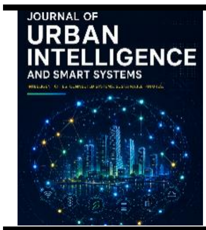

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Data-Driven Urban Decentralization: Modeling Mode and Destination Choice in the X-Minute City via Stated Preferences

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ABSTRACT

There are significant social, environmental, and public health advantages to encouraging cycling over automobile transportation. Although the "x-minute city" concept aims to decentralize urban services within a short bike ride or walk, there is currently little empirical modeling of how this framework affects individual behavioral choices. This study assesses the effect of proximity on bicycle adoption using intelligent urban modeling. We generated Multinomial Logit (MNL) models to examine mode and destination choice dynamics using two stated preference experiments conducted through a face-to-face survey (N=390) in Kerman, Iran. Travelers are successfully diverted from the city center by creating decentralized, replicated urban services within a 10-minute cycling radius, according to the predictive analytics. When combined with push-factors like congestion pricing and smart infrastructure expenditures like dedicated parking and bike lanes, this behavioral shift is further enhanced. For transportation planners and legislators using data intelligence to create sustainable, polycentric smart cities, these results offer crucial quantitative insights.

1. Introduction

Cities worldwide are growing, and the population of urban areas is increasing (Behnisch et al., [1] and United Nations, [2]). As urban areas expand, transportation needs to reach various services also increase. Since most cities are car-dependent, traffic congestion, air and noise pollution, and increased travel time are challenging that citizens and policymakers face. Given these challenges, municipal governments around the world are investing in bicycle infrastructure to promote sustainable and active modes of transportation, such as walking and cycling that provide benefits for people's mental and physical health and reduce car usage and carbon emissions (Avila-Palencia et al., [3] Fishman, [4], and Neves and Brand, [5]). Since bicycles are suitable for short-distance trips (≤3 km), land use planning of cities should be considered when promoting cycling. The x-minute city

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concept is one of the urban planning concepts that has recently received much attention. An x-minute city is a city where all residents can meet their daily needs and reach various services within 5 to 20 minutes of walking or cycling from their homes. Therefore, an x-minute city has mixed-use development and diversity in destinations (Moreno et al., [6]). This study aims to investigate the impact of the x-minute city on people's willingness to change their mode and/or destination, if there is a destination similar to their destination in the city center, within 10 or 20 minutes of cycling from their homes, by considering their socio-economic and travel behavior characteristics.

In what follows, Section 2 provides a review of the literature related to the modal shift to bicycles and the x-minute city concept. Section 3 presents the methodology employed in this study, providing an overview of the study area, questionnaire design, data collection, and modeling procedure. In Section 4, we present the results of our analysis and engage in a discussion of the main findings. This section models the relationships between socio-economic and travel behavior characteristics regarding attributes influencing mode and destination preferences in scenarios. In Section 5, we outline the policy implications of this study and provide recommendations that could be useful for city authorities. Finally, Section 6 summarizes the results of this study and concludes the paper by summarizing the key findings and suggesting future studies.

2. Literature review

This literature review is divided into two sections. In the first part, the findings related to influencing factors of the modal shift to bicycles are discussed, and in the second part, the literature explores key themes from recent studies on the x-minute city concept.

2.1 Modal shift to bicycles

Shifting to cycling is now seen as an appropriate way to promote active and sustainable travel behavior in urban areas. There are various factors affecting bicycle adoption. Recent studies have shown that dedicated bicycle lanes are essential for boosting bicycle use. They have found that cities investing in bicycle infrastructure implementation and expansion, such as bicycle lanes, bike sharing programs, and bicycle parking, see a jump in cycling. For instance, in countries such as the Netherlands, Denmark, and Germany (Buehler and Pucher., [7], Mitra et al., [8], and Pucher et al., [9]). Regarding policy interventions, those limiting private car use, such as congestion pricing and low-emission zones, can encourage more bicycle use. For instance, congestion charging in London increased the odds of cycling, and the removal of urban road pricing in Milan reduced the use of bike sharing in this city (Transport for London, a [10] and b; [11], and Cornago et al., [12]). Moreover, perceived safety is important in encouraging cycling. Research shows that people are more likely to travel by bicycle if they believe it is a safe mode of transportation. Safety concerns often discourage potential cyclists (Félix et al., [13]). Furthermore, socio-economic characteristics such as age, gender, and income impact travel habits and mode choice. Men, younger, and low-income individuals are more likely to cycle compared to women, the elderly, and wealthy individuals, respectively. (Acheampong and Siiba, [14] Prati et al., [15], and Timpabi et al., [16]). In the context of the studies related to the coronavirus pandemic and bike sharing programs, research shows that users replacing car trips and using bike sharing programs as a first/last mile connector to public transport were less affected by the pandemic than similar users replacing public transport or walking trips. Additionally, the main reasons for users to choose bike sharing programs instead of a personal bicycle were theft concerns (Teixeira et al., [17]). Regarding travel behaviour studies in the study area, previous research shows that safety concerns and availability of bicycle infrastructure are the main factors affecting bicycle usage in Kerman city. (Emadi et al., [18])

2.2. The x-minute city

This concept has gained popularity in response to urban challenges such as traffic congestion, air and noise pollution, and social isolation. A 15-minute city promotes equitable access to services and reduces car use (Núñez et al., [19]). Six types of services should be included in a 15-minute city: living, working, commerce, healthcare, education, and entertainment. Effective implementation of the x-minute city requires revising urban zoning to facilitate mixed-use developments (Moreno et al., [6]). Cities such as Paris, Barcelona, and Melbourne lead the implementation of the x-minute city concept (Teixeira et al., [20]).

To sum up, it is obvious that there is a relationship between the modal shift to the bicycle and the creation of the x-minute city. Since the bicycle is one of the main travel modes in the x-minute city, a city like this should be designed to reduce long-distance trips by car and promote short-distance trips by bicycle. Recent studies have examined the factors that influence people’s willingness to choose a bicycle as their main travel mode, and in the research on the x-minute city concept, the focus has been on accessibility to various services by walking or cycling in different cities worldwide, such as Birkenfeld et al., [21] Hosford et al., [22] Knap et al., [23], and Staricco, [24]. This study adds to current knowledge by filling the gap regarding the lack of studies related to people’s opinions on the x-minute city concept and the possibility of choosing a bicycle to reach various services in a city like this. The novelty of this study stems from filling the gap of modal shift to bicycle and x-minute city studies by mixing these two subjects using travel behaviour and demand analysis.

3. Methodology

3.1 Study area

The city of Kerman is a city in the central district of Kerman County that serves as the capital of Kerman Province and is located in the southeast of Iran. The city consists of 5 municipal regions and (last population census, [25]) is home to almost 537,000 inhabitants on 220 square kilometers and a population density of 2441 inhabitants per square kilometer, making it the fourteenth most populous city in Iran (Fig. 1). Kerman is an appropriate case study for promoting cycling and implementing the x-minute city concept. Firstly, it benefits from a moderate climate with an average annual temperature of 15.9 degrees Celsius, and the city is flat in terms of topography. In addition, the city relies heavily on cars, with about 55 percent of trips being made by private vehicles, leading to many long-distance trips from the city outskirts to the city center. Kerman city has about 30 kilometers of bicycle lanes and racks in some areas. Moreover, the municipality is planning to extend its cycling lanes and make a network that connects main origin-destinations in the city, but still the percentage of people who cycle as their primary mode of transportation is about 2 percent (Municipality of Kerman City, [26]).

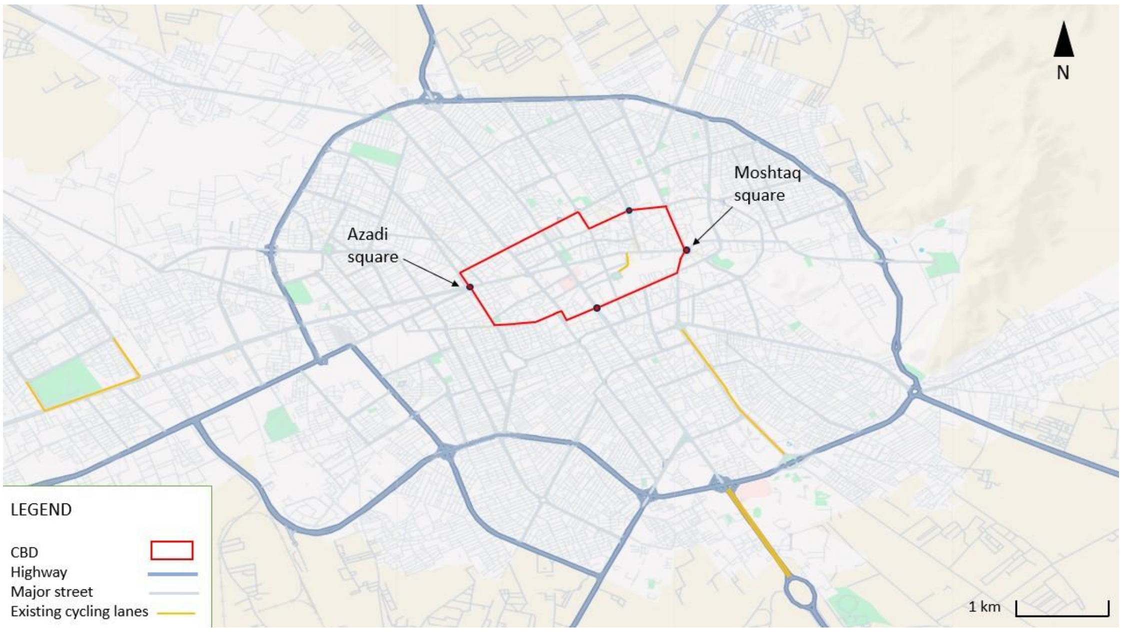

Fig. 1. Kerman's layout and its city center

3.2 Questionnaire design

The questionnaire in this study is divided into four parts: (1) revealed preference questions about the latest trip of each respondent to the city center, (2) the importance of several factors that reduce respondents' willingness to use a bicycle in their mentioned trip, on a 5-point Likert scale of responses. Annex 1 shows the 10 factors presented to participants in the question, (3) stated preference scenarios to investigate respondents' mode and destination preferences, and (4) a set of questions about individual socio-economic characteristics.

3.2.1 Stated preference experiments

In this study, after examining various factors that influence people's preferences to shift from other modes of transportation to bicycles, three attributes were selected and included in the scenarios' design, and 2 to 3 levels were set for each attribute to appropriately represent the different characteristics of each alternative. The level values of the attributes were set according to a realistic and reasonable range for two groups of respondents: (1) those who own or use a private car (first group) and (2) those who do not own or use a private car (second group). The respective values for each group are summarized in Table 1 and Table 2, respectively. There are two levels for the attribute "access time to a similar destination by bicycle" which is included in scenario designs of both groups: 10 and 20 minutes. The attribute "city center entrance price" includes three levels: 200, 300, and 500 thousand Iranian Rials (IRR). For the first group, bicycle facilities include one attribute with two levels: available bicycle lanes and none to reach the x-minute destination, and for the second group, bicycle facilities include two attributes, each with two levels: available bicycle lanes or none to reach the x-minute destination, and available bicycle parking or none in the x-minute destination. In scenarios, bicycle lane availability attribute for both groups of respondents is considered based on the extended cycling network, not the current cycling lanes. Accordingly, the number of scenarios for the first group was 12, which were designed in 3 types of questionnaires, and for the second group was 8 in 2 types of questionnaires, so for both groups, each questionnaire type had 4 scenarios. Since each group of respondents has its different parameters and factors that affect their decision-making, especially in mode choice, and also because their travel behaviour is different, we made two groups of respondents, each with different attributes in experiments, for better analysis of the factors affecting each group. Moreover, since each alternative has 2 parts (one is the mode and one is the destination), we wanted to examine how the combination of mode and destination choices in various scenarios can affect the respondent's choice.

Table 1
Attributes and their levels in scenarios for those who own or use a private car (first group).

Attribute (unit)	Levels
Access time to a similar destination by bicycle (min)	10 20
City center entrance price (per entrance from 7:00 to 17:00, (thousand IRR)	200 300 500
Bicycle lane availability	0 1

Note: 1 USD = 550,000 IRR

Table 2
Attributes and their levels in scenarios for those who do not own or use a private car (second group).

Attribute (unit)	Levels
Access time to a similar destination by bicycle (min)	10 20
Bicycle parking availability	0 1
Bicycle lane availability	0 1

For the first group, in each scenario, the respondent was presented with five alternatives each consisting of mode and destination options: (1) bicycle/x-minute destination (B-1), (2) bicycle/city center destination (B-2), (3) private car/city center destination (P-1), (4) private car/x-minute destination (P-2), (5) taxi, bus, or walk/city center destination (E-1). For the second group, the respondent was presented with four alternatives: (1) bicycle/x-minute destination (B-1), (2) bicycle/city center destination (B-2), (3) current mode/city center destination (C-1), (4) current mode/x-minute destination (C-2). With no explicit recommendation of a better one.

3.3 The data

This study used a face-to-face survey in which respondents were interviewed by the surveyors, who described four scenarios in detail to each respondent. Before the main survey, we did a pilot with 21 respondents who were city residents. The surveyors were the first author, with two other university students. We did not consider incentives for respondents, but as some transport projects were being carried out in the city, respondents had an interest in providing detailed responses. The main goal of our study was to evaluate the willingness of people with different travel behavior and socio-economic characteristics to change their travel mode to bicycle regarding their destination change from the city center to an x-minute destination. Our target population was those who came to the city center by any mode except by bicycle, even though we asked the surveyors to fill out the survey with those who came to the city center by bicycle to have their opinion on the x-minute city concept and their willingness to change their destination from the city center to an x-minute destination. Moreover, we trained the surveyors on details and punctuality in terms of finding appropriate respondents. Hence, the surveyors stopped some questionnaires because the origin of the respondents was not in Kerman city. The questionnaire was designed on the Epoll website (an Iranian website for designing questionnaires), which made the interviews faster and easier. The interviews were conducted in 7 locations in Kerman's city center. The field data were collected in 6 days from March 9 to March 24, 2024. A total of 424 samples were collected. Out of the 424 interviews conducted, 390 samples were valid and used for data analysis and modeling. Out of the 390 valid questionnaires, 212 belonged to the first group, while 178 belonged to the second group. In experiments for the first group, 74, 75, and 63 questionnaires were type-1, type-2, and type-3, respectively. In experiments for the second group, 87 questionnaires were type-1, and 91 questionnaires were type-2. The socio-economic and travel behavior characteristics of respondents are provided in Table 3 and Table 4, respectively.

Table 3
Socioeconomic characteristics of respondents.

Variable	Category	Frequency	N (%)
Gender	Male	241	61.79
	Female	149	38.20
Age	<18	23	5.89
	18-29	198	50.76
	30-49	137	35.12
	>49	32	8.20
Education level	Primary or secondary	102	26.15
	Technical	63	16.15
	Higher education	225	57.69
Job type	Employee	116	29.74
	Self-employment	140	35.89
	Student	83	21.28
	Unemployed, retired, housekeeper	51	13.07
Car ownership	0	45	11.53
	1	238	61.02
	2	94	24.37
	3	13	3.33
Bicycle ownership	0	152	38.97
	1	175	44.87
	2	54	13.84
	3	9	2.30
Household monthly income level	<150 million IRR	99	25.38
	150-200 million IRR	151	38.71
	>200 million IRR	140	35.89
Family members	1	0	0
	2	33	8.46
	3	54	13.84
	4	160	41.02
	5	115	29.48
	>5	28	7.17

Table 4
Travel behavior characteristics of respondents.

Variable	Category	Frequency	N (%)
Trip purpose	Working (commuting)	111	28.46
	Education	19	4.87
	Shopping	125	32.05
	Personal business	65	16.66
	Recreation	70	17.94
Mode choice	Private car (driver)	129	33.07
	Private car (passenger)	55	14.10
	Motorcycle	16	4.10
	Bus	80	20.51
	Taxi	43	11.02
	App taxi	30	7.69
	Bicycle	7	1.79
	Walking	31	7.94
Travel time	<10 minutes	45	11.53
	10-20 minutes	187	47.94
	20-30 minutes	132	33.84
	>30 minutes	26	6.66
Number of city center visits	Once a day	122	31.28
	Twice a day	62	15.89
	Once a week	81	20.76
	Twice a week	59	15.12
	Once a month	60	15.38
	Other (unusual visits)	6	1.53

3.4 The model

In this study, the data were modeled using a discrete choice model, which is a model for analyzing transportation demand. This model is based on random utility theory, which indicates that when individuals make a choice, they compare the available options and choose the one with the highest utility. The probability that decision maker n chooses alternative i is expressed as Eq. (1):

$$P_n(i) = Prob\ (U_{in} \geq U_{jn}) = Prob\ (V_{in} + \varepsilon_{in} \geq V_{jn} + \varepsilon_{in}), \quad \forall\ j \in C_n,\ j \neq i \tag{1}$$

Where:

U_{in}: is the utility of the decision maker n choosing an alternative i.

U_{jn}: is the utility of the decision maker n choosing an alternative other than i.

C_n: is the set of feasible alternatives for decision maker n.

The utility function can be divided into an observable V_{in} and a random unobservable error term ε_{in}. The relationship between the dependent variable and independent variables in a logit model is shown in Eq. (2)

$$U_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{2}$$

Where:

X_{in}: represents a vector of independent variables.

β_i: are the parameters of the model for each alternative i.

ε_{in}: denotes an error term explaining the effects of unobserved factors.

In this study, the individual mode and destination choice preferences were modeled using Multinomial Logit (MNL) models. In MNL, each alternative displays the independence from irrelevant alternatives (IIA) assumption, i.e., the probability ratio of choosing an alternative is only related to the observable partial utility of the alternative (Hensher et al., [27]). The attributes used in the model estimation of each group of respondents are shown in Table 5 and Table 6. We considered the current mode and destination as the base alternative in each group. The final model estimation results are shown in Table 7 and Table 8. The results show that the rho-squared (ρ^2) values of the models are 0.252 and 0.258, respectively, which means that both models fit well.

Table 5
The attributes used in the model estimation (first group).

Attributes (unit)	Definition	Min	Max	Average
Access time to a similar destination by bicycle (min)	10 mins = 1, 20 mins = 0	0	1	0.5
City center entrance price (thousand IRR)	Low = 200, medium = 300, high = 500	20	50	33.46
Bicycle lane availability	Yes = 1, No = 0	0	1	0.5
Acceptable cycling time from home to the city center (min)	5, 10, 15, or 20 (generic in B-1 and B-2)	5	20	14
Actual travel time (min)	Continuous	5	35	17
Travel purpose	Shopping and own business purposes = 1, otherwise = 0	0	1	0.5
Influencing factors-long distance	If the importance of the long distance factor is very much = 1, otherwise = 0 (Generic in B-1 and C-2)	0	1	0.73
Influencing factors-visiting various places	If the importance of visiting various places factor is very much = 1, otherwise = 0	0	1	0.56
Influencing factors-comfort of other modes	If the importance of comfort of modes factor is very much = 1, otherwise = 0	0	1	0.74
Number of bicycles in household	Continuous (generic in C-1 and C-2)	0	3	0.77
Sex	Female = 1, otherwise = 0	0	1	0.31
Age	Continuous (generic in B-1 and C-2)	18	67	33
Education	People holding a higher education degree = 1, otherwise = 0	0	1	0.66
Household monthly income (thousand IRR)	Continuous	70	350	200
Average car ownership	Number of household vehicles divided by the number of household persons	0.17	1	0.37

Table 6
The attributes used in the model estimation (second group).

Attributes (unit)	Definition	Min	Max	Average
Access time to a similar destination by bicycle (min)	10 mins = 1, 20 mins = 0	0	1	15
Bicycle lane availability	Yes = 1, no= 0	0	1	0.5
Bicycle parking availability	Yes = 1, no = 0	0	1	0.5
Acceptable cycling time from home to the city center (min)	5, 10, 15, or 20 (generic in B-1 and B-2)	5	20	11.57
Travel purpose-Shopping	Shopping travel purpose = 1, otherwise = 0	0	1	0.47
Travel purpose-commuting	Commuting travel purpose = 1, otherwise = 0	0	1	0.20
Actual travel time > 20 (min)	Yes = 1, otherwise = 0	0	1	0.48
Household monthly income (thousand IRR)	Continuous	70	350	176
Influencing factors-long distance	If the importance of the long distance factor is very much = 1, otherwise = 0	0	1	0.82
Influencing factors-visiting various places	If the importance of visiting various places factor is very much = 1, otherwise = 0	0	1	0.77
Influencing factors-comfort of modes	If the importance of comfort of modes factor is very much = 1, otherwise = 0 (generic in C-1 and C-2)	0	1	0.83
Female-Influencing factors-cultural limitations	Dummy variable: Female × Influencing factor-cultural limitations) = 1, otherwise = 0 (generic in B-1 and B-2)	0	1	0.33

4. Results and discussion

Out of 848 scenarios of the first group of respondents, in 268, 103, 249, 200, and 28 scenarios, respondents selected B-1, B-2, P-1, P-2, and E-1 alternatives, respectively. Out of 712 scenarios of the second group, in 362, 82, 160, and 108 scenarios, respondents selected B-1, B-2, C-1, and C-2 alternatives, respectively. The results of the model estimation provide insights into the factors that influence mode and destination choices in two groups of respondents. As for the first group (Table 7), in the B-1 utility function, the positive coefficient for x-10 (1.11, z-test: 6.55) indicates that when the access time to services by bicycle is 10 minutes, respondents are more likely to choose the B-1 alternative. This highlights how proximity and distance influence people's choice of using a bicycle as their main mode of transportation. The positive coefficient of bicycle lane availability (1.95, z-test: 10.54) shows the importance of infrastructure. Our results are in line with those of Benedini et al., [28] and Márquez et al., [29] in terms of the importance of cycling infrastructure in encouraging cycling. Furthermore, the positive coefficient for maximum acceptable cycling time, indicates that as respondents' acceptable cycling time increases, so does their inclination to cycle. In terms of influencing factors that reduce respondents' willingness to choose a bicycle, visiting various places factor decreased respondents' willingness to choose B-1, which indicates that the creation or development of an x-minute city should be mixed-use to encourage more individuals to change their destination. The fact that the long distance factor has a positive sign indicates that people who think that long distance is a key factor in their decision not to choose a bicycle for their trip to the city center were more inclined to choose B-1 because it requires less travel distance. Regarding socio-economic factors, respondents with higher ages are more likely to choose B-1 and P-2. This indicates people of higher ages tend to make trips with less travel distance. Moreover, those respondents with shopping and personal business travel purposes were more likely to choose B-1, which indicates that people prefer short-distance trips for these travel purposes.

Considering the B-2 utility function, bicycle lane availability (2.06, z-test: 7.89) significantly increases the likelihood of choosing this alternative; with a higher impact, it shows that safety concerns are more important in trips to the city center compared to those to the respondent's neighborhood. Conversely, actual travel time acts as a deterrent, reflecting that the higher travel time by private car in the respondent's mentioned trip to the city center, the less willingness to choose B-2. Regarding household monthly income, cycling to the city center is less attractive among wealthier individuals. Our results are in line with Timpabi et al., [16].

In the case of the P-1 utility function, as the city center entrance price increases (-0.03, z-test: -5.52), respondents are less likely to opt for their private car to travel to the city center. In terms of influencing factors, comfort levels of alternative modes compared to bicycles increase car adoption. This suggests that despite the costs, individuals who are less satisfied with the comfort of bicycles; may still opt for private vehicles. The educational attainment of individuals positively influences car adoption, suggesting that those who possess higher education degrees are more likely to choose P-1. Moreover, more bicycle ownership decreases respondents' willingness to choose P-1 and P-2 alternatives, which means those who own more bicycles, are less likely to choose P-1 and P-2 alternatives.

In the P-2 utility function, the positive influence of sex shows that women are likely to change their destination, but still choose a private car as their travel mode. The positive sign of the long-distance factor suggests that those who care about cycling distance are more likely to change their destination but still use a private car. Additionally, those who had shopping or own business travel purposes were more likely to change their destination, which indicates that people prefer short-distance trips for these travel purposes. Average car ownership strongly supports private car usage, indicating those with higher car ownership rates are less likely to change their mode associated with their destination change. This is consistent with Fu and Farber, [30].

Lastly, the positive sign of the city center entrance price in the E-1 utility function (0.03, z-test: 2.24), shows that as the price increases, the willingness to choose other modes of transportation to go to the city center increases. The constant terms of the four alternatives are significant and negative, suggesting that inherent preferences for these alternatives might be weak without other influencing factors.

Table 7
The model estimation results (first group)

Alternative (mode/destination)	Variable name	Coefficient	P-value	Z-test
Bicycle/x-minute destination (B-1)	Constant B-1	-4.50	0.000	-8.62
	Access time to a similar destination by bicycle	1.11	0.000	6.55
	Bicycle lane availability	1.95	0.000	10.54
	Acceptable cycling time from home to the city center	0.09	0.000	6.73
	Age	0.02	0.002	3.06
	Influencing factors-visiting different places	-0.59	0.000	-3.53
	Influencing factors-long distance	0.39	0.050	1.96
	Travel purpose-shopping and personal business	0.38	0.029	2.17
Bicycle/city center destination (B-2)	Constant B-2	-2.53	0.000	-4.27
	Bicycle lane availability	2.06	0.000	7.89
	Acceptable cycling time from home to the city center	0.09	0.000	6.73
	Actual travel time	-0.03	0.009	-2.61
Private car/city center destination (P-1) (Base)	Household income	-0.04	0.008	-2.65
	City center entrance price	-0.03	0.000	-5.52
	Influencing factors-comfort of modes	0.68	0.001	3.28
	Number of bicycles in household	-0.28	0.009	-2.60
	Having a higher education degree	0.38	0.028	2.19
Private car/x-minute destination (P-2)	Constant P-2	-3.17	0.000	-6.35
	Sex	0.47	0.010	2.56
	Influencing factors-long distance	0.52	0.016	2.41
	Age	0.02	0.002	3.06
	Number of bicycles in household	-0.28	0.009	-2.58
	Travel purpose-shopping and own business	0.51	0.006	2.72
	Average car ownership	2.29	0.000	4.26
Taxi, bus, or walk/city center destination (E-1)	Constant E-1	-4.35	0.000	-5.80
	City center entrance price	0.03	0.025	2.24
	Model results			
	Number of observations	848		
	LL(0)	-1364		
	LL(β)	-1020		
	ρ^2	0.252		
	DF	23		
	AIC	2087		

Turning to the second group (Table 8), in the B-1 utility function, similar to the first group, the positive effect of x-10 (0.82, z-test: 4.36) shows that the availability of a comparable destination within 10 minutes of cycling from respondents' homes increases their willingness to choose B-1. The coefficients for bicycle lane availability (1.45, z-test: 7.57) and bicycle parking availability (0.69, z-test: 3.75) suggest that the availability of these facilities can enhance the appeal of cycling. The impact of bicycle lane availability is double that of bicycle parking. The negative coefficient for female-cultural limitations indicates that gender plays an important role in deterring cycling, with women being less likely to choose B-1 and B-2 alternatives influenced by cultural or social limitations. The positive coefficient for the maximum acceptable cycling time from home to the city center suggests that the higher the acceptable cycling time from home to the city center, the more likely respondents are willing to cycle.

The utility function for B-2 reveals similar influences. Infrastructure remains important, particularly in terms of the availability of bicycle lanes (2.73, z-test: 8.12) and bicycle parking facilities (1.26, z-test: 4.37), highlighting the significance of cycling infrastructure in travel to the city center. This is consistent with Gutiérrez et al., [30]. Regarding household income, cycling is less attractive among wealthier individuals. As the respondents' household income increased, they were less likely to choose B-2.

In the C-1 utility function, the negative sign of the x-10 (-0.48, z-test: -2.10) implies that access to a similar destination within 10 minutes of cycling decreases their willingness to choose C-3. The positive coefficient for travel purpose-commuting, suggests that those with commuting travel purposes are more inclined to choose their current mode and destination. The positive coefficient for the comfort of modes factor indicates that for those whose comfort levels of modes compared to bicycle were important, the willingness to choose C-1 and C-2 was high.

Considering the C-2 utility function, the positive sign of the long distance factor suggests that if the long distance was a significant factor in discouraging respondents from adopting bicycles for their trip, they were more inclined to alter their destination without changing their mode of transportation. Furthermore, the positive coefficient for actual travel time > 20 minutes implies that longer travel times may still favor current modes, but may lead to a change in destination due to shorter travel times. Moreover, the positive coefficient for travel purpose-shopping, suggests that those with shopping travel purposes are more likely to choose C-2, which indicates that people prefer short-distance trips for this travel purpose. As with the first group, the constant terms for all four alternatives are significant and negative, suggesting that inherent preferences for these alternatives may be weak without other influencing factors.

In summary, creating an x-minute city associated with infrastructure investments, particularly creating and expanding bicycle lanes, could increase bicycle adoption. Moreover, model estimation results confirm the important role of infrastructure in promoting bicycle use, in particular the availability of bicycle lanes. This finding highlights the importance of infrastructure and accessibility factors that may need to be addressed to promote cycling. This study has two limitations. First, the reliance on stated-preference surveys may overestimate demand for bicycle usage in an x-minute city. Second, our data covered only those whose destination was the city center. Future studies can be done by analyzing the travel behavior of people in an x-minute city, regardless of their destination.

Table 8
The model estimation results (second group).

Alternative (mode/destination)	Variable name	Coefficient	P-value	Z-test
Bicycle/x-minute destination (B-1)	Constant B-1	-1.28	0.001	3.26
	Bicycle lane availability	1.45	0.000	7.57
	Access time to a similar destination by bicycle	0.82	0.000	4.36
	Bicycle parking availability	0.69	0.000	3.75
	Acceptable cycling time from home to the city center	0.08	0.000	6.32
	Actual travel time	0.02	0.018	2.35
	Female-influencing factor-cultural limitations	-0.81	0.000	-4.23
Bicycle/city center destination (B-2)	Constant B-2	-2.24	0.000	-4.02
	Bicycle lane availability	2.73	0.000	8.12
	Bicycle parking availability	1.26	0.000	4.37
	Acceptable cycling time from home to the city center	0.08	0.000	6.32
	Female-influencing factor-cultural limitations	-0.81	0.000	-4.23
Current mode/city center destination (C-1) (Base)	Household income	-0.04	0.022	-2.29
	Access time to a similar destination by bicycle	-0.48	0.035	-2.10
	Influencing factors-comfort of modes	0.61	0.020	2.31
	Travel purpose-commuting	0.51	0.030	2.17
Current mode/x-minute destination (C-2)	Constant C-2	-1.64	0.001	-3.91
	Influencing factors-long distance	0.80	0.041	2.04
	Influencing factors-comfort of modes	0.61	0.020	2.31
	Actual travel time > 20	0.51	0.030	2.17
	Travel purpose-shopping	0.38	0.090	1.69
	Model results			
	Number of observations	712		
	LL(0)	-987		
	LL(β)	-732		
	ρ^2	0.258		
	DF	18		
	AIC	1501		

4.1 The impact of the city center entrance price on the share of alternatives

After fitting the model of the first group of respondents (those who own or use a private car), we calculated the utilities and probabilities of alternatives. The charts show the impact of the city center entrance price, ranging from 100 to 700 thousand IRR, on the share of alternatives in different scenarios when access time to services by bicycle is 10 or 20 minutes, and whether there are dedicated bicycle lanes or not to show the impact of city center entrance price, bicycle lane availability, and availability of services within 10 or 20 minutes of cycling from home. When access time to services by bicycle is 10 minutes, and there are dedicated bicycle lanes (Fig. 2), the share of

B-1 is higher than all other alternatives. It gradually increases as the price rises from 0.45 in 100 thousand IRR to 0.60 in 700 thousand IRR. This trend indicates a shift toward B-1 as the price rises. B-2 follows a similar trend to B-1, with the share gradually increasing as the price increases, though at a slower rate. The share for P-1 shows a significant decline as the price increases, suggesting that higher costs make it a less attractive alternative. Unlike P-1, P-2 sees an increase in share as price rises but at a slower rate than B-1 and B-2.

When access time to services by bicycle is 20 minutes, and there are dedicated bicycle lanes (Fig. 3), the share of B-1 increases moderately as the price increases, though not as sharply as when access time was 10 minutes. B-2 share also increases with rising prices, but at a slower rate than B-1. Additionally, the share for P-1 shows a significant decline as prices increase. In this scenario, the B-1 share is more than P-2.

When access time to services by bicycle is 10 minutes, and there are no dedicated bicycle lanes (Fig. 4), the share of B-1 and P-2 increases with the price increase, but the share of P-2 is higher than B-1. Similar to previous charts, there is a significant reduction in P-1 share as the prices rise.

Finally, when access time to services by bicycle is 20 minutes, and there are no dedicated bicycle lanes (Fig. 5), P-1 shows a steady decline in share with higher prices, similar to previous charts. On the contrary, the share of P-2 increases sharply, and the share of B-1, B-2, and E-1 shows a slight increase as the price increases.

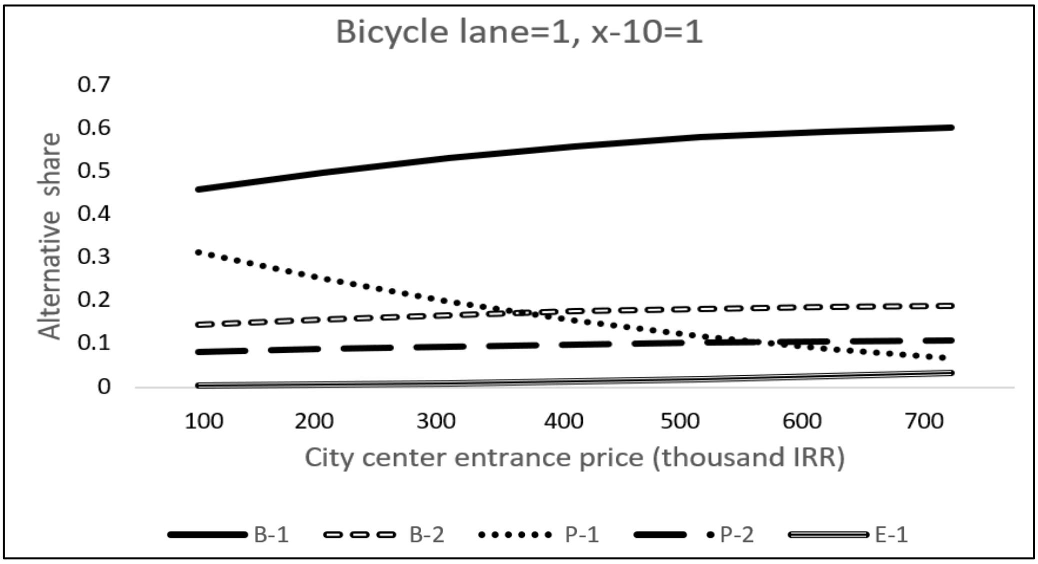

Fig. 2. The probabilities of choosing each alternative when bicycle lane=1 and x-10=1

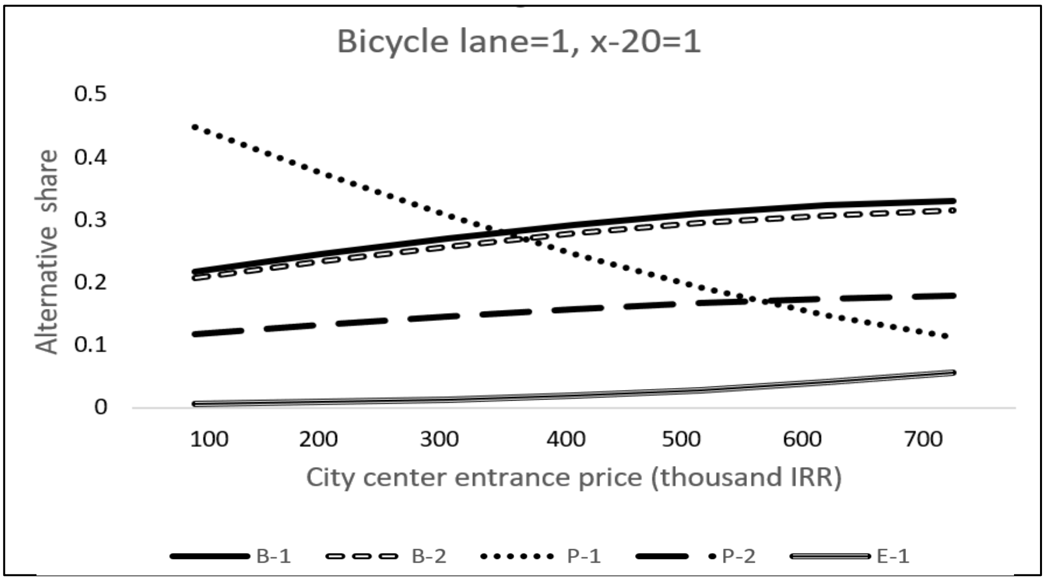

Fig. 3. The probabilities of choosing each alternative when bicycle lane=1 and x-20=1

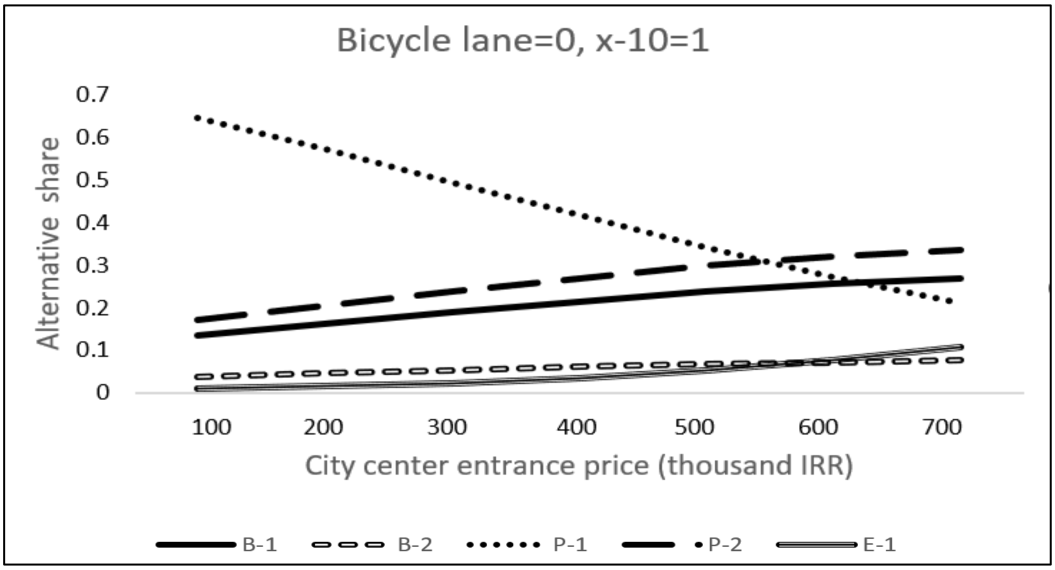

Fig. 4. The probabilities of choosing each alternative when bicycle lane = 0 and x-10 = 1

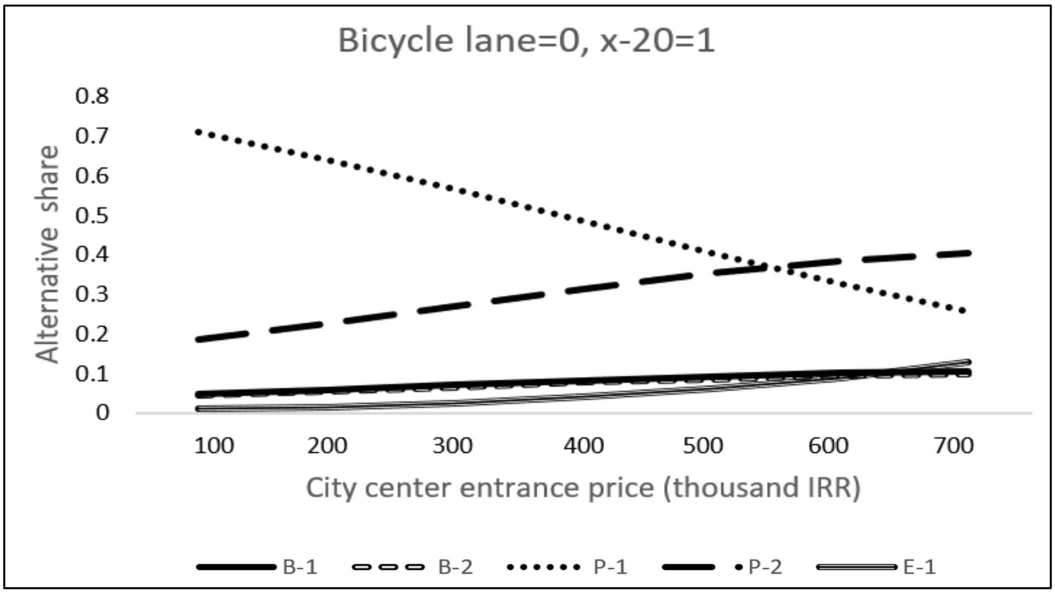

Fig. 5. The probabilities of choosing each alternative when bicycle lane=0 and x-20=1

In all 4 scenarios, the share of E-1 increases slightly as the city center entrance price increases. Overall, when there are no dedicated bicycle lanes, the share of B-2 is low even at high prices, which shows the importance of bicycle lane availability in trips to the city center by bicycle. When there are no bicycle lanes, the preference of choosing a private car over a bicycle to reach services within the neighborhood is high. These trends support the impact of congestion pricing on reducing private car use in favor of more sustainable and low-cost alternatives like bicycles and destination changes.

5. Policy implications

The findings of this study suggest that implementing the x-minute city concept in urban areas can encourage people to use bicycles to reach their destinations, especially when there are bicycle lanes and access time to various services is within 10 minutes of cycling from people's place of residence. Moreover, implementing policies such as congestion pricing can motivate those who use private cars to change their travel mode associated with their destination choice. Municipalities and urban planners can consider accessibility to various services and land use planning based on the x-minute city concept when making policies to encourage people to shift from other modes of transportation to cycling. This can be done by increasing mixed-use development throughout the city, especially around residential centers, which can encourage people to choose short trips by bicycle to reach services in their neighborhood over long-distance trips by private car to the city center. Nevertheless, to achieve the best results, it is important to invest in cycling infrastructure and mixed-use development simultaneously.

6. Conclusions

Encouraging people to use bicycles to reach their destinations can reduce car dependency and traffic congestion and promote an active lifestyle. The x-minute city concept aims to encourage people to use active modes of transportation by offering various services within their neighborhoods. In this study, we aimed to investigate the impact of this concept on people's willingness to change their mode of travel to bicycle, as associated with their destination choice. We designed two SP experiments and developed two MNL models for those who own and use private cars and those who do not. The results of this study show that access to a destination similar to respondents' destinations in the city center, within 10 minutes of cycling from their homes, can encourage them to use a bicycle to access that destination. Even though this can be increased by the availability of cycling infrastructure such as bicycle lanes and parking, and more specifically for those using private cars, policy interventions such as congestion pricing can encourage people to change their mode to bicycle, associated with their destination change. We found that the availability of separated bicycle lanes is the most important variable for people to choose bicycles as their main travel mode.

This study focused on the impact of the x-minute city concept, availability of cycling infrastructure, and congestion pricing variables on people's preferences to change their mode to bicycle associated with their destination choice, but investigating the influence of the x-minute concept on people's willingness to choose walking can be considered in future studies. Furthermore, studying the influence of other variables, such as bike-sharing programs associated with the x-minute city concept, can also be taken into account in the future.

Annex 1

How much does each of the following factors reduce your willingness to use a bicycle as your travel mode in your mentioned trip to the city center:

1. Not owning a bicycle
2. Safety concerns
3. Long distance from destination (city center)
4. The comfort of other modes (compared to bicycles)
5. Going to the destination with another person
6. Visiting various places on the way to the city center or back home
7. Cultural/social limitations
8. Bicycle theft concerns
9. Lack of experience or ability to ride a bicycle
10. The weather conditions.

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Data Availability Statement
The data used in this paper are available upon request by emailing the corresponding author.

Conflicts of 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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