 CNY/month) have a lower likelihood of choosing a conventional bike. The respondents have a higher likelihood of choosing to cycle if home or the workplace is far from a metro exit.

4.3.3 Original car user model

Among the original car users (Table 8), male respondents have a lower likelihood of choosing a bus as the alternative mode. Those aged less than 25 years have a lower likelihood of choosing a conventional bike while those aged between 25 and 39 have a higher likelihood of choosing a bus. Those with higher incomes (between 5,000 and 8,000 CNY/month) are more likely to choose a car than to choose any other mods listed. Those who own a car have a lower likelihood of choosing a conventional bike or a bus. Those with a high level of environmental awareness have a higher likelihood of choosing a conventional bike and the metro. Those who own a car have a lower likelihood of choosing a conventional bike and a bus. Finally, the respondents have a lower likelihood of choosing a bus if home or the workplace is slightly far from a bus stop.

5. DISCUSSION

E-bikes are an increasingly popular transport mode in many cities in China because they require less physical effort and travel faster than a conventional bike, especially in an urban area. However, because of safety concerns, there is an increasing trend of restricting or even prohibiting the use of e-bikes, which, in turn, could result in significant changes in the travel pattern. This study attempts to understand current e-bike users' choice preferences if e-bikes were no longer available. It also aims to identify the possible factors affecting decision making, including environmental awareness, demographic and socioeconomic characteristics and trip attributes. We conduct stratified analyses on the original transport modes of e-bike users. Table 9 demonstrates the key factors that affect current e-bike users' alternative mode choice preferences.

5.1 Environmental awareness

The level of e-bike users' environmental awareness plays an important role in their choice of alternative transport mode. Those with a high level of environmental awareness have a higher likelihood of choosing a zero-emission mode (cycling) and a lower likelihood of choosing a high-emission mode (cars). In particular, original car users (high-emission mode) who have a high level of environmental awareness have a higher propensity to opt for moderate- (the metro) or zero-emission modes (cycling). Original moderate-emission mode (buses and the metro) users who have a high level of environmental awareness prefer to choose a zero-emission mode or revert to the original moderate-emission mode. Lastly, original zero-emission mode users who have a high level of environmental awareness are less likely to choose moderate- and high-emission modes.

The findings suggest that a high level of environmental awareness exerts a positive effect on the use of more environmentally friendly transport modes. Such findings are ~~in accordance with~~consistent to those of previous studies (Gardner and Abraham, 2010; Kumagai and Managi, 2019; Lind et al. 2015; Liu et al., 2017; Mei et al., 2017; Xu et al., 2020; Zhou et al., 2020). Environmental awareness can also influence the individuals' low-carbon behaviours ~~not only in developed countries but~~ in developing countries (not just in developed countries). The studies conducted in three Chinese cities, Beijing, Shanghai and Tianjin ~~have similar~~echoed the current findings that environmental awareness can influence the citizens' willingness to choose low-carbon travel modes ~~to~~ at a moderate degree (Kumagai and Managi, 2019; Liu et al., 2017). A Malaysian study ~~from Malaysia~~ also ~~confirms~~ reinforced that environmental awareness plays a ~~great~~ major role in shaping low carbon choice behaviour among suburban residents (Mei et al., 2017).

The findings provide insights into environmental policies, traffic management measures and development strategies for ~~traffic managers~~transport planners and engineers. Educational programs, for example, the promotion~~s~~als and publicity~~organized~~ activities on low carbon travel may be necessary to enhance environmental awareness ~~levels~~of general public. As the current study reveals, although more than 70% of the respondents have some level of knowledge with regard to transport emissions, the majority do not consider the negative impact of transport emissions when deciding on the alternative transport mode to e-bikes. ~~Though the~~For the effect of environmental awareness, ~~the environmental policies~~policy interventions including carbon tax and tradable credit can influence the citizens' ~~low-carbon~~choice behaviours. In Nanjing, ~~a preferential policy~~financial incentives are provided for ~~on the transfer among~~ public transits ~~is implemented to encourage citizens to use public transits~~. For example, public transit users ~~Citizens~~ can enjoy~~have~~ a discount of up to 1.6 CNY (equivalent to 0.25 USD) for the~~a~~ transfer among public transits. Additionally, the bus priority is implemented to improve the bus level of service in Nanjing. Bus-~~specific~~only lanes are set ~~up~~ out on ~~many~~ major ~~roads~~corridors. Also, part-time ~~The~~ bus-only lanes are set out ~~for bus only~~ during the peak hours (i.e. 7:00 am - 9:00 am and ~~17~~5:00 pm - 7~~19~~:00 pm) every day. Furthermore, ~~the government improves the~~ subsidizing policy for new energy vehicles can be introduced. Subsidy~~ies~~ ~~worth of~~ up to 30,000 CNY (i.e. 4,300 USD) ~~are~~ is available for purchasing a new energy vehicle. ~~Combining~~ Integrated with~~a~~ increased ~~high~~ level of environmental awareness, ~~with~~ effective green ~~environmental~~ transport policies can increase the share ~~influence the citizens' preferences~~ of lower-carbon modes.

5.2 Demographic and socioeconomic characteristics and trip attributes

The results indicate that age plays an important role in the preferred choice of alternative transport modes. Middle-aged e-bike users tend to have a higher likelihood of choosing moderate- or high-emission transport modes (i.e., buses and cars) and a lower likelihood of choosing a zero-emission mode (cycling). These results could be attributed to the degraded physical capability and increased wealth of middle-aged e-bike users compared to their younger counterparts (Johnson and Rose, 2013; MacArthur et al., 2014).

Monthly income significantly affects the alternative mode choice. Those with lower incomes are more likely to choose public transit, walking and cycling, while those with higher incomes are less likely to choose public transit and cycling. As expected, car ownership and conventional bike ownership have significant impacts on the alternative mode choice. Those who own a car or a conventional bike are more likely to choose to drive or to cycle as an alternative.

Trip attributes also affect the alternative transport mode choice. With the increase in trip distance from home to the workplace, the likelihood of choosing a car, a bus and the metro increases. This finding is consistent with a previous study (Hu et al., 2018). Part of the reason may be that increases in travel distances exceed the comfortable range of walking and cycling (Cherry et al., 2016). As expected, e-bike users are less likely to choose a bus or the metro if home or the workplace is slightly far from a bus stop or metro exit. Users whose home or workplace is slightly far from a bus stop or metro exit are more likely to choose to cycle.

5.3 Implications for the mode shift in urban transport

The findings of this study provide insights into the potential mode shift within the current transport system in the absence of e-bikes. The consequences of such a shift could impact the development of transport management measures that aim to enhance the operational efficiency and sustainability of urban transport systems. In Nanjing, e-bikes constitute 26% of commuting trips (Cheng et al., 2019). Among non-e-bike users, the shares of zero-emission (walking and cycling), moderate-emission (buses and the metro) and high-emission (cars and taxis) modes are 46%, 23% and 31%, respectively.

If the use of e-bikes is restricted or even prohibited, e-bike users will switch to an alternative mode. In accordance with the current survey, 40.5% of current e-bike users would switch to zero-emission modes (walking and cycling), 38.9% would switch to moderate-emission modes (buses and the metro), and 20.6% would switch to high-emission modes (taxis and cars).

Such shifts would change the overall share of zero-, moderate- and high-emission transport modes.

Among current e-bike users, 46.2% were originally bus and metro users. If the use of e-bikes is discouraged, 38.9% of them will revert to buses or the metro. On the other hand, 20.6% of current e-bike users would switch to high-emission modes (cars and taxis), which is slightly lower than the proportions of those who were originally car/taxi users (23.1%). This difference would offset the reduction in the number of high-emission mode users generated by the introduction of e-bikes. However, 58% of original car/taxi users would not switch back, which could be due to their high level of environmental awareness. Therefore, it is worth exploring ways to improve the general population's environmental awareness and to encourage car-sharing applications (e.g., Uber and Didi) as well as the uptake of zero-emission transport modes.

Although only 30.8% of current e-bike users were originally zero-emission mode (walking and cycling) users, 40.5% would switch to walking and cycling if the use of e-bikes was restricted or prohibited. Such switching would lead to a 9.7% increase in e-bike users using zero-emission transport modes. According to Ji et al. (2017), such a remarkable shift could be the result of the introduction of public bike-sharing schemes in Nanjing in recent years.

Overall, this study suggests that there would be a potential shift in the mode share from high-emission transport modes to zero-emission modes if the use of e-bikes was discouraged, especially for e-bike users with a high level of environmental awareness. Approximately 54% of current e-bike users would switch to a conventional bike and buses. Some research indicates that e-bikes may act as an intermediate mode and move users from lower-emission to higher-emission transport modes (e.g., from conventional bikes to buses or from buses to cars) (Cherry et al., 2016). However, this study argues that the presence of public bike-sharing systems could push the shift in the opposite direction, i.e., from higher-emission to lower-emission transport modes.

Furthermore, the level-of-service of public transport, e.g., transit priority (de Ona et al., 2016; Ji et al., 2017), should be improved to mitigate the potentially excessive burden on the public transit system. It is important for transport planning and policy measures to recognize the potential consequences and to be ready for such shifts so that the development of a sustainable urban transport system will not be interrupted.

6. CONCLUSION

Given their increased mobility and accessibility, e-bikes are a popular transport mode, especially in Asia. However, several jurisdictions have restricted (or plan to restrict) the use of e-bikes because of safety concerns. In this study, we examine the choice behaviour of the alternative transport mode of current e-bike users if e-bikes were unavailable. In particular, we categorize the transport modes considered into zero-emission (walking and cycling), moderate-emission (the metro and buses) and high-emission (cars and taxis) modes. The possible factors considered are demographic and socioeconomic characteristics, trip attributes and environmental awareness. Regarding the original transport mode, we establish both the overall choice model and disaggregated choice models using the MMNL regression approach. The results indicate that factors including gender, age, education, monthly income, the level of environmental awareness, conventional bike and car ownership, the trip distance from home to the workplace and the distance to a bus stop and metro exit could influence e-bike users' alternative mode choice preferences. In particular, those with a high level of environmental awareness are more likely to switch to zero-emission or moderate-emission modes. This result could imply potential changes in the mode share, given the implementation of new transport policy and regulatory initiatives. Additionally, the results should inform education and promotion strategies that can enhance citizens' environmental awareness and, therefore, the development of a sustainable urban transport system. Additionally, transport management and policy measures that can improve the efficiency of bike-sharing and public transit systems will be essential.

However, due to the lack of comprehensive information, we did not include certain trip attributes, such as travel time and monetary cost in the current study. Some emerging transport modes and services, for example, ~~the~~ shared bikes, ~~the~~ electric vehicles and e-hailing service, are also not included, because they ~~were~~ had not been widely available during the survey period ~~of the survey~~. Additionally, due to the limited research time, we did not measure the safety perception of e-bike users. Future research can focus on the effects of the perception of level-of-service (i.e., travel time reliability, generalized travel cost) and safety performance on the choice behaviours of commuters when comprehensive information is available. Additionally, it would be worth exploring the impacts of emerging technologies, for example, bike-sharing, electric vehicles, navigation and ride-sharing applications, on choice behaviours when information on emissions and environmental impacts are available to travellers.

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