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Determinants of Dockless Bicycle-Sharing Adoption and Usage Intensity for Commuting and Errands: Evidence from Disadvantaged Neighborhoods

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Abstract: The emergence of dockless bicycle sharing has transformed urban transportation, particularly in China, by offering a flexible and accessible travel option. However, understanding the factors driving its adoption and usage in disadvantaged neighborhoods is crucial, as these areas often face unique mobility challenges. This study explores these determinants, providing a more comprehensive analysis than prior research by focusing specifically on disadvantaged communities. Using survey data from four such neighborhoods in Xi'an, China, we apply Structural Equation Modeling to investigate the factors influencing individuals' decisions to adopt and intensively use dockless bicycle sharing for commuting and errands. The results reveal key determinants, including psychological factors, demographic characteristics, and spatial and social contexts, and their interaction mechanisms. Attitudes are found to have a substantial impact on bicycle-sharing behavior for both commuting and errands, while social norms and perceived behavioral control (PBC) mainly influence usage for errands. Interestingly, PBC affects adoption but not usage frequency. The findings also highlight that proximity to schools, subways, and neighborhood aesthetics positively correlate with bicycle-sharing adoption for errands, whereas bicycling infrastructure significantly influences usage intensity. However, none of the neighborhood environment factors were found to significantly affect adoption for commuting purposes. These insights are especially valuable for developing targeted strategies to promote bicycle sharing as a sustainable transportation solution in disadvantaged neighborhoods, where improved access can significantly enhance mobility and quality of life.

Keywords: bicycle sharing; neighborhood environment; adoption; usage frequency; disadvantaged neighborhood

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1. Introduction

Shared bicycles offer a sustainable solution to urban transportation challenges, including alleviating traffic congestion, reducing air pollution, and decreasing dependence on fossil fuels [1]. They contribute to transportation equity [2] and public health improvements [3], while also lowering personal transportation expenses and supporting the development of multimodal transportation systems [4]. Operating on a membership or pay-per-use basis, bicycle sharing embodies the principles of being economical, efficient, and eco-friendly [5]. Its user-friendly approach, which eliminates concerns such as maintenance, storage, and theft risk, attracts a diverse user base, including individuals transitioning from other active travel modes [6–8]. Notably, shared bicycles offer a cost-effective alternative for many low-income individuals deterred by the expenses associated with bicycle ownership and maintenance [9]. It can be seen that the shared bicycle system is vital for improving transportation equity, public health, and environmental sustainability.

China, as a global leader in dockless bicycle-sharing adoption, presents a unique and relevant context for this research. The localization of dockless bicycle sharing in China presents significant advantages stemming from the country's unique context, characterized

by a high land mix rate, population density, and cultural acceptance. This environment fosters the ideal conditions for developing bicycle-sharing systems that address the "first and last mile" of mobility, serving as an alternative transportation mode [10]. Particularly noteworthy is the emergence of a "cycling–transit–cycling" travel chain model, effectively resolving the challenge of active travel distance [4]. This advancement plays a vital role in enhancing transportation equity in China, notably by improving access for disadvantaged groups [11]. Furthermore, the superior convenience, enhanced integration with public transport, and extensive urban coverage of dockless shared bicycles have propelled their widespread adoption, surpassing docked counterparts and reshaping the Chinese market dynamics [12,13]. This trend is gaining greater prominence in China, both now and in the foreseeable future, which is why we have focused our research on dockless bicycle sharing.

Over the past decade, there has been a growing interest in studying bicycle-sharing systems to reduce motorized traffic and promote sustainable transportation policies. Despite numerous studies examining bicycle-sharing usage, they frequently present mixed results regarding the determinants influencing usage patterns. Furthermore, there remains a limited academic understanding of the multifaceted aspects of bicycle-sharing travel behavior, particularly in terms of adoption and usage intensity for various travel purposes [14–16]. We use an extended version of the Theory of Planned Behavior (TPB), integrating neighborhood environmental characteristics to offer a more comprehensive model of bicycle-sharing behavior. This study promotes a nuanced understanding of how environmental and personal characteristics interact through psychological mechanisms to influence bicycle-sharing choices. The combination of endogenous psychological variables with exogenous neighborhood characteristics provides a dual-perspective analysis that enhances our understanding of the factors that either enable or inhibit bicycle-sharing adoption and usage intensity for commuting and errands.

Since much of the research has focused on general urban areas [17–19], this leaves a significant gap in understanding how these factors operate in disadvantaged neighborhoods, where unique socio-economic and spatial constraints may influence adoption and usage behaviors differently. Disadvantaged neighborhoods often face mobility challenges such as lower access to infrastructure, safety concerns, and economic limitations [20,21], yet little attention has been paid to how these factors shape the effectiveness of bicycle-sharing systems in such contexts. Additionally, the impact of differing built environments and cultural contexts across countries and regions on bicycle-sharing usage patterns also represents a significant area of disparity [12], further underscoring the need for targeted research in underrepresented areas, including disadvantaged neighborhoods. To address these gaps, this study focuses specifically on four disadvantaged communities in Xi'an, China. By examining these underrepresented communities, our research provides critical insights into how environmental and psychological factors influence bicycle-sharing choices, thus advancing the discourse on transportation equity. By shedding light on these factors, this research provides crucial insights for promoting active travel, optimizing transportation policies, and advancing transport equity in disadvantaged neighborhoods.

2. Literature Review

In this review, we conducted an in-depth examination of bicycle-sharing behavior, analyzing a comprehensive range of factors that significantly influence this transportation mode, particularly for commuting and other purposes. We scrutinized the variations in how diverse factors impact bicycle-sharing adoption and usage frequency. Moreover, we explored psychological theories that underpin the travel decision-making process, elucidating the intricate motivations and cognitive mechanisms driving individuals to choose bicycle sharing as a transportation option.

2.1. The General Factors Regarding Bicycle-Sharing Behavior

The contribution of environmental factors, both natural and anthropogenic, to bicycle-sharing behavior is substantial, encompassing aspects such as geographical distribution,

natural landscapes, and the built environment. High-density areas with mixed land use typically feature shorter travel distances, enhancing the convenience of bicycle sharing as a transportation option [18,22]. Moreover, scenic landscapes and attractive surroundings may bolster the appeal of cycling, motivating individuals to opt for bicycles for both transportation and recreation [23]. Conversely, natural obstacles such as steep inclines, uneven terrain, or water bodies can impede cycling and influence bicycle-sharing utilization patterns [4]. Safe and convenient cycling and parking facilities increase the likelihood of bicycle-sharing usage [24,25], and a dense network of bicycle-sharing systems promotes frequent use [26]. Strategically positioned shared bicycle stations near public transit hubs facilitate the integration of cycling into multimodal travel routes [27]. Well-lit, traffic-calmed areas can heighten perceptions of safety, encouraging greater bicycle-sharing adoption [28].

Individual factors also play a considerable role, such as demographic characteristics, personal attitudes, and habitual practices [5,29–31]. For instance, younger individuals, due to heightened environmental awareness and ease with emerging technologies, are more inclined to use bicycle-sharing systems compared to older individuals [32,33]. Additionally, positive attitudes toward cycling and sustainability can motivate people to adopt bicycle sharing [15]. Perceived barriers, such as lack of safe cycling infrastructure or concerns about theft, discourage usage [34,35]. Habitually, those with a background in cycling or active transportation are likelier to engage in bicycle sharing [36], as familiarity with cycling and recognition of active travel's advantages enhance the propensity to participate in bicycle-sharing programs [37].

However, these factors may differ significantly in disadvantaged neighborhoods, where access to resources, infrastructure, and safety can be lower [38,39]. Research in disadvantaged communities remains sparse, despite their residents often exhibiting distinct travel behaviors and a greater dependence on affordable, flexible transportation modes like bicycle sharing. Understanding how environmental and individual factors intersect in these contexts is critical for promoting transport equity and addressing the unique barriers these populations face.

2.2. The Determinants Influencing Various Bicycle-Sharing Behaviors

2.2.1. Different Travel Purposes

Recent studies have increasingly focused on the use of bicycle-sharing systems for diverse travel needs, including commuting, leisure, and errands. In the context of commuting, land use is a significant factor influencing demand, with the density of job and employment centers playing a key role [40]. Higher density and mixed land use in communities often lead to greater reliance on bicycles for commuting [41]. Shorter distances encourage users to choose bicycle sharing, while longer distances typically result in users opting for other transportation modes [12].

In contrast, bicycle sharing for errands or recreational activities tends to be more flexible and is strongly linked to Points of Interest (POIs) and nearby amenities [42]. Dockless bicycle-sharing systems, which allow for fewer restrictions on starting and ending points, are particularly effective for errands, providing greater convenience compared to commuting [43]. However, the existing literature has often overlooked the role of disadvantaged neighborhoods in this dynamic, where bicycle sharing can be an essential solution for residents with limited access to other transportation options [44,45]. More attention is needed to examine how these communities utilize bicycle sharing for both commuting and utilitarian purposes, particularly in light of the socio-economic barriers they face.

2.2.2. Distinctions and Linkages for Adoption and Frequency of Bicycle Sharing

Both mode access and usage frequency are critical in assessing travel demand [46]. Adoption of bicycle sharing refers to the initial decision to use the service, whereas the frequency of use indicates how regularly or intensively it is utilized by adopters [47]. Environmental factors such as proximity to shared bicycle stations, key destinations, and transit hubs have been shown to facilitate both adoption and frequent use [27,48]. How-

ever, climate and other natural environmental factors can also discourage bicycle-sharing usage [6,49,50]. While disadvantaged groups may initially exhibit lower adoption rates due to economic and infrastructural challenges, studies have shown that once these groups begin using bicycle-sharing systems, their frequency of use can be higher than that of other demographic groups [51]. This suggests that these communities could greatly benefit from improved bicycle-sharing infrastructure and supportive policies.

2.3. The Psychological Theory of Bicycle Sharing

Previous studies have often employed utility maximization theory to explore the relationship between the built environment and bicycle-sharing travel behavior. However, this approach has limitations, and more recent research has shifted toward incorporating psychological theories to gain a deeper understanding of individual motivations and attitudes. As emphasized by Zhu et al. [52], successful implementation of bicycle sharing cannot be achieved without considering factors such as user attitudes, experiences, and preferences. The Theory of Planned Behavior (TPB) remains one of the most frequently used frameworks, positing that an individual's intention to perform a behavior is shaped by their attitudes, subjective norms, and perceived behavioral control (PBC) [53]. Within the bicycle-sharing framework, these elements collectively influence an individual's intent to utilize bicycle sharing, subsequently affecting their actual usage [36,54]. Attitudes encompass beliefs about the advantages and challenges of bicycle sharing and the willingness to embrace this transport mode [55]. For instance, viewing bicycle sharing as eco-friendly and convenient can heighten the inclination to use it [15]. Subjective norms involve the perceived expectations of significant others, like family, friends, or colleagues, regarding bicycle-sharing usage. Endorsement from one's social circle can bolster the intent to engage in bicycle sharing [56,57]. PBC relates to an individual's perception of how easy or challenging it is to use bicycle sharing, factoring in aspects like availability, cost-effectiveness, accessibility, and cycling proficiency [58]. A strong sense of control and adequate resources can positively sway the decision to adopt bicycle sharing [59,60].

In disadvantaged neighborhoods, psychological factors may play an even more critical role, as residents often face additional barriers such as economic constraints and concerns about personal safety [61]. Understanding how attitudes, social norms, and PBC influence adoption and usage in these communities is essential for designing interventions that effectively promote bicycle sharing and improve transportation equity. Integrating psychological and environmental perspectives in such contexts can provide a more comprehensive understanding of the factors driving bicycle-sharing behavior across diverse socio-economic groups.

2.4. Review Summary

Existing studies on bicycle-sharing systems highlight the pivotal roles of environmental factors (e.g., land use, infrastructure, and accessibility), demographic characteristics, and psychological factors in shaping adoption and usage behavior. However, the influence of these factors varies significantly across contexts, and targeted research is needed, especially for disadvantaged communities, which face unique barriers such as financial constraints and lower infrastructure availability. Despite the wealth of literature on bicycle-sharing systems, several critical gaps remain: There is limited research on disadvantaged communities, where travel may have its own characteristics; a lack of integration of psychological constructs and environmental factors in explaining adoption and use intensity; an insufficient distinction between the determinants of commuting and errands; and few studies explicitly investigate the difference between adoption and use frequency. By focusing on disadvantaged communities in Xi'an, China, this study will address these gaps.

3. Research Methodology

3.1. Study Design

We conducted a survey in Xi'an, China, between 20 August and 4 November 2018, through face-to-face interviews in four disadvantaged neighborhoods with diverse characteristics. Xi'an is one of the oldest cities in China, with a population of over 13 million. It is characterized by rapid urbanization, a high population density, and a combination of historical and modern infrastructure. Despite these advantages, it has many disadvantaged communities due to historical reasons. These characteristics make Xi'an an ideal setting for this study.

In the implementation of the survey, disadvantaged neighborhoods were selected based on a combination of the socioeconomic level of the majority of the population and the type of neighborhood itself. Specifically, we considered neighborhoods with lower average household incomes, higher unemployment rates, and less infrastructure and services. Four neighborhoods were selected for this study to ensure that the characteristics of the built environment varied sufficiently, including (1) Bajia, a redeveloped shantytown; (2) Sanyin, an old-style workplace community; (3) Lougetai, a typical traditional urban village; and (4) Changfengyuan, a redeveloped urban village. A common feature is that most of the residents are unemployed workers, migrant farmers, and urban migrants, who are generally older, less educated, and have poor incomes.

Face-to-face interviews were particularly beneficial given the characteristics of our target population—mainly disadvantaged groups with low levels of education. The survey was facilitated by the authors and trained graduate students. Before the formal survey, we conducted a pilot test with volunteer residents to refine the questions. Interviewers provided necessary clarifications, enhancing data accuracy. The formal data collection occurred at central community locations over two weeks per neighborhood, from 9 am to 9 pm, including weekends. Participants in the survey were voluntary and could receive a small thank-you gift for their time. We collected socio-economic data, including age, gender, marital status, and education level, to ensure the accuracy of the survey. To ensure the representativeness of the sample, we employed a stratified sampling strategy. We aimed for 300 responses per neighborhood, ultimately collecting 1263 responses, of which 921 were valid after quality control, which consisted of excluding incomplete or invalid answers, filtering by time (must be over 18 min), and a "trap" question to ensure attention. Table 1 presents the sample characteristics: the sample was predominantly female (69.8%), with 64.2% of respondents over the age of 45. Education levels were generally low, with less than 16% holding a bachelor's degree or higher. The sample also had a high unemployment and retirement rate (60%), and the majority of respondents were married. Additionally, 74.2% of participants did not possess a driver's license.

3.2. Modeling Method

This study hypothesized three basic elements of TPB related to bicycle sharing, including attitudes, social norms, and PBC, as potential endogenous variables affecting the three outcome variables, while socio-demographic factors, along with built and social environmental characteristics, were hypothesized as exogenous variables that could directly or indirectly impact bicycle-sharing behavior. This research introduces more detailed measures of bicycle-sharing behavior than previous studies, specifically "bicycle-sharing adoption for commuting" (BSAC), "bicycle-sharing adoption for daily errands" (BSAE), and "bicycle-sharing frequency for daily errands" (BSFE). Notably, the BSAC analysis underwent a filtering process, selecting 368 employed individuals based on their formal employment status. This step aimed to eliminate the potential bias from those without regular commuting patterns, thereby refining the accuracy of the findings. The entire study's theoretical framework, grounded in TPB, is illustrated in Figure 1.

We employed a structural equation model (SEM) to operationalize the pathways outlined in our TPB-based conceptual framework. This approach allowed us to examine the direct effects of socio-demographic and neighborhood environmental factors on

bicycle-sharing behavior change, while also evaluating the mediating role of individual psychological factors. Since our two dependent variables, BSAC and BSAD, are categorical dummy variables, we used the Weighted Least-Squares Mean and Variance Adjusted (WLSMV) estimation method in our analysis, implemented through Mplus 8.11 software.

Table 1. Sample characteristics.

	Number	Percent
Age groups		
Below 30	122	13.2
30–45	200	19.0
45–60	234	11.6
60–70	234	16.6
70 and over	130	22.0
Gender		
Female	643	69.8
Male	278	30.2
Married		
Married/cohabiting	778	84.5
Single/divorced/widowed	143	15.5
Education level		
Did not go to school	16	1.7
Finished primary school	64	7.0
Completed secondary school qualification	520	56.5
Completed technical school	75	8.1
Completed junior college	128	13.9
Completed bachelor's degree qualification	104	11.3
Completed post-graduate qualification	14	4.5
Annual household income		
CNY 1–19,999 per year (CNY 1–1666 per month)	96	15.5
CNY 20,000–39,999 (CNY 1667–3333)	154	24.8
CNY 40,000–59,999 (CNY 3334–5000)	110	17.7
CNY 60,000–79,999 (CNY 5001–6666)	84	13.5
CNY 80,000–99,999 (CNY 6667–8333)	62	10.0
CNY 100,000–149,999 (CNY 8334–12,499)	72	11.6
CNY 150,000–199,999 (CNY 12,500–16,666)	21	3.4
CNY 200,000 and above (CNY 16,667 and above)	22	3.5
No. of cars in household		
0	320	34.7
1	470	51.0
2	95	10.3
>2	36	3.9
No. of bikes in household		
0	520	56.5
1	284	30.8
2	87	9.4
>2	30	3.3
No. of e-bikes in household		
0	474	51.5
1	347	37.7
2	74	8.0
>2	26	2.8
Driving license		
Yes	238	25.8
No	683	74.2
Employment status		
Employed (including full-time and part-time)	368	40.0
Unemployed (including unemployment and retirement)	553	60.0

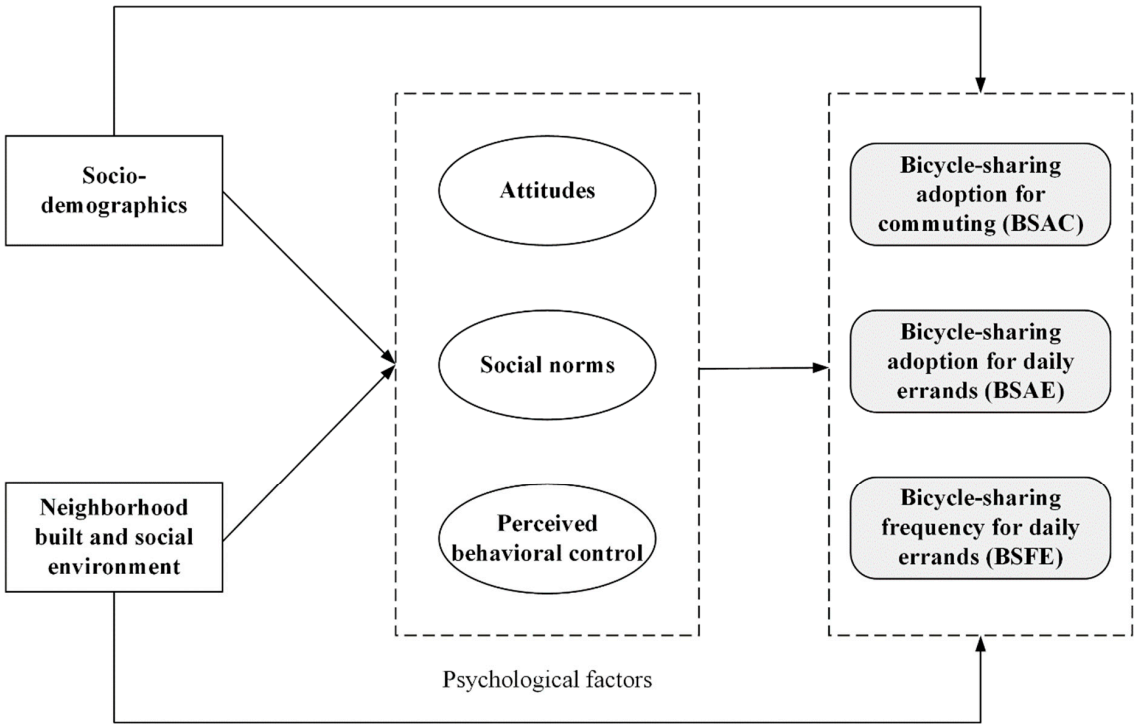


Figure 1. Conceptual framework.

3.3. Research Variables

Table 2 outlines all the variables used in this study. We employed an extended version of the Theory of Planned Behavior (TPB) to investigate bicycle-sharing behaviors, focusing on attitudes, social norms, and PBC as core variables. These variables were measured using validated survey questions that are well-established in the existing literature.

Bicycle-sharing adoption is categorized into two main purposes: commuting and daily errands. Respondents were asked to report their bicycle-sharing trips from home to work, as well as to six types of destinations: civic buildings, service providers, stores, restaurants or cafes, entertainment/recreational venues, and exercise venues. Adoption was measured as a binary variable (1 for use as a primary mode of transport, 0 for not used as a primary mode). For daily errands, the study further examined usage frequency, using a 6-point scale ranging from 1 (never) to 6 (twice or more per week). The total score across the six categories represents the overall frequency of bicycle-sharing usage. Figure 2 illustrates the distribution of respondents' bicycle-sharing usage for various trip purposes. The data show that 82.34% of respondents were unlikely to adopt bicycle sharing for commuting, while 46.8% considered using it for daily errands, though only a minority did so frequently.

We assessed environmental factors using the Neighborhood Environmental Walkability Scale (NEWS), which employs a four-point Likert scale ranging from "strongly disagree" to "strongly agree" to capture respondents' perceptions of their surroundings. The scores were summarized to reflect environmental features such as building density, street connectivity, aesthetics, and safety [62]. Environmental safety was further divided into two indicators—traffic hazards (including accidents and congestion) and crime rates—as suggested by [63]. Service accessibility was measured by the walking time to 14 local destinations, including stores, supermarkets, post offices, schools, coffee shops, restaurants, hospitals, bus stops, subway stations, and parks. To address variable inconsistencies, we conducted a Principal Component Analysis (PCA), which identified three primary accessibility components: amenities, schools, and medical facilities. Additionally, walking times to bus stops, subway stations, and parks were treated as separate variables. Other factors, such as the presence of bicycle lanes, safety, bicycle-sharing infrastructure, and user satisfaction, were also measured using a four-point Likert scale.

Table 2. Description of variables.

Variable	Description	Code or Unit
Behavior		
Bicycle-sharing adoption for commuting (BSAC)	Use bicycle sharing as the main mode of transportation for commute	0 = False; 1 = True
Bicycle-sharing adoption for daily errands (BSAE)	Use bicycle sharing as the main mode of transportation for daily errands (from home to the destinations nearby: civic buildings, service providers, shops, restaurants or cafes, places for entertainment/recreation, and places to exercise)	0 = False; 1 = True
Bicycle-sharing frequency for daily errands (BSFE)	If BSAE = 1, how often has the respondent used bicycle sharing for daily errands in the past month?	Count
Socio-Demographics		
Age		Continuous variable
Gender		0 = Male; 1 = Female
Married	Marital status	0 = False; 1 = True
Education level	Education level	1–8 = From "illiterate" to "postgraduate or above"
Annual household income	Annual household income	1–8 = From "none" to "200,000 + CNY/per year"
No. of cars	No. of cars in household	Count
No. of bikes	No. of bikes in household	Count
No. of e-bikes	No. of e-bikes in household	Count
Holding a driving license	Holding a driving license	0 = False; 1 = True
Employed	Current working status	0 = Unemployed; 1 = Employed
Attitudes		
Preference	I like riding a shared bicycle.	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Neither agree nor disagree; 4 = Somewhat agree; 5 = Strongly agree
Riding better	It is easier for me to ride a shared bicycle than to ride my own bicycle.	
Convenience	Using a shared bicycle has greatly facilitated my daily travel.	
Social Norms		
SN1	Most people who are important to me, for example, my family and friends, think I should ride a (shared) bicycle more.	1 = Strongly disagree; 2 = Somewhat disagree; 3 = Neither agree nor disagree; 4 = Somewhat agree; 5 = Strongly agree
SN2	Most people who are important to me, for example, my family and friends, would support me riding a (shared) bicycle more.	
SN3	Many of my family, friends, and co-workers ride a (shared) bicycle to get to places, such as errands, shopping, and work.	
Perceived Behavior Control		
PBC1	For me to ride a (shared) bicycle for daily travel would be easy.	1 = Strongly disagree; 2 = Somewhat disagree; 3 = Neither agree nor disagree; 4 = Somewhat agree; 5 = Strongly agree
PBC2	I know where safe bike routes are in my neighborhood.	
PBC3	Many of the places I need to get to regularly are within bicycling distance of my home.	

Table 2. *Cont.*

Variable	Description	Code or Unit
Neighborhood Environment		
Density	How would you describe the type of housing unit where you currently live?	Weighted sum
Accessibility to amenities	Walking time to shop, supermarket, restaurant, etc.	Factor score
Accessibility to schools	Walking time to primary/middle school	Factor score
Accessibility to bus stop	Walking time to bus stop	5 = Under 5 min; 4 = 6–10 min; 3 = 11–20 min; 2 = 21–30 min; 1 = More than 30 min
Accessibility to subway	Walking time to subway station	5 = Under 5 min; 4 = 6–10 min; 3 = 11–20 min; 2 = 21–30 min; 1 = More than 30 min
Accessibility to park	Walking time to park	5 = Under 5 min; 4 = 6–10 min; 3 = 11–20 min; 2 = 21–30 min; 1 = More than 30 min
Street connectivity	(1) The distance between street intersections in my neighborhood is generally short; (2) There are many alternative routes on the streets in my neighborhood; (3) The streets in my neighborhood do not have many cul-de-sacs.	Mean
Aesthetics	(1) There are trees along the streets in my neighborhood; (2) There are many streets with greenery in my neighborhood; (3) There are many interesting things in my neighborhood; (4) There are many attractive natural sights in my neighborhood; (5) There are many attractive buildings and shops in my neighborhood.	Mean
Traffic hazards	(1) There is so much traffic along the streets in my neighborhood that it feels bad to walk; (2) There is so much traffic along the streets in my neighborhood that it feels bad to ride a (shared) bicycle; (3) Most drivers exceed the speed limit along the streets in my neighborhood; (4) The speed of traffic is slow (40 km/h or less) on most streets in my neighborhood (reverse indicator, RI); (5) It is common to see/smell exhaust fumes from motor vehicles when walking in my neighborhood (RI).	Mean
Crime rate	(1) There is a high crime rate in my neighborhood; (2) I feel unsafe walking during the day; (3) I feel unsafe walking at night; (4) My neighborhood is unsafe enough to not allow a 10-year-old boy to walk along the streets.	Mean
Social cohesion and trust	(1) People around here are willing to help their neighbors; (2) This is a close-knit neighborhood; (3) People in this neighborhood can be trusted; (4) People in this neighborhood generally don't get along with each other (RI); (5) People in this neighborhood do not share the same values (RI).	Mean
Bicycle infrastructure	(1) There are off-street bike trails or paved paths in or near my neighborhood that are easy to get to; (2) There are bike lanes that are easy to get to; (3) There are well-maintained and safe bike lanes; (4) There are quiet streets, without bike lanes, that are easy to get to on a bike.	Mean
Availability of bicycle-sharing services	It's easy to find shared bicycles in my neighborhood.	1 = Strongly disagree; 2 = Somewhat Disagree; 3 = Neither Agree nor Disagree; 4 = Somewhat agree; 5 = Strongly agree

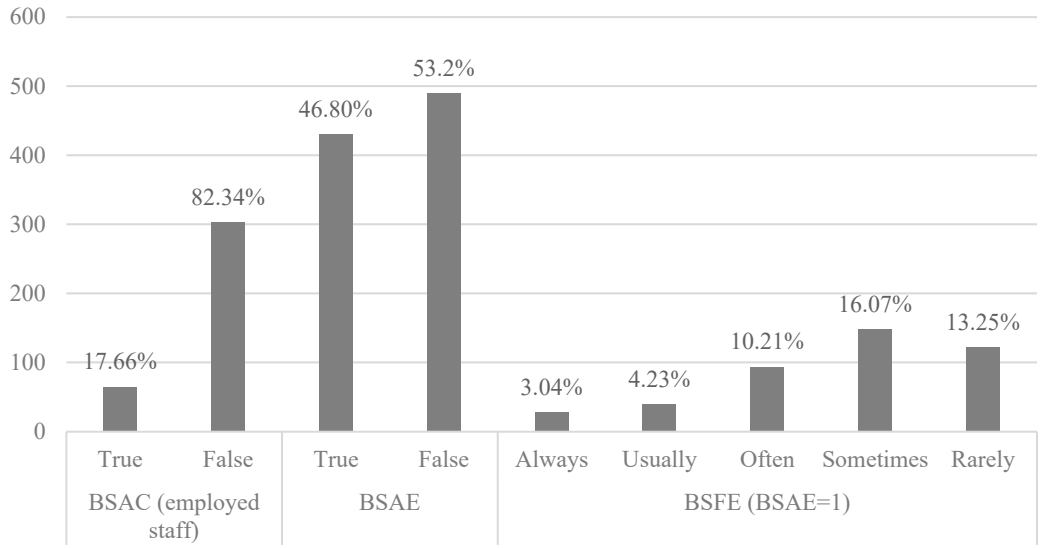


Figure 2. Different bicycle-sharing usage behaviors of the same respondents. Notes: True = bicycle sharing is the primary mode; False = bicycle sharing is not the primary mode; Always = "more than twice a week"; Usually = "once a week"; Often = "about once every two weeks"; Sometimes = "once or twice a month"; Rarely = "less than once a month".

For the neighborhood social environment, we used an adapted version of the Neighborhood Cohesion Scale, which includes measures of "mutual support", "connectedness", "trust", "friendliness", and "shared values" among neighbors [64]. These statements were rated on a four-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (4). The mean scores of these five items were calculated to represent overall measures of social cohesion and trust.

4. Results and Discussion

4.1. Factors Associated with Bicycle-Sharing Adoption for Commuting (BSAC)

The SEM model results for BSAC are presented in Table 3. The model fit indices, including CFI (0.900) and RMSEA (0.057), suggest a good fit based on the criteria set by [65,66]. Furthermore, the standardized loadings for the three latent constructs of the Theory of Planned Behavior (TPB) exhibit substantial magnitudes: 0.810 to 0.826 for attitudes, 0.455 to 0.808 for social norms, and 0.581 to 0.767 for PBC. All the coefficients in the tables are standardized. Our primary focus is to interpret the coefficients that are statistically significant at the 5% and 1% levels; we have also reported those that are significant at the 10% level for informational purposes.

According to the model results, of the three TPB constructs, only attitude ($p < 0.01$) has a positive impact on the adoption of using bicycle sharing for commuting. This suggests that the more positive a commuter's attitude toward using bicycle sharing, the more likely he or she is to use bicycle sharing, which is consistent with the findings of related studies [37,56,61,67]. Unexpectedly, neither social norms nor PBC are statistically associated with the adoption of using bicycle sharing for commuting. While social norms can significantly influence behavior in various contexts, their impact may be attenuated when predicting a behavior as specific and routine as daily commuting. In Chinese cities, where bicycle sharing may be primarily perceived as a practical mode of transportation rather than a social activity, social norms related to bicycle-sharing behavior may carry less weight in influencing adoption decisions for daily commuting. The predictive power of PBC may also be limited in the context of daily commuting. Individuals' beliefs about their ability to perform the behavior (i.e., using bicycle sharing for daily commuting) may be less variable or influential compared to behaviors that allow for greater flexibility and choice.

In situations where the behavior is perceived as routine and obligatory, perceived control may be less salient in shaping adoption decisions.

Table 3. BSAC model results (n = 355).

	Attitudes R^2 = 0.072		**Social Norms** R^2 = 0.149		**PBC** R^2 = 0.167		**BSAC** R^2 = 0.121			
	Direct effects		Direct effects		Direct effects		Direct effects		Total Effects	
Psychological factor										
Attitudes							0.250	***	0.250	***
Social Norms							0.109		0.109	
Perceived Behavior Control							0.096		0.096	
Neighborhood environment										
Accessibility to amenities	0.102		−0.104		0.073		−0.081		−0.06	
Accessibility to schools	−0.057		0.033		0.117	**	0.040		0.040	
Accessibility to bus stop	0.000		−0.146	**	−0.097		0.115	**	0.089	
Accessibility to subway	−0.076		0.090		−0.024		0.028		0.017	
Accessibility to park	0.032		−0.051		0.015		0.041		0.045	
Street connectivity	0.018		0.121	**	0.230	***	−0.077		−0.038	
Aesthetics	0.091		0.022		−0.071		−0.021		−0.002	
Traffic hazards	0.020		−0.113	*	−0.084		−0.001		−0.017	
Crime rate	−0.117	**	0.006		−0.062		−0.012		−0.046	
Social environment	−0.032		−0.017		0.053		0.044		0.039	
Bicycle infrastructure	−0.015		0.079		0.086		0.001		0.014	
Availability to bicycle-sharing	0.081		0.072		0.017		−0.042		−0.012	
Socio-demographics										
Age	−0.01		−0.011		0.073		0.007		0.010	
Female	−0.07		−0.044		−0.058		0.103	*	0.075	
Married	0.006		0.051		−0.042		−0.051		−0.048	
Education level	−0.07		−0.093		−0.084		0.087		0.051	
No. of bikes	0.116	**	0.159	***	0.139	**	0.039		0.099	*
Driving license	0.055		−0.122	*	0.047		−0.131	**	−0.126	**

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Regarding the role of the perceived neighborhood environment, most variables were not directly associated with the likelihood of adopting bicycle sharing for commuting, except for accessibility to bus stops. This is probably because many commuters prefer to use bicycle sharing for the initial or final leg of their bus journey [68], facilitating a smooth transition between transport modes [52,69]. This pattern is particularly pronounced in areas with limited access to transit [70–72]; a more complementary and synergistic relationship between the two modes of transport, bicycle sharing and bus, will emerge in the long term [73,74]. Similarly, none of the perceived neighborhood environment variables have significant total effects on using bicycle sharing for daily commuting, although some are directly associated with three psychological constructs. These findings emphasize the lack of significant total effects from home-located community context on bicycle sharing for commuting, indicating that psychological factors and personal attitudes might play a more substantial role in the decision to use bicycle-share programs. This implies that interventions aimed at promoting bicycle sharing for commuting may benefit more from focusing on enhancing the perceived convenience and reliability of bicycle-sharing systems rather than solely improving the physical attributes of the neighborhood environment.

4.2. Factors Associated with Bicycle-Sharing Adoption for Daily Errands (BSAE)

The results of the SEM model concerning bicycle sharing for errands (BSAE) are presented in Table 4. The model fit indices, including CFI (0.937) and RMSEA (0.051), suggest a good fit. The higher R^2 value for BSAE compared to bicycle sharing for commuting (BSAC) indicates that the model has greater explanatory power for errand-related bicycle sharing. This suggests that the factors considered in the model are more effective in explaining the

use of bicycle sharing for errands than for commuting. Moreover, more variables show significant direct and total effects on BSAE than on BSAC. This disparity likely arises because commuting trips are generally more restrictive in terms of bicycling use compared to daily errands. Commuting often involves fixed schedules, longer distances, and less flexibility, which may limit the influence of neighborhood environment and psychological factors. In contrast, errand trips typically offer more flexibility in terms of timing and routes, making them more susceptible to the influence of these factors.

Table 4. BSAE model results (n = 885).

	Attitudes R^2 = 0.097		**Social Norms** R^2 = 0.256		**PBC** R^2 = 0.124		**BSAE** R^2 = 0.396			
	Direct effects		Direct effects		Direct effects		Direct effects		Total Effects	
Psychological factor										
Attitudes							0.207	***	0.218	***
Social Norms							0.155	***	0.171	***
Perceived Behavior Control							0.150	***	0.016	***
Neighborhood environment										
Accessibility to amenities	−0.033		−0.044		0.077	*	−0.072	**	−0.074	**
Accessibility to schools	−0.011		−0.041		−0.021		0.095	***	0.083	**
Accessibility to bus stop	0.011		−0.061		−0.058		−0.003		−0.019	
Accessibility to subway	0.005		−0.019		−0.016		0.077	***	0.072	**
Accessibility to park	0.040		0.063		0.067	*	−0.018		0.010	
Street connectivity	−0.091	**	−0.007		0.088	**	−0.042		−0.049	
Aesthetics	0.074	*	0.037		−0.011		0.083	***	0.102	***
Traffic hazards	0.059		−0.003		0.006		0.027		0.039	
Crime rate	−0.071	*	−0.006		−0.024		0.022		0.003	
Social environment	−0.006		−0.011		0.035		−0.012		−0.01	
Bicycle infrastructure	0.040		0.078	**	0.086	**	−0.006		0.027	
Availability to bicycle-sharing	0.115	***	0.085	**	0.057		−0.066	**	−0.02	
Socio-demographics										
Age	−0.171	***	−0.348	***	−0.233	***	−0.331	***	−0.455	***
Female	−0.022		−0.071	**	−0.086	**	−0.099	***	−0.127	***
Married	0.009		0.081	**	0.090	***	0.002		0.030	
Education level	0.018		−0.052		−0.035		0.038		0.028	
No. of bikes	0.006		0.111	***	0.152	***	0.044		0.085	***
Driving license	0.010		−0.102	***	−0.005		0.001		−0.013	
Employment Status	0.083	*	0.079	*	−0.007		0.024		0.052	

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

All three psychological factors, attitudes towards bicycling, social norms, and PBC, are positively associated with BSAE. This finding implies that individuals who perceive cycling as enjoyable, convenient, and beneficial are more inclined to use bicycle-sharing services. This finding also suggests that when cycling is viewed as a socially accepted and encouraged behavior, individuals are more likely to adopt it. This highlights the role of community and societal influences in promoting bicycle sharing. PBC, which reflects individuals' confidence in their ability to cycle under various circumstances, further enhances the likelihood of adopting bicycle sharing. This indicates that individuals who feel they have the necessary skills, resources, and opportunities to cycle are more likely to use bicycle-sharing services. This finding also implies that improving infrastructure, providing accessible and well-maintained bicycles, and ensuring safe cycling environments can empower individuals in low-income neighborhoods and reduce barriers to cycling.

Among the perceived neighborhood environment variables, several have significant total effects on BSAE. Specifically, accessibility to schools, accessibility to subways, and neighborhood aesthetics are positively associated with BSAE. These factors indicate that a supportive and appealing neighborhood environment can encourage the adoption of bicycle sharing for daily errands. For example, the proximity of schools can make bicy-

cle sharing a convenient option for parents and students running school-related errands, aligning partially with findings from Guo et al. [12]. Similarly, aesthetically pleasing and well-maintained neighborhoods make cycling more enjoyable for non-commuting purposes [23]. Further, the positive association between accessibility to subways and BSAE underscores the importance of integrating different modes of transport. Subways and bicycle-sharing systems can complement each other, providing seamless multimodal travel options that enhance overall mobility. Similar findings suggest that the presence of better subway availability in a neighborhood stimulates the use of bicycle sharing [40] and that such increases are higher for non-commuting than for commuting purposes [75]. These findings suggest that urban planners and policymakers should consider these environmental factors when designing and implementing bicycle-sharing programs. Enhancing accessibility to key destinations like schools and subways and improving neighborhood aesthetics can significantly boost the adoption of bicycle-sharing services by people (especially disadvantaged populations) for daily errands.

Unexpectedly, proximity to amenities is negatively associated with BSAE. This finding suggests that when amenities are closely located, individuals may prefer walking to cycling for short trips, as walking is often perceived as more convenient and requires no additional equipment or preparation [18,76]. Moreover, the presence of nearby amenities might reduce the perceived need for a bicycle-sharing service, as the distance is easily walkable. Walking frequency and amenity accessibility are validated in the relevant evidence [77]. This highlights a potential trade-off in urban design, where overly convenient access to amenities might reduce the use of active transport options like bicycle sharing.

Compared to the model results for BSAC, more neighborhood environment variables are significantly associated with BSAE. This suggests that the neighborhood environment may play a more important role in the adoption of bicycle sharing for daily errands than for daily commuting. This could be because running errands often involves shorter, more frequent trips that are more sensitive to local environmental factors, such as the availability of bike lanes, proximity to destinations, and perceived safety. In contrast, commuting typically involves longer, more routine journeys that may be less influenced by immediate neighborhood characteristics.

4.3. Factors Associated with Bicycle-Sharing Frequency for Daily Errands (BSFE)

Unlike the BSAE model, the BSFE model examines factors associated with the frequency of using bicycle sharing for daily errands. The model results presented in Table 5 (CFI = 0.933, RMSEA = 0.044) suggest a good fit. Among the three psychological constructs examined, both attitudes towards bicycle sharing and social norms are significantly and positively associated with BSFE. This finding implies that individuals who have a favorable view of bicycle sharing and perceive it as a socially endorsed behavior are more likely to use these services frequently. Notably, based on previous knowledge, the factors that motivate travelers to use bicycle sharing do not necessarily increase the frequency of use [27,47]. For instance, PBC significantly affects the adoption of bicycle sharing for daily errands but does not influence the frequency of its use. This differentiation suggests that while feeling capable and in control is crucial for initially deciding to adopt bicycle sharing, it does not necessarily translate to frequent use. Once individuals overcome initial barriers and adopt bicycle sharing, their continued and frequent use depends more on their attitudes towards the service and the social norms surrounding it.

Among the neighborhood environment variables, the presence of bicycling infrastructure is positively associated with BSFE. This indicates that well-developed bicycling infrastructure plays a crucial role in promoting the frequent use of bicycle-sharing services for daily errands. Conversely, this variable is insignificant in the BSAE model, highlighting that while bicycling infrastructure is critical for frequent use, it is not as influential in the initial adoption of bicycle sharing for daily errands. This suggests that once individuals in disadvantaged communities decide to use bicycle-sharing services, the availability and quality of bicycling infrastructure significantly impact how often they use these services.

Table 5. BSFE model results (n = 407).

	Attitudes R^2 = 0.150		**Social Norms** R^2 = 0.190		**PBC** R^2 = 0.192		**BSFE** R^2 = 0.202			
	Direct effects		Direct effects		Direct effects		Direct effects		Total Effects	
Psychological factor										
Attitudes							0.151	***	0.151	***
Social Norms							0.148	**	0.148	**
Perceived Behavior Control							−0.001		−0.001	
Neighborhood environment										
Accessibility to amenities	0.094		−0.085		0.116	*	−0.017		−0.015	
Accessibility to schools	0.072		0.037		0.055		−0.017		0.000	
Accessibility to bus stop	−0.078		−0.138	**	−0.149	**	−0.035		−0.068	
Accessibility to subway	−0.118	**	−0.045		−0.072		0.102	*	0.078	
Accessibility to park	−0.033		−0.101		0.003		−0.128	**	−0.148	***
Street connectivity	0.142	**	0.207	***	0.223	***	−0.153	***	−0.101	**
Aesthetics	0.065		0.028		0.015		0.068		0.082	
Traffic hazards	0.144	***	−0.124	**	0.005		0.084	*	0.088	*
Crime rate	−0.168	***	0.035		−0.005		−0.032		−0.052	
Social environment	−0.081		−0.007		0.040		−0.014		−0.027	
Bicycle infrastructure	0.037		0.103		0.019		0.175	***	0.195	***
Availability to bicycle−sharing	0.148	***	0.123	**	0.112	**	−0.087	*	−0.046	
Socio−demographics										
Age	0.168	**	−0.008		0.207	***	−0.139	**	−0.115	*
Female	0.006		0.016		0.016		0.026		0.029	
Married	−0.037		−0.018		−0.085		−0.002		−0.011	
Education level	−0.021		−0.123	**	−0.068		0.032		0.011	
No. of bikes	0.043		0.086		0.121	**	0.077		0.097	**
Driving license	0.059		−0.158	**	0.001		−0.038		−0.052	
Employment Status	0.097		0.083		−0.013		0.061		0.088	

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Unexpectedly, the results of this paper differ from the findings of previous related studies on park accessibility which concluded that parks attract substantial recreational trips, thereby promoting frequent bicycle-sharing use [12,78]. While parks are generally seen as positive urban features, their presence might not directly facilitate or encourage the use of bicycle sharing for errands. This counterintuitive finding might be explained by several factors. Parks are often destinations for leisure rather than for running errands. In disadvantaged communities that are closer to neighborhood recreation sites such as parks, individuals may prefer walking due to its cost-effectiveness and alignment with recreational purposes. For another, some Chinese parks may prohibit the use of bicycle sharing. Street connectivity is also negatively associated with BSFE. High street connectivity can sometimes lead to increased traffic and congestion, making bicycling less safe and appealing [79]. This could discourage frequent use of bicycle-sharing services, even if the overall connectivity of the area is high. Interestingly, street connectivity is positively associated with the three psychological constructs (attitudes towards bicycle sharing, social norms, and PBC), while it is negatively associated with BSFE. The mixed effects of street connectivity on bicycle-sharing use are particularly noteworthy. On one hand, high street connectivity reduces travel distances and makes bicycling easier, positively influencing attitudes towards bicycle sharing, social norms, and PBC. On the other hand, increased traffic and congestion in highly connected streets may make bicycling less safe and appealing, thereby reducing the frequency of bicycle-sharing use.

5. Conclusions and Policy Implications

5.1. Conclusions

This study provides a comprehensive analysis of the factors influencing the adoption and frequency of bicycle sharing for commuting and daily errands in disadvantaged

neighborhoods. Using Structural Equation Modeling (SEM) and the Theory of Planned Behavior (TPB), we examined the complex relationships between psychological constructs, perceived neighborhood environment variables, and bicycle-sharing behavior in these underrepresented areas. The focus on disadvantaged neighborhoods, where residents face unique mobility and infrastructure challenges, adds a crucial dimension to our findings, underscoring the importance of equitable transportation solutions.

The key findings, summarized in Figure 3, reveal distinct differences between the factors influencing bicycle sharing for commuting and those affecting its use for daily errands. For commuting, only attitudes towards bicycling significantly impact adoption. In contrast, for daily errands, all three psychological constructs—attitudes, social norms, and PBC—positively influence bicycle-sharing adoption. This highlights the importance of individual perceptions, societal influences, and confidence in using bicycle sharing for errands, which are more critical in disadvantaged neighborhoods, where transportation options are often limited.

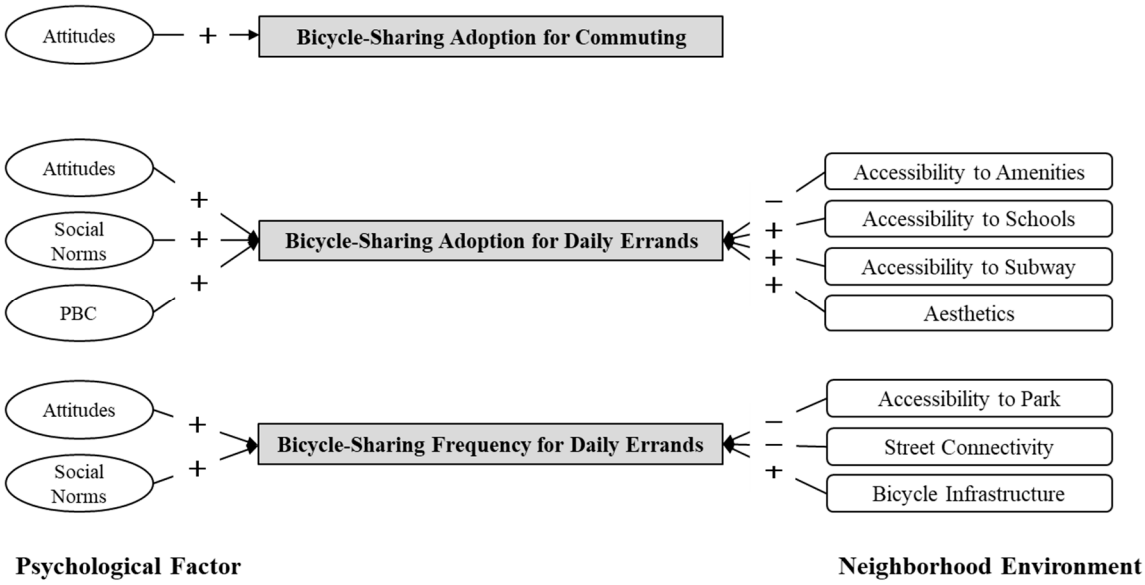


Figure 3. Summary of model results.

Neighborhood environment variables also showed varying impacts on bicycle-sharing behavior. Accessibility to schools, subways, and neighborhood aesthetics positively influence the adoption of bicycle sharing for errands, highlighting the importance of well-integrated urban infrastructure in these areas. However, negative associations were found between proximity to amenities, accessibility to parks, and street connectivity and frequent use of bicycle sharing. These counterintuitive results suggest that while certain environmental features are generally beneficial, their influence on bicycle-sharing behavior can be complex and context-dependent, particularly in disadvantaged neighborhoods. A plausible explanation for these negative associations is the competition between walking and bicycling as modes of transport for daily errands. Proximity to amenities, accessibility to parks, and street connectivity are well-established measures of walkability, and in areas where destinations are easily accessible by foot, walking may be preferred over bicycling for short trips. This finding underscores the nuanced differences between walkability and bikeability.

5.2. Policy Implications

The unique contributions of this study offer valuable insights for urban planners and policymakers, particularly with respect to promoting bicycle-sharing programs in disadvantaged neighborhoods. Initiatives to improve public attitudes towards bicycle sharing, strengthen positive social norms, and foster a bike-friendly culture can significantly boost adoption rates. Educational campaigns, community engagement activities, and social

incentives should be targeted specifically to underrepresented communities to increase awareness and address barriers related to safety and accessibility. In these areas, efforts to improve PBC—by ensuring the availability of well-maintained bicycles, enhancing safety measures, and providing user-friendly infrastructure—are particularly crucial for increasing bicycle-sharing adoption, especially for daily errands.

The positive association between public transit accessibility and bicycle sharing underscores the need for integrated transportation solutions, particularly in neighborhoods where access to transportation is limited. Policies should focus on creating seamless connectivity between bicycle-sharing stations and other public transport modes, such as subways and buses, to facilitate efficient travel. This is especially relevant in disadvantaged neighborhoods, where access to affordable, multimodal transportation options can greatly enhance mobility and quality of life.

Furthermore, the role of bicycling infrastructure in promoting frequent use for errands highlights the importance of continuous investment in dedicated bike lanes, secure parking, and supportive facilities. In disadvantaged neighborhoods, where safety and infrastructure gaps are often more pronounced, such investments can address key barriers to bicycle-sharing usage. Urban planners should also consider how features like street connectivity, traffic patterns, and safety concerns interact with bicycle-sharing behavior, adjusting land use and urban design to maximize positive outcomes and mitigate potential drawbacks, such as traffic congestion and safety risks.

In conclusion, the findings of this study offer valuable insights for advancing transport equity through targeted bicycle-sharing policies and infrastructure improvements in disadvantaged neighborhoods. By addressing the unique challenges faced by these communities, policymakers can help ensure that bicycle sharing serves as an inclusive, sustainable transportation solution that enhances mobility and quality of life for all residents. The emphasis on differentiated policy approaches based on specific trip purposes and neighborhood characteristics can lead to more effective interventions that enhance transportation equity and sustainability.

5.3. Future Work

Although this study includes valuable research, certain limitations remain.

First, females accounted for a large proportion of the respondents in our sample, which may be considered a limitation. Future studies could use alternative data collection methods, such as stratified sampling or conducting interviews at different times of the day, to ensure a more gender-balanced sample. Second, future research could further explore differences between disadvantaged and general neighborhoods, providing a clearer understanding of how socio-economic and environmental factors uniquely impact bicycle-sharing behaviors and informing more targeted policy recommendations. Third, the study focuses on a specific location (Xi'an, China), which may limit the generalizability of the findings to other regions or countries with different socio-economic and cultural contexts. Broader studies across diverse geographic areas could provide a more comprehensive understanding of bicycle-sharing dynamics. Fourth, the research employed a cross-sectional survey design, capturing data at a single point in time. This approach limits the ability to assess changes in bicycle-sharing behavior over time or to establish causal relationships between variables. Longitudinal studies would be beneficial to track changes and trends. Fifth, the reliance on self-reported data may have introduced response bias, as the participants might have provided socially desirable answers rather than reporting their true behaviors or attitudes. This could have affected the accuracy of the findings related to psychological constructs and usage patterns. Sixth, the study may not fully account for external factors that could influence bicycle-sharing adoption, such as local policies, economic conditions, or seasonal variations in weather. These factors can significantly impact transportation choices and should be considered in future research.

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