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To bike or not to bike: Exploring cycling for commuting and non-commuting in Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

In recent years, Bangladesh has started moving its transportation vision towards achieving sustainability goals such as increasing bicycle infrastructure, sidewalks, reducing air pollution, etc. To contribute to the ongoing discussion, we explored factors that influence the use of bicycles for different trip purposes in Rajshahi, a medium-sized city in Bangladesh. A face-to-face household survey was conducted to collect individuals' socio-demographic characteristics, their travel patterns for different trip purposes, and perceptions of the built environment. We developed four Integrated Choice and Latent Variable (ICLV) models to understand the influence of latent perceptions on bicycling for commuting and non-commuting (i.e., grocery shopping, going for tea, and recreational) trips. The analysis indicates that women are more likely to choose a bike for commuting trips but are less likely to use bikes for recreational trips. The results also show that the choice of commuting by bicycle is positively associated with commuting distance and negatively associated with residential land use. Walkability perception has a significant positive association with the choice of bikes for commuting and non-commuting trips. Road safety perception for active travel is positively associated with bike choice for recreational trips, and crime perception of the neighborhood is negatively associated with bike choice for grocery trips. The results from this study will be helpful for policymakers to understand and improve the built environment to attract individuals towards bike use.

Background

Like many others in the developing world, urban practitioners and researchers in Bangladesh are increasingly emphasizing bicycling as a regular commute mode among city dwellers (Chiran, 2019; Tasnim, 2020a; Zaman, 2019). Although the use of non-motorized modes in the developing world is prevalent, a rise in the use of motorized vehicles in those countries has been recently noticed (Cervero, 2014; Li, 2011). This increase has resulted in negative externalities such as severe traffic congestion, higher collision rates, air pollution, and deteriorated population health and well-being worldwide (Faiz, 1993; Nantulya and Reich, 2002; Wang et al., 2019).

Being one of the world's most densely populated countries, Bangladesh has started developing a vision for implementing sustainability in its transport sector. An Integrated Multimodal Transport Policy has been developed that recommended several policies in favor of public transport and active transportation (Government of Bangladesh, 2013). The policy also suggested several improvements for promoting active transportation such as a 'Pedestrian First' program by giving priority to pedestrians at traffic signals, widening footpaths, creating short walking distances to services in non-urban areas, and constructing separate bicycle lanes in urban areas. The motivation behind these proposed initiatives in Bangladesh includes high crash and mortality rates, the high level of motorized traffic congestion and related air pollution, and deteriorating public health conditions (Chowdhury and Imran, 2010; Islam and Dinar, 2021; Jamal and Mohiuddin, 2020; Labib et al., 2014).

Although there are ongoing conversations on improving cycling infrastructure, there is a knowledge gap at the decision-making level that overlooks the intersections between cycling and the different social, cultural, and environmental factors that influence bicycling's viability as an alternative and sustainable mode of transportation. There is a lack of understanding of the various benefits (e.g., health, emission

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reduction, road investment economy, etc.) of active modes and the effectiveness of sustainable transportation planning interventions among the public and at the policy-making level, especially regarding interventions for promoting active transport in the developing world (Bhuiya et al., 2020; Rahul and Verma, 2013; Zhao and Li, 2016). This gap in knowledge has resulted in the bicycling promotion being absent in the planning practices in the developing world, unlike bicycling promotion found in other parts of the world (Te Brömmelstroet and Bertolini, 2010). Coupled with these gaps in the knowledge generation process, modernization in the form of increased motorization has led to the marginalization of the bicycle as a mode, as Koglin and Rye (2014) found in some developed countries. This marginalization has influenced societal beliefs regarding bicycling. One study from Ghana found that an individual's intentions towards bicycling to work are negatively influenced by the societal beliefs about the status of cycling compared to other modes (Acheampong, 2017). Also, the influence of urban elites, the main users of automobiles, on transport policies and planning regarding active transport are recognized as the barriers in developing countries as the politicians and other urban elites consider active transportation as a symbol of backwardness (i.e., unsmart mode, cheaper mode, etc.) (Dimitriou and Gakenheimer, 2011). Existing cultural and gender inequalities present additional barriers to bicycling - as a result, a very few bicyclists are females (Islam et al., 2020; Jamal et al., 2020; Nawaz and Taharat, 2015; Sarker et al., 2020). A study by Japan International Cooperation Agency and Dhaka Transport Coordination Authority (2016)showed that among bicyclists in Dhaka, the capital city of Bangladesh, a larger proportion belong to low-income groups and only a negligible portion belong to high-income groups.

In the context of the developed world, numerous studies have explored the factors affecting bicycling behavior through ample empirical evidence and reviews of the literature. For example, age, gender, income, and studentship status were found to have significant impacts on individuals' cycling behavior (e.g., Emond et al. 2009; Xing et al., 2010; Handy and Xing 2011; Whalen et al. 2013, Manaugh et al. 2017; Useche et al. 2018; Martín and Páez, 2019). Regarding gender, women are less likely to bicycle compared to men (Goel et al., 2022). In addition, built environment-related attributes have been found to be an important factor in determining bicycling behavior. For example, density, land use, infrastructure, accessibility, distance, street network, street connectivity, pollution exposure, crime rate, and traffic collision propensity influences individuals' decision to bike, own a bicycle, and their frequency of bicycling (e.g., Dill and Carr, 2003; Herala 2003; Moudon et al., 2005; Beenackers et al., 2012; Næss, 2012; Gao et al. 2018; Mertens et al., 2017; Yang et al., 2019; Mitra and Nash 2019; Banerjee et al. 2021). Commuting distance, which varies by geography, is also an important factor in determining the choice of bicycling (Banerjee et al., 2021). Individuals' use of public transit can also influence bicycling for the first mile of transit (from trip origin to the transit stop) and the last-mile portion of the transit trip (transit stop to the trip destination) (Mohiuddin, 2021). Weather is an important factor in determining cycling behavior (e.g., Nankervis 1999; Buehler and Pucher, 2012; Amiri and Sadeghpour, 2015; Zhao et al. 2018). Studies have also explored the impact of perceptions, attitudes, and life course events on cycling behavior and suggested that cycling autonomy, the flexibility of travel, travel habits, childhood experiences, perceived environmental condition of the neighborhood, perceived safety from traffic and crime, living arrangements, and the birth of a child are highly likely to influence the bicycling behavior of individuals (e.g., Timperio et al., 2004; Akar and Clifton, 2009; Van Acker et al., 2010; Lawson et al., 2013, Passafaro et al., 2014; Janke and Handy, 2019; Thigpen 2019; Useche et al., 2019; Haustein et al., 2020).

Although studies have explored the influence of socio-demographic and travel behavior on the choice of bicycling, they have been limited in examining the influence of latent perception of the built environment on bicycling, and evidence has especially been scarce in the contexts of developing countries. Studies have found consistency between perceptions of the environment and features of the built environment (Páez, 2013), and sometimes perceptions of the environment are better predictors of travel behavior than the original physical built environment feature (Arellana et al., 2019; Ma and Cao, 2017; Rossetti et al., 2019). For Toronto and Vancouver, Canada, Winters et al. (2012) found there are only marginal differences between perceived and observed safety for bicyclists, and perceptions are more likely to influence cycling decisions and behaviors. According to the 'Theory of Planned Behavior', an individual's attitude and perception influence their behavior (Ajzen, 1985; Ajzen and Fishbein, 1977). This theory has been applied in transportation research, especially in the last two decades with a general understanding that attitudes and perceptions play an important role in shaping individuals' travel behavior and mode choice. For instance, a study in Delft, Netherlands found that attitudes regarding awareness such as convenience, cost, health benefits, and perception of safety significantly influence individuals' decision to commute by bicycle (Heinen et al., 2011). Wang et al. (2018) also found a positive relationship between attitudes and perceptions and intention to adopt bicycle sharing (Wang et al., 2018). In their review study, Willis et al. (2015) concluded that perceptions, attitudes, habits, and social environment are highly likely to influence cycling behavior. However, only a few studies have investigated the impact of latent variables on biking in developing countries (Acharjee and Sarkar, 2021). Latent perceptions and attitudes are crucial for making choices as these factors highly influence preferences for choices and behavioral intentions of choices (Kroesen et al., 2017; McFadden, 1986).

This study examines the perceptions of environmental factors and incorporates socio-demographic characteristics collected through a household survey to explore the impact of latent perceptions on the decision to bicycle in Bangladesh. We are not aware of any other study that analyzes latent perceptions of safety and walkability on biking decisions in Bangladesh. As GIS-based built environment feature data are generally not available for developing countries, such as Bangladesh, we collected survey data on the perceptions of the built environment to better understand motivations for bicycling. This study focuses on the research question, "What are the different factors that influence individuals' decision to use a bicycle for commute and non-commute trips?". We look at commute and non-commute trips separately as individuals' mode choice behaviors differ by trip purposes (Firth et al., 2021; Porter et al., 2020; Stinson et al., 2014; Xing et al., 2010). We use Rajshahi, Bangladesh as our case study and investigate the influence of age, gender, income, household size, studentship status, and travel characteristics such as daily walking and biking duration, trip distance, and bike and motor vehicle ownership on bicycle use. To accurately include these factors into the modeling process, we utilized the Integrated Choice and Latent Variable (ICLV) model to understand how socio-demographic, travel habits, and perceptions of the built environment influence biking decisions in Rajshahi. Our results show a significant influence of both different socio-demographics and the latent perception of the built environment on the choice of bicycling for both commuting and non-commuting trips. We also find that the perception of the built environment varies for different socio-demographic groups. These findings can assist in further developing policies for promoting active transportation in similar cities.

Data and method

Study area

Rajshahi is the fourth-largest municipality in Bangladesh. The City has a population of 0.45 million and a density of 9,359 persons per square kilometer (Bangladesh Bureau of Statistics, 2015). The City is different from the rest of the country in terms of the promotion of bicycling as a suitable travel mode which is evident by the City's recent initiatives of building cycling lanes (the first bicycling lane constructed in the country), wider sidewalks, and integrated transport and land use planning with a focus on the environment and users' safety (United Nations Economic and Social Commission for Asia and the Pacific, 2016). Although national and city-wide household travel surveys are unavailable in Bangladesh, recent studies showed that 57% of households in Rajshahi own a bicycle, and like in many other countries, it is most popular among the younger generations (Haque, 2014; Mitra, 2016). The bicycle has a 17.2% share of vehicular traffic in the City, which is higher compared to the rest of the country (Haque, 2014). For example, in the capital city, Dhaka, only 1% of the daily trips are made by bicycles (Hossain and Susilo, 2011a). There may be two underlying reasons for the prevalence of bicycling in Rajshahi. First, Rajshahi is known as the 'Education City' of Bangladesh where six of the country's largest academic institutions are located, and many students travel by bicycle every day for their daily activities (Jamal and Mohiuddin, 2020). In Rajshahi, 22% of all trips made by different modes are related to education (Haque, 2014). Second, in recent years, bicycling has become popular among the young generation in Bangladesh, who are mostly students (Pritom, 2017; Khadija, 2015; Zaman, 2019). To understand the recent popularity of bicycling and encourage its growth, it is necessary to explore the different factors (i.e., socio-demographic, latent perception, and travel behavior) that influence the choice of bicycling as a mode for travel in the context of Rajshahi.

Data collection

We conducted a face-to-face household questionnaire survey between July to August 2017 in Rajshahi to collect data on respondents' socio-demographic profiles such as age, gender, occupation, income, and the number of household members. Respondents were also asked about travel patterns for different purposes, including daily routine activities, mode, travel time, and distance, along with the number of bicycles and motorized vehicles owned by their households. Following that, we asked the respondents about their surroundings on their walking and cycling trips to capture residents' perception of the active transport conditions. A 5-point Likert-type scale (very poor—poor—moderate—good—very good) was used to measure their perceptions of the built environment, where 1 represents a very poor condition and 5 represents a very good condition. Other survey questions include perceptions regarding safety from crime, and the amount of local traffic while walking and cycling on the local and main roads. Total 12 perception based questions were asked in the questionnaire. The survey collected 402 complete responses. More details on the survey can be found in Jamal and Mohiuddin (2020). Table 1 and Table 2 provide the summary statistics of the variables used in this paper.

Dependent variables

We developed separate behavioral models for commute and non-commute trips. We considered three types of non-commute trips – grocery shopping, going for tea, and recreational trips. Our dependent variables were binary– whether respondents are biking for a particular trip purpose (=1) or not (=0). As our objective was to explore biking decisions for commute and non-commute trips and to what extent the latent variables influence them, we chose to analyze our dependent variables as dummy variables in our models. The following section describes the behavioral modeling methodology we used to explore the study objective.

Modeling approach

To effectively incorporate attitudes and perceptions into our model of bike mode choice, an understanding of the relationship of the attitude and perception-related statements to the latent variables (towards the built environment) was necessary. An exploratory factor analysis was applied to understand the association of the statements with different latent perception variables. The results of the exploratory factor analysis

Table 1
Summary Statistics of the Data Used for Modeling (Sample size = 402).

Variable		Summary
Age		29.26 (mean)
Land use of the individual's residence	Residential	65.67%
	Non-residential	34.33%
Gender	Women	15.42%
	Men	84.58%
Income (Monthly Mean)		35,162 Taka (approx. 410 USD)
Student		41.5%
Household Size		4.7 persons (mean)
Bicycle ownership	0	24.63%
	1	55.97%
	2	18.91%
	3	0.5%
Motor vehicle ownership	0	59.7%
	1	35.57%
	2	3.48%
	3	0.25%
	4	0.25%
	6	0.75%
Daily Walk time		64.68 min (mean)
Daily Cycle time		31.1 min (mean)
Commute distance		1.25 km (mean)
Commute Mode	Bicycle	36.8%
Non-commute mode (recreation)	Bicycle	11.6%
Non-commute mode (going for tea)	Bicycle	6.2%
Non-commute mode (grocery)	Bicycle	17.4%

Table 2
Responses to Selected Twelve Perception Statements.

Statements	Very Poor (%)	Poor (%)	Moderate (%)	Good (%)	Very Good (%)
Rate the walkability environment of the road in your neighborhood from your home					
Going to work/business/school	1.00	2.49	18.41	53.73	24.38
Going to grocery store	2.49	1.74	28.36	43.53	23.88
Going to social places (e.g., tea stalls, restaurants)	0.00	2.99	22.89	51.24	22.89
Going to recreational/entertainment places (e.g., parks, natural places, movies)	0.25	15.17	43.03	28.86	12.69
This neighborhood is a good place for riding a bicycle	3.73	6.97	19.40	26.37	43.53
This neighborhood is a good place for walking	11.44	29.10	34.58	19.65	5.22
It is safe from traffic to walk in the local streets	1.00	7.71	38.56	43.53	9.20
It is safe from traffic to walk in the main roads in this neighborhood	0.00	2.99	20.90	62.69	13.43
It is safe (from traffic) to ride a bicycle in the local roads	0.75	4.98	39.55	44.53	10.2
It is safe (from traffic) to ride a bicycle in the main roads	2.24	16.42	53.73	20.65	6.97
The crime rate in my neighborhood makes it unsafe to go on a walk/bike during day light	1.99	10.20	41.54	36.57	9.70
The crime rate in my neighborhood makes it unsafe to go on a walk/bike when it is dark outside	4.48	48.01	22.14	16.42	8.96

Table 3
Result of the Exploratory Factor Analysis with the Selected Twelve Statements.

Statements	Factor 1 Walkability perception	Factor 2 Road safety perception for active travel	Factor 3 Neighborhood crime perception
Rate the walking environment of your neighborhood road for			
Going to work business school	**0.452**	0.335	−0.064
Going to grocery store	**0.574**	0.226	–0.139
Going to social places (e.g., tea stalls, restaurants)	**0.581**	0.118	0.174
Going to recreational/ entertainment places (e.g., parks, natural places, movies)	**0.477**	0.153	–0.017
The crime rate in my neighborhood makes it unsafe to go on a walk/ bike during day light	−0.026	0.066	**0.781**
The crime rate in my neighborhood makes it unsafe to go on a walk/ bike when it is dark outside	0.116	0.022	**0.632**
This neighborhood is a good place for riding a bicycle	0.172	**0.742**	−0.229
This neighborhood is a good place for walking	0.168	**0.782**	0.146
It is safe from traffic to walk in the local streets	0.202	**0.543**	0.285
It is safe from traffic to walk in the main roads in this neighborhood	**0.643**	0.271	0.165
It is safe (from traffic) to ride a bicycle in the local roads	0.379	**0.420**	0.093
It is safe (from traffic) to ride a bicycle in the main roads	**0.859**	0.011	0.140

*The higher factor loadings are shown in bold for associated statements.

indicated three factors (using the criterion of an eigenvalue greater than 1) from the twelve statements, which were then used as the three latent variables (Table 3). Based on the three factors identified through the factor analysis, we developed final structural equations for different latent variables and associated measurement equations.

We initially developed a base model as a starting point for the development of a more sophisticated model. The base model estimated a binary logit model assuming that bike mode choice is dependent on socio-demographic variables such as age, gender, household income, and the frequency of bicycling and walking. We also incorporated land-use variables for the household location of the respondents to capture differences in the physical environment on bicycling. Built environment perception statement variables were not included in this model.

Many approaches have been employed to incorporate attitude and perception statements into the choice models. An approach like adding attitudinal statements directly or pre-estimated factor scores directly into the utility specification as explanatory variables can lead to measurement error and endogeneity biases (Ashok et al., 2018; Ben-Akiva et al., 2002; Daly et al., 2011). This framework can be improved through the Integrated Choice and Latent Variable (ICLV) model consisting of two components, a choice model (the use of a bike for commuting and non-commuting trips) and a latent variable model. This framework allows the joint estimation of the model resulting in an efficient estimate of the model parameters (Ben-Akiva et al., 2002; Daly et al., 2011).

In the ICLV model framework, the latent variables (from now on we will use the term "latent variables" to describe the perception variables from the statements) were considered structural variables in which observed socio-demographic variables influence latent variables. The structural latent variable model incorporates a secondary model that uses the latent variables as explanatory variables to predict the responses of the individual to different attitudinal statements from the survey (Daly et al., 2011). Individuals' perception of the built environment is reflected in their measurement equation but is also thought to be caused by socio-demographic variables that support the use of structural equations in the model. Therefore, the complete model consists of a group of structural equations for latent variables and a group of measurement model equations. The structural models describe latent variables in terms of observable variables (i.e., socio-demographic) and specify the utility function based on latent variables and observable variables. The measurement model links latent variables to the perception statements. The whole framework is shown in Fig. 1. This structure allows inferences on the influence of the latent variables on choice, the association of socio-demographics with latent variables, and the measurement of the latent variables by the selected statements. Thus, this is a much better framework for estimating choice models compared to the traditional approach of directly adding statements in the model or adding the statement results through factor scores.

Based on the above discussion, we build our theoretical framework of the study, as illustrated in Fig. 1, and the associated ICLV model equations are formed based on this framework.

Equation [1] represents the utility for bike mode choice which includes both observable explanatory variables and vector of latent variables predictors, three **equations [2.1 to 2.3]** represent the structural equation model for latent variables, and **equation [3]** represents the generalized measurement model of the selected twelve statement indicators (Vij and Walker, 2016).

The choice utility equation of the ICLV can be described in the following way. Considering all the bike mode choices as binary, for the ICLV model in our case, the utility specification becomes,

$$u_n = ASC + \beta_1 Age_n + \beta_2 Gender_n + \beta_3 Income_n + \beta_4 Landuse_n + \beta_5 Student_n + \beta_6 Distance_n + \beta_7 Number\ of\ Bikes_n + \beta_8 Household\ Members_n + \beta_9 Number\ of\ Motor\ vehicles_n + \beta_{10} Walktime_n + \beta_{11} Biketime_n + \Gamma_1 Walkability\ perception_n + \Gamma_2 Road\ Safety\ Perception_n + \Gamma_3 Neighborhood\ Crime\ perception_n + \epsilon_n \quad [1]$$

ϵ_n is a random error or disturbance term, which describes the unobservable effect. These disturbance terms are assumed to be statistically independent. Three latent variables, including walkability perception, road safety perception, and neighborhood crime perception are incorporated into the utility specification in **equation [1]**, where, Γ_1, Γ_2, and Γ_3 indicates the impact of the latent variables on the utility choosing bike.

The structural equation model assumes that the latent variables follow linear structural relationships with exogenous variables. The equations we used for structural equations for the latent variable model portion are expressed below from **equation [2.1 to 2.3]**.

These equations were developed based on the results of the factor

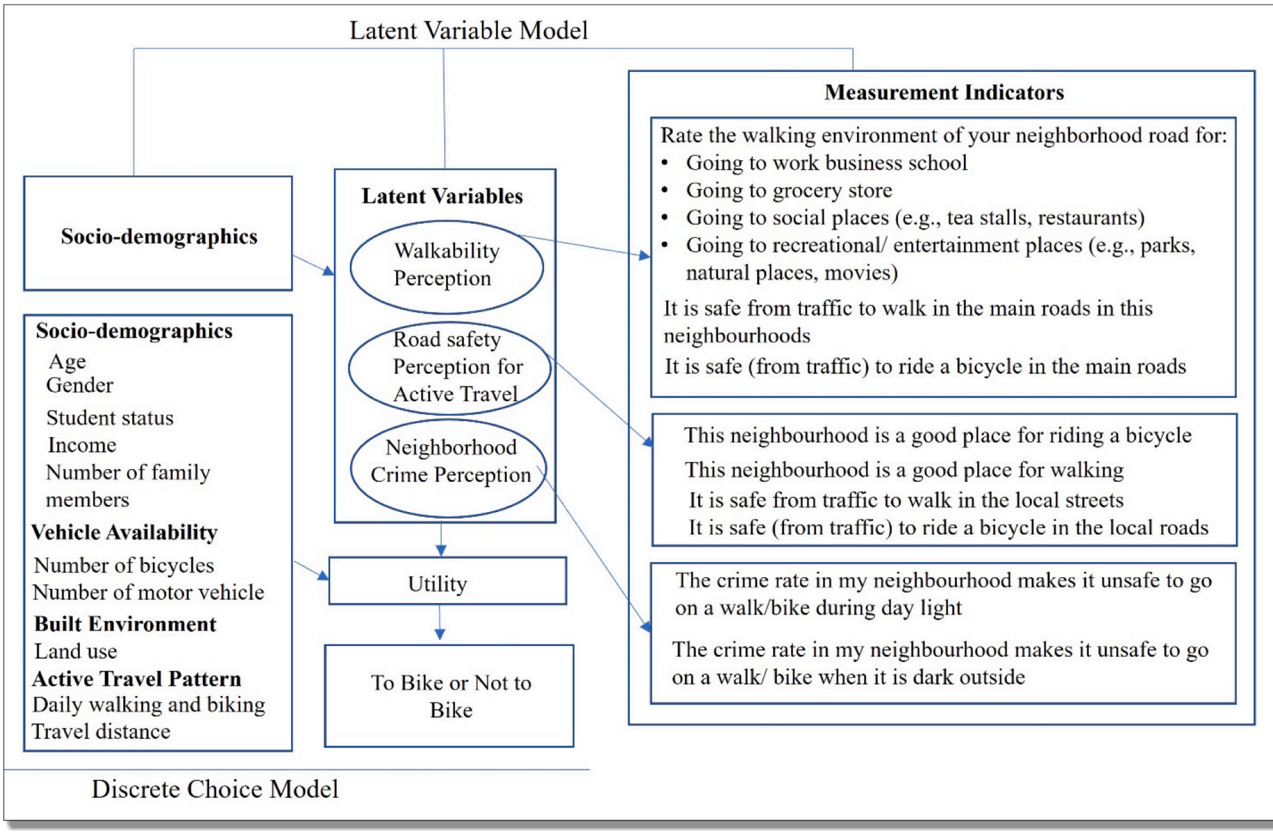

Fig. 1. Theoretical Framework of The Bike Mode Choice Model (adapted from Potoglou et al. (2015)).

analysis and regression. From factor analysis with the statements, we extracted three factors and the factor scores were then regressed on the socio-demographic variables to understand the relationship of the three extracted factors with the exogenous socio-demographics. We selected the significant socio-demographic variables at a 10% significance level associated with the three factor scores. We found gender was significant with the walkability perception factor, no variable was significant with the road safety for active travel factor, and gender and student were significant with the neighborhood crime perception factor. From the regression output, we can understand the relationship of latent variables with socio-demographics. We used those selected socio-demographic variables to develop the structural equation models (**equation 2.1 to 2.3**) of the latent variables in the ICLV model. The factor analysis result is shown in Table 3, and the regression result based on the factor score is not reported here as they are not the focus of the study.

Based on the above-mentioned method, we developed the following structural equation models.

$$Walkability\ \ perception_n = A_1 Gender_n + v_n \quad [2]$$

$$Road\ \ Safety\ \ Perception\ \ for\ \ Active\ \ Travel_n = v_n \quad [3]$$

$$Neighborhood\ \ Crime\ \ perception_n = A_1 Gender_n + A_2 Student_n + v_n \quad [4]$$

Here, the A parameters represent the impact of the socio-demographic variables on latent variables and the v_n is the stochastic component or the unobserved disturbance term of the equation (Vij and Walker, 2016). All the v_n are assumed to be statistically independent and normally distributed. As the logit probability is conditional to the unobserved disturbance term, the total probability should be determined by integrating over v_n. Therefore, here we are working with a mixed logit model in the binary logit framework as the choice of bicycling is binary.

Measurement equation models

The measurement equation describes how the twelve perception statements using a 5-point level Likert type scale reflect the three latent variables. Before entering those twelve statements in the model, they

Table 4
The output of the Base Model and Associated ICLV of Choice of Bike (n = 397**).

Dependent Variable: Choice of Biking for Commuting Trips	Commuting without Latent Variable		Commuting Trips with Latent Variable (ICLV)	
Log-Likelihood of Choice of Bike for Commuting Trip Model	−175.9782		−179.5322	
Explanatory Variables	Estimate	Robust t-ratio	Estimate	Robust t-ratio
Alternative Specific Constant	−0.3587	−0.3635	−0.5145	−0.5081
Age	0.0154	0.6594	0.0222	0.9031
Gender (Base = Men)	0.3095	0.9052	**0.6629**	**1.7337**
Income	−0.000006	−0.7229	−0.000008	−0.7953
Student Status dummy	0.0237	0.0496	0.1654	0.3275
Travel Distance	**0.1503**	**2.9675**	**0.0949**	**2.0086**
Household Members	**−0.4330**	**−3.4785**	**−0.4523**	**−3.5754**
Bike Ownership dummy	**0.7705**	**2.6856**	**0.7156**	**2.3575**
Land use (Base = Non-residential)	**−1.1824**	**−4.0497**	**−1.0019**	**−3.1982**
Daily Walking Time (in minutes)	0.0043	1.3471	**0.0057**	**1.7649**
Daily Biking Time (in minutes)	**0.0230**	**2.5125**	**0.0248**	**2.6075**
Motor Vehicle Ownership dummy	−0.1298	−0.8574	−0.2777	−1.4303
Walkability Perception	–	–	**0.7513**	**4.1027**
Structural Model for Walkability Perception based on equation (2.1)				
Gender (Base = Male)	–	–	**−0.4312**	**−3.9205**

*Bold variables are significant at a 10 percent significance level.
**Missing value reduces the sample size to 397.

Table 5
Result of the ICLV Model for Non-commuting Trips.

Dependent variable: Choice of Bikes for non-commuting trips	**Grocery Trips (n = 394)**		**Going for Tea Trips (n = 312)**		**Recreational Trips (n = 302)**	
Log-Likelihood Choice of Bike for Non-Commuting Trips Model	−134.0902		−72.50988		−101.7821	
Explanatory Variables	Estimate	Robust t- ratio	Estimate	Robust t-ratio	Estimate	Robust t-ratio
Alternative Specific Constant	−0.4889	−0.3795	1.0518	0.5283	−0.3730	−0.1503
Age	0.0130	0.4700	0.0211	0.5288	−0.0082	−0.1199
Gender (Base = Male)	−0.1762	−0.3387	2.1162	1.3024	**−1.9655**	**−2.0996**
Income	−0.00001	−0.9946	**−0.0001**	**−1.9301**	−0.00003	−1.4731
Student Status dummy	0.3728	0.6381	1.4925	0.9354	0.7079	0.5741
Travel Distance	**0.5136**	**5.3881**	0.2878	1.2016	**0.2502**	**3.4695**
Household Members	**−0.6688**	**−4.0378**	**−0.6525**	**−1.8826**	**−0.5197**	**−1.8728**
Bike Ownership dummy	**1.1102**	**3.3073**	0.7152	1.1489	**0.9799**	**1.6720**
Land use (Base = Non-residential)	**−1.2209**	**−3.2463**	**−2.2021**	**−1.9351**	**−1.2378**	**−1.9503**
Daily Walking Time (in minutes)	**−0.0063**	**−1.7975**	**−0.0164**	**−1.8447**	−0.0076	−1.1861
Daily Biking Time (in minutes)	**0.0127**	**2.9851**	**−0.0078**	**−1.6827**	−0.0007	−0.1820
Motor Vehicle Ownership dummy	0.0266	0.1354	0.3311	1.1111	−0.2249	−0.7247
Walkability Perception	**0.4759**	**2.3208**	**1.4094**	**2.6055**	**1.3755**	**3.3067**
Road Safety Perception for Active Travel					**0.7391**	**1.8212**
Neighborhood Crime Perception	**−0.5783**	**−2.4024**	**1.9237**	**3.2482**	0.8713	1.6281
Structural Equation Model for the Walkability Perception based on equation (2.1)						
Gender (Base = Male)	**−0.4609**	**−3.8856**	**−0.4664**	**−3.2873**	**−0.6405**	**−3.1757**
Structural Equation Model for the Road Safety Perception for Active Travel based on equation (2.2)						
No socio-demographics were significant with this latent variable						
Structural Equation Model for the Neighborhood Crime Perception based on equation (2.3)						
Gender (Base = Male)	**−0.3779**	**−2.2976**	**−0.4557**	**−1.6534**	**−0.5597**	**−2.5098**
Student Status	**−0.2023**	**−2.3256**	−0.0908	−0.7948	−0.1031	−0.9281

*Bold variables are significant at a 10 percent significance level.
**The Sample size is different as not all individuals make different types of non-commuting trips.

were standardized by subtracting the mean. The measurement model equation is provided in **equation [3]** , where D is a vector of parameters representing the sensitivities of the measurement indicators (the selected twelve statement variables) to the respective three latent variables (i.e., walkability perception, road safety perception for active travel, and neighborhood crime perception) in matrix form x_n^* (*5*). Here, i_k indicates the k^{th} perception statements and η_n is the stochastic component of the equation. All the η_n are assumed to be statistically independent and normally distributed.

$$i_{k,n} = Dx_n^* + \eta_n \quad [5]$$

Fig. 1 illustrates the statement used in the measurement equation models and how they are used to develop the structural equation models. Each statement produces one measurement equation. Table 5 shows both the D estimates (the sensitivity of the measurement statement to the associated latent variables, developed based on the factor loading of different statements to three factors in the exploratory factor analysis). Table 3 shows that all six statements are positively associated with the walkability perception of the built environment factor 1. Therefore, higher values of this latent variable indicate a higher positive perception towards the walkability of the built environment. Two neighborhood crime-related statements are positively associated with factor 3 which indicates another latent variable for crime perception of the neighborhood. The four safety-related statements are positively associated with factor 2 and indicate the latent variable for road safety perception.

Taken together the whole framework of utility equation, structural equations, and measurement equations form an Integrated Choice and Latent Variable model (Malik et al., 2021; Vij and Walker, 2016). For maximum likelihood estimation of the model parameters, computing the likelihood of observed dependent variables and indicators, the package *Apollo* in the R platform was used (Hess and Palma, 2019). The maximum likelihood requires integrating over multiple disturbance terms. This was performed through 100 inter individual standard normal draws (as we have cross sectional data i.e., one observation per individual) for η_n based on Halton draws (Halton, 1960; Hess and Palma, 2019). The use of Halton draws is appropriate here as we have less than five (i.e., three) random coefficients in the structural equation model (Bhat, 2003).

Limitations.

The main limitation is the budget and the difficulty of conducting a face-to-face household survey in the context of Bangladesh. Due to limited funding, the samples were limited to 402. The survey is biased towards male respondents: in the Bangladesh context, men are generally the household head who are likely to participate in the face-to-face household surveys. Additionally, we have a large percentage of students in our sample.

Result and discussion.

Base Model and ICLV Model

The results for the base model and ICLV model for bike mode choice for commuting trips are shown in Table 4. The base model shows that the choice of bike for commuting is significantly influenced by travel distance, the number of members in the household, bike ownership, daily biking duration, and land use of the individual's residence. Based on this outcome from the base model, we built the ICLV model. As the ICLV model consists of several models (described above), here we only report the log-likelihood of the portion of the choice model as this model is our focus of analysis.

Choice of bike for commuting trip

Effect of gender

The base model shows that gender does not significantly influence the use of a bike for commuting trips (Table 4). However, after controlling for the latent perception of the built environment through the ICLV model, the gender variable became significant. The ICLV model indicates that women are more likely to choose a bike for commuting trips compared to men. This is a very surprising finding given the limited mobility pattern of women in the developing country context. Studies show that women are less likely to use bicycles due to cultural norms and obstacles (Kuranami and Winston, 1994). The mobility pattern of women may be different in the context of Rajshahi, which is considered the "Education City" of Bangladesh and has a large student population. Also, there has been an increase in the use of bikes for school trips among younger individuals who are mostly students. This boost in bicycling is assisted by the formation of different bicyclist groups and campaigning on social media (Pritom, 2017; Khadija, 2015; Zaman, 2019). Research shows that safety perception, as well as social and environmental factors, influence the bicycling behavior of women (Emond et al., 2009). It may be possible that the use of bicycling by students may also influence bicycling among other Rajshahi residents. Overall, the gender effect of bike choice is one of the most significant findings in the context of Rajshai, Bangladesh and needs further investigation with the more detailed city and neighborhood-level data.

Effect of commuting distance

Interestingly, commuting distances are positively associated with the choice of bikes for commuting. There may be two reasons for this: the city of Rajshahi has a high density and has a mixed type of land use in combination with residential and commercial areas, thus most of the commuting distances are short, where either walking or biking is the most convenient option. The descriptive statistics from Table 1 also show that the mean commute distance is 1.25 km which supports the statement as well. Additionally, our survey data suggest that one-third of Rajshahi residents commute by biking. Furthermore, the low rate of motor vehicle ownership could be another reason for individuals to bike for their commutes (Mitra, 2016).

Effect of other predictors

The model shows that bike ownership is positively associated with the choice of bike for commuting, which is expected. On the other hand, individuals living in residential land use are less likely to choose a bike for commuting.

Effect of latent variables

The walkability perception of the built environment positively influences the choice of biking. This is expected and important in the context of Bangladesh. This indicates that policymakers can attract more individuals towards biking through careful design of the built environment. The latent perception of the built environment is an important predictor in describing choice as it reflects the cognitive response of the travelers as they move through the physical built environment (Arellana et al., 2019; Ma and Cao, 2017; Rossetti et al., 2019). These latent perceptions are important in determining individuals' decisions towards how they move through the built environment and consequently their choice of activities and modes. Latent perception towards the built environment is an especially important influencer for traveling decisions for women (Sethi and Velez-Duque, 2021; Wilson, 2021).

Effect of active travel habit

Daily walking and biking duration are positively associated with the choice of bike for commuting. This association is expected as individuals with a stronger habit of active traveling are more likely to choose a bike for commuting. A large portion of our survey sample walks or bikes regularly. The positive perception of walking in the built environment may have influenced this habit.

Interaction of socio-demographics with latent variables

Although our model shows that positive walkability perception positively influences the choice of bicycle, the structural equation model shows that women, as compared to men, are more likely to give a low rating to the walkability of the built environment. This is expected as the built environment was mostly designed with male individuals in mind and not necessarily the needs of female travelers. Thus, responses to the same physical built environment can be different for different socio-demographics, such as between women and men, which in turn may influence their choice of modes. These findings are in line with previous research showing how different features of the built environment influence women's perceptions (Hidayati et al., 2020; Sethi and Velez-Duque, 2021).

In the ICLV framework, this gender effect on the walkability perception can also be termed as the indirect effect of the gender variable on mode choice utility that works through the latent variable walkability perception on the choice of bike for commuting trips (Vij and Walker, 2016). Thus, the gender variable both directly and through the latent variable indirectly affects an individual's mode choice decision.

Choice of Bike for Non– commuting Trips

For non-commuting trips, we selected three trip purposes namely, grocery trips, recreational trips, and going for tea trips. The first two purposes are very important non-commuting trips (Jiao et al., 2011; Yeh et al., 2006). The third one is important in the context of Bangladesh where most people generally go out and socially gather at different times of the day for drinking tea. There are about a million tea stalls in Bangladesh (Farhat Ubaid and Krukkert, 2014). For selecting the three purposes from various other non-commuting purposes (e.g., social trips, visiting family, personal errands except grocery shopping) collected from the survey, we looked at the average frequency of those trips from our respondents and selected the top three most frequent trip purposes. We did not report the base models for non-commuting trips for simplicity as our focus is on the ICLV models to understand the influence of the latent variables. The result ICLV models for three non-commuting trip purposes are shown in Table 5. As the ICLV model consists of several models (described above), here we only report the log-likelihood of the portion of the choice model as this model is our focus of analysis.

Effect of gender

For grocery trips, the gender variable is not significant. This is expected as individuals tend not to take a bike to grocery trips as they need to carry shopping goods. In general, individuals in Bangladesh tend to use another active mode known as the "Rickshaw" for carrying shopping and grocery items (Hossain and Susilo, 2011b). Gender was not significant for going for tea purposes as women are still lacking behind in participating in a social gatherings and social actvities in public places compared to men in the context of Bangladesh. For recreational trips, we found a significant and large negative coefficient for the gender variable, which indicates women are much less likely to use bikes for recreational trips compared to men.

Effect of non-commuting trip distance

Except for going for tea trips, the other two non-commuting trip models show that with the increase of the non-commuting trip distance, the likelihood of choosing bike increases. This is expected because of the high number of tea stalls in Bangladesh (Farhat Ubaid and Krukkert, 2014). Tea stall locations are often near residential locations and most people tend to walk to those locations. Thus, the signs and significance of the distance predictor are expected for the non-commuting model.

Effect of latent variables

Walkability perception of the neighborhood road has a significant positive association with the choice of bikes for all non-commuting trip purposes. Road safety perception for the active travel latent variable is only significant for recreational trip purposes. Neighborhood crime perception is negatively associated with the choice of bikes for grocery trips, which is expected due to fear of theft or robbery. However, the choice of bike for going for tea is significantly positively associated with the crime perception of the neighborhood which needs further investigation with more data in the context of Rajshahi.

Effect of active travel habit

The daily walking time is negatively associated with the choice of bikes for non-commuting trips. Although this may seem counterintuitive, after controlling for the trip distance, we can understand individuals with daily walking duration habits are likely to walk for different non-commuting purposes. Daily biking time is positively associated with the choice of bike for grocery trips. However, daily biking time is negatively associated with going for tea by biking.

Interaction of socio-demographics with latent variables

One interesting finding is that women, as compared to men, have assigned lower value to the different built environments walkability conditions, and safety from crime perception of the neighborhood. This lower rating by women for the built environment is expected and described in the previous section and is in line with previous research findings (Sethi and Velez-Duque, 2021). It may also be the case that when women perceive higher vulnerability on the neighborhood roads, using a motorized vehicle is perceived to be safer compared to walking or biking. As described previously, the effect of the gender variable on the latent variable can also be termed the indirect effect of gender on mode choice.

Students also tended to provide a lower rating regarding safety from crime on the neighborhood roads compared to non-students. Several crime incidents happened involving students, and the number of reported crime incidents is higher in Rajshahi as compared to other city corporations of a similar size (Bangladesh Police, 2020). Although the direct effect of being a student in our model was not significant, the indirect effect of being a student through the latent variable on mode choice is significant.

Recommendation and conclusion

In our analysis of bicycle mode choice for both commuting and non-commuting trips in Rajshahi, Bangladesh, we found that women are more likely to commute by bike compared to men. We also found that gender, as an exogenous variable, both directly and indirectly (through the latent built environment perception variable) influences the choice of bicycling. This is an interesting finding in the context of Bangladesh as the cultural environment generally discourages females from bicycling. This is also different from the findings of most other studies, such as Twaddle et al. (2010), Mitra and Nash (2019), Grudgings et al. (2018), and Goel et al. (2022). However, this finding does align with Haustein et al., 2020, who found that women are more likely to bicycle than men in Copenhagen. In our case, Rajshahi as an education center and one of the most bicycle-friendly cities in Bangladesh may be uniquely positioned, and our results merit additional investigation with other cities in Bangladesh.

The modeling results show that commuting distance is positively associated with the choice of bikes for commuting. One study of several countries and cities shows that commuting distance tends to be negatively associated with the choice of bicycling; the distance band used in that study is inclusive of the commuting distance we found from Rajshahi (Banerjee et al., 2021). We found the median one-way commuting distance in Rajshahi to be 3 km, which can be considered comfortable for a bicycle commute and falls within the range of commuting distances found in current literature (Banerjee et al., 2021; Nelson et al., 2008). We also found regular bicycling habits are positively associated with bicycling for both commuting and non-commuting trips, which aligns with the findings of Willis et al. (2015). Additionally, we found individuals living in areas with residential land uses are less likely to choose bicycling for commuting. This may be due to the land use pattern of Rajshahi where a large portion of residential areas are located with or in proximity to employment locations (Kashem et al., 2009). This pattern of land use influencing travel behavior aligns with the findings of Næss (2012). Both of these findings on distance and land use have implication for other cities in Bangladesh, highlighting how land-use planning can influence bicycling behavior.

We also find that perceptions of the different features of the built environment are positively associated with the choice of bicycling for commuting and non-commuting. The ICLV modeling framework described how the perception of the built environment influences mode choice and how different socio-demographics influence perceptions of built environment features. Some of our findings are in line with previous research in the context of developing countries (Hidayati et al., 2020). Our results slightly differ from Heinen et al. (2011) as we found that perception of safety (both road safety perception and neighborhood safety perception) was not significant for bicycling choices for commuting trips. This may be unique as Rajshahi does not emphasize safety in their promotion of bicycling for commuting. However, neighborhood safety perception has a significant negative influence on bicycling for non-commuting trips. This may be due to the time of those non-commuting purposes, especially recreational trips as those trips tend to be off-peak when streets are not crowded, and individuals may perceive a safety risk in traveling alone.

As we found that the perception of the built environment influences individuals' choice to bicycle, policymakers can focus on improving the built environment by giving special focus on the needs of women. Interestingly, despite the lack of bicycle infrastructure, we still observed a significant percentage of our survey respondents use a bike for transportation. Therefore, we can expect that with the development of bicycle infrastructure, cities like Rajshahi may experience an increase in bicycling. The findings from this study suggest that by improving the perceptions of the built environment, bicycle ridership can be increased. We found that gender indirectly influences the choice of bicycling through the latent variable. Thus, if we can improve the positive perceptions towards the built environment by providing safe and adequate infrastructure, that will, in turn, increase bicycling adoption, especially among women. It is necessary to provide not only bike lanes, which Bangladesh has currently implemented in several cities, but also safe bike parking facilities in different locations to encourage individuals towards bicycling. To achieve a higher level of bicycling, not only is the provision of adequate infrastructure necessary, but also an assurance of the safety of different bicycle users. Additionally, encroachment of active transport infrastructure is common in the context of Bangladesh, which hampers the use of and lowers the perception of the facility. Thus, an appropriate policy for active transport infrastructure is necessary to better manage infrastructures from encroachments and to maintain unimpeded access for bicyclists and other users.

The modeling and the data collection framework used in this study can also be applied to the context of other cities in Bangladesh, especially the megacity Dhaka which has also recently implemented bike lanes (Tasnim, 2020). Bicycling infrastructure is likely to generate favorable perceptions towards the built environment among individuals and attract more bicycling. Thus, future research can focus on data collection initiatives in multiple cities and develop both city-specific and combined models to better understand an individual's choice of bicycling for commuting and non-commuting trips. Those additional studies will be useful in developing sustainable transport policies and in the long run assist Bangladesh in achieving multiple Sustainable Development Goals (SDGs), specifically, SDG 3 of good health and wellbeing, SDG 7 of clean and affordable energy use, SDG 12 of responsible consumption and production, and SDG 13 of successful climate action (World Bicycle Relief, 2018). The importance of public awareness among individuals and in policy discussions regarding the benefits of bicycling and the issues brought by motorized vehicles should be emphasized. Future studies are recommended to analyze in more detail the influence of perceptions of built environment features, particularly through the lens of gender, in the context of other cities in Bangladesh.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

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