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Public preferences towards bicycle sharing system in developing countries: The case of Mashhad, Iran

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ABSTRACT

Bicycle Sharing System (BSS) has been introduced as an alternative mode of urban transportation which can mitigate the consequences of excessive motor vehicle usage and contribute to sustainable urban development. Adoption of BSS within transport networks relies on their key attributes such as safety, accessibility, cost and convenience to meet the public needs. Yet, the required infrastructure is often developed without much explicit knowledge about the public preferences. The consequence of this lack of knowledge is more acute in developing countries where there are economic and cultural constraints in adopting new modes of urban transportation.

This study aims to provide more insight on the key attributes that are considered by the public in selecting BSS as the primary mode of urban transportation against the other alternatives in a developing country. First, a thorough literature review is conducted to find common BSS attributes that have been investigated within developed countries in North America, Europe, Asia and Australia. An empirical list of BSS attributes is then explored for the current bicycle sharing system in the city of Mashhad, the second most populated city in the developing country of Iran, based on frequent costumers' judgment and experts' opinion. A Stated Choice Experiment (SCE) survey is then designed and public preference data are collected from a sample of 90 randomly selected residents in Mashhad. Multinomial logit (MNL), mixed multinomial logit (MMNL) and latent class multinomial logit (LCMNL) models are used to investigate factors contributing to selection of BSS against other transport modes.

We found that the MMNL model outperformed the other models in terms of statistical fit. More importantly, we found that bicycle fare, separated bicycle lane, bicycle quality, pavement quality, proximity of bicycle stations to bus stops, bicycle training programs, gender and employment status of respondents significantly influence public preferences towards BSS in Mashhad. People are willing to pay substantially more than the current bicycle fare to have safety, accessibility and convenience. The impact of gender and employment status on the public preferences is not homogeneous across individuals. Overall, the findings of the study have important implications to cost-benefit analysis of bicycle sharing system development plans in Mashhad.

1. Background

Over the past decades, motorized vehicles have been used as the primary mode of transportation to fulfil the increasing demand for urban development, especially in developing countries (Pucher, Peng, Mittal, Zhu, & Korattyswaroopam, 2007; Schwarzlose et al., 2014). However, excessive use of motor vehicles has led to negative environmental impacts such as greenhouse gas emissions and exploitation of natural resources. Minimizing these environmental impacts is paramount in maintaining sustainable transportation infrastructure which itself is a pivotal element in sustainable urban development and smart urban planning (Motieyan & Mesgari, 2017; Rahman & Van Grol, 2005). There is, thus, growing interest in promoting green and energy efficient modes of transportation (Goldman & Gorham, 2006; Jones, Cherry, Vu, & Nguyen, 2013) which can replace motor vehicles particularly in urban areas. Bicycle Sharing System (BSS) has been recently introduced as one of these environmental friendly modes which is referred to a shared cycling facility in which bicycles are provided at self-service stations to enable short term trips from one docking station to another (Fishman, Washington, & Haworth, 2013).

BSS provides numerous advantages over motorized vehicles: it is reliable and sustainable (Faghih Imani, Anowar, Miller, & Eluru, 2017);

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it promotes cycling culture and contributes to public health (Faghih Imani et al., 2017); it improves physical activity (Shaheen, Guzman, & Zhang, 2010); it reduces greenhouse gas emissions; it does not require technical and operational expertise; and it has low financial risk (Paul & Bogenberger, 2014). In spite of these substantial benefits associated with bicycle sharing systems, research findings are not still conclusive whether BSS can alter the public preferences of transportation mode from motor vehicles to bicycles (Faghih Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014; Fishman et al., 2013). On the one hand, some countries have been successful in introducing BSS into their urban transportation networks. For instance, Japan has developed "Ekirin-kun", the intermodal railway-station-bicycle system and has successfully expanded it due to its effective integration with railway. The system has been widely used for daily commute to work and shopping centers (Tomita & Nakayama, 2017). Another example of successful BSS is the public bicycle system in Bogota, Columbia. The strong integrated link between bicycle lanes and Bus Rapid Transit (BRT) in Bogota has resulted in high bicycle usage rate as well as bus ridership (Duarte & Rojas, 2012). The majority of the current BSS users in Hangzhou, China – a globally renowned city for adopting BSS within its urban transport network – used public transport before introducing BSS (Fishman, Washington, & Haworth, 2015).

On the other hand, research has shown that sometimes high BSS usage rate is an artefact of the public tendency towards public transport (Tang, Pan, & Shen, 2011). Shaheen et al. (2010) concluded that car ownership in Beijing, China increased the chances of using BSS showing the dependency of these systems on the public demographics and culture. While there are other BSS examples from developed countries where the transfer rate from motor vehicles to bicycles is low (Consulting, 2011; London, 2010; Murphy, 2010), it seems that the rate in developing contries may be even lower because of the economic and cultural constraints. As a result, it may be more efficient to obtain further knowledge about the key factors affecting public preferences towards bicycle sharing systems prior to their adoption as an *"active"* mode of transportation. Such knowledge may include (but not limited to) *safety*, *accessibility* and *cost*.

Safety has been a long-lasting concern for cyclists in urban transport networks (Karsch, Hedlund, Tison, Leaf, & Group, 2012; Lee, Simons-Morton, Klauer, Ouimet, & Dingus, 2011; Mokhtari, 2011), and as a result, numerous studies have focused on potential factors contributing to perceived risk in cycling context. Studies show that proximity of bicycle lanes to intersections, presence of pedestrians (Ahmadi & Karimi, 2017), low visibility (Madsen, Andersen, & Lahrmann, 2013; Ahmadi & Karimi, 2017), high volume of motor vehicles (Allen-Munley, Daniel, & Dhar, 2004; Klop & Khattak, 1999; Turner, Francis, Roozenburg, & Transport, 2006), presence of heavy vehicles (Nabizadeh, Tafazoli, & Naraghi, 2011), high speed limit (Allen-Munley et al., 2004), lack of traffic calming facilities such as chicanes, speed humps, speed camera and traffic diverters (Minikel, 2012) are among important factors contributing to bicycle safety. Lack of safety significantly discourages the public from using bicycles (Faghih-Imani, Anowar, Miller, & Eluru, 2017) especially if the cycling infrastructure is shared with motorized vehicles –which is commonly referred to as *"shared bicycle lane"*. This lack of safety may be even more acute in developing countries where aggressive driving and lack of enforcement result in high number of fatalities (Odero, Garner, & Zwi, 1997). Alternatively, a cycling facility which is separated from vehicular traffic –commonly referred to as "*separated bicycle path"* may enhance cyclists' safety although with higher initial cost.

Accessibility may be another key factor considered by the public to select bicycle sharing systems. BSS is a shared transport facility in which the users are required to return bicycles to the stations at certain intervals (e.g. every 30 min). This property may prevent users from selecting BSS if there are not enough bicycle stations evenly distributed across urban areas (spatial accessibility). Even if there are enough stations within the network, lack of available bicycles during the day (temporal accessibility) may significantly affect the public preference towards BSS.

The cost of renting a bicycle in a BSS may be another concern affecting public preferences towards BSS. Although the BSS fare may have minimal effect on the public preferences towards bicycle usage in high income countries, it may substantially prevent users to become attracted to bicycles in low income countries. Finally, the tendency to change the primary mode of daily transportation from motorized vehicles –which are fast and convenient, to bicycles may require cultural incentives which in and of itself may be considered a challenge in developing countries.

Despite the above-mentioned challenges in adopting bicycle sharing systems, limited research has been dedicated to understand how people evaluate BSS based on its key attributes and so the impact of these attributes on the public preferences is less known. Measuring the magnitude of such impact is a challenging task because sometimes not only a single factor, but the interactions of several factors build up the overall quality of the BSS infrastructure. In addition, there is a possibility of unobserved heterogeneity in public preferences towards BSS. There may be unobserved differences (e.g. different cultural backgrounds, different psychological characteristics, etc.) across different members of the public leading to their varied attitudes and decision making processes. For example, females who have religious background, or have been raised in a religious family may be hesitant towards cycling in general. As such, female preferences towards BSS may be heterogeneous in the society and thus a reliable BSS assessment framework should take this heterogeneity into consideration.

In sharp contrast to the earlier studies in which the impact of BSS attributes on its usage rate have been investigated from the transport network perspective in developed countries, this study aims to provide more insight on the key factors that are considered by the public in a developing country when they want to select BSS as their primary mode of urban transportation. More specifically, we examine the public sensitivity towards BSS attributes in the developing country of Iran and conduct a comparative analysis of potential benefits achieved by improving each attribute. In addition, we take into account the interactions of BSS attributes as well as unobserved heterogeneity in the socio-demographic characteristics of the public. To achieve these goals, an empirical list of BSS attributes is explored for a bicycle sharing system in the city of Mashhad, the second most populated city in Iran, based on frequent costumers' judgment and experts' opinion in a focus group. A stated choice experiment (SCE) survey is then designed and the public preference data are collected from a sample of 90 randomly selected residents in Mashhad. Multinomial logit (MNL), mixed multinomial logit (MMNL) and latent class multinomial logit (LCMNL) models are used to investigate the impact of every factor on the public preferences towards selecting BSS as the primary mode of transportation.

The rest of this paper is structured as follows: Section 2 provides general statistics about the study area and presents the context of the study. The stated choice experiment methodology is presented in Section 3. Survey data and selected BSS attributes are presented in Section 4. Model specifications for the employed choice models are presented in Section 5. The results of the superior choice model are presented in Section 6 followed by a detail discussion about the findings. The implications of the research findings are presented in Section 7 and conclusions and future directions are presented in Section 8.

2. Study context

Iran is a developing country with the population of about 81 million people and unemployment rate of 11.7% (Iran SCO, 2016). The Gross Domestic Income (GDP) is $19,050 per capita and the minimum wage is $2.00 per hour (Iran, C O T I R O, 2016). Mashhad is the second largest city in Iran with the population of about 2.7 million people and sex ratio of about 101 males per 100 females. Mashhad's population is young –mostly aged between 15 and 55 years old (Iran SCO, 2016).

Similar to any other big city in the world, Mashhad also suffers from the consequences of excessive motor vehicle usage. According to the Center of Environmental Pollutants in Mashhad, the Air Quality Index (AQI) has been within "*unhealthy*" and "*absolute unhealthy*" thresholds during 90 and 20 days in 2015, respectively. Not surprisingly, fuel consumption for transportation purposes has reached the highest level in 2015 during the same period. The average monthly fuel consumption for motor vehicles has been 27.6 liters per capita during the polluted days while the annual average monthly fuel consumption has been 25.4 liters per capita ("Monthly monitoring of transportation & traffic indices in Mashhad, 2015). According to a study conducted on the causes of air pollution in Mashhad (Miri et al., 2016), the excessive use of motor vehicles as the primary mode of transportation within the city's transportation system has been largely responsible for air pollution. Air pollution in Mashhad has become even worse in recent years because the city hosts tourists and immigrants from all over the world every year causing dramatic increase in the population and even more severe air pollution. The excessive use of fossil fuels and motorized vehicles has alarmed city authorities to search for an alternative urban transportation system within the city of Mashhad.

Mashhad city council has recently developed a bicycle sharing system within the city's transportation network. The current bicycle sharing system in Mashhad has been adopted from its counterpart in Isfahan, another large metropolitan city in Iran. It currently covers more than 60% of Mashhad's transport network. The implemented infrastructure consists of 120 km of shared bicycle facility connecting 113 bicycle stations. The spatial coordinates of the BSS stations have been collected from Mashhad city council and Mashhad department of traffic control and transportation. The density of BSS stations across the city is illustrated in Fig. 1.

Empirical studies conducted on bicycle sharing systems in Iran indicate that less than 50% of the system's total capacity is currently used (Nabizadeh et al., 2011; Soltani & Shariati, 2014) showing the inefficiency of these systems in the current situation. According to the past studies, the major barriers limiting bicycle usage from the public perspective in Iran are the slope of bicycle lane (more than 3%) (Nabizadeh et al., 2011; Soltani & Shariati, 2014), land use and lack of connectivity between bicycle paths (Nabizadeh et al., 2011; Rezaei, Mohammadzadeh, & Omrani-Pour, 2016; Soltani & Shariati, 2014), presence of intersections with motorized vehicles (Moghadam, Minai, & Naderi, 2016; Nabizadeh et al., 2011; Rezaei et al., 2016; Soltani & Shariati, 2014), lack of protective equipment such as bicycle locks and safe parking spots (Safar & Azimzadeh, 2017; Toorzani & Habibian, 2016) and long distance between BSS stations and residential neighbourhoods (Moghadam et al., 2016; Mokhtari, 2011). On the contrary, proximity of BSS stations to each other (Soltani & Shariati, 2014), sufficient light during the night (Rezaei et al., 2016; Soltani & Shariati, 2014), landscape surrounding the cycling facility (Rezaei et al., 2016; Soltani & Shariati, 2014) and ease of access to shopping centres and tourism attractions can significantly increase bicycle usage and promote BSS as an alternative mode of daily transport in Iran.

3. Method

To evaluate the public preferences towards BSS in Mashhad, Stated Choice Experiment (SCE) is employed which has widely been used to assess people's choice and preferences towards developing new goods and services (Hensher, Rose, & Greene, 2005). In doing so, survey questionnaires are designed and distributed among a sample of targeted population. Hypothetical scenarios are then presented to respondents and their choice (preference) towards the system is asked. These scenarios contain several combinations of system attributes as well as respondents' personal attributes. The SCE provides many potential advantages compared to other evaluation methods including (Hensher et al., 2005):

- It measures economic benefits (monetary values) resulted from change in a single or multiple attributes.
- It measures social welfare obtained from changing levels of a single attribute in a system.
- It has minimal endogeneity problem; the system attributes presented to the respondents in survey are not related to the current market or environment and therefore, they are exogenous and not collinear.
- It has high level of statistical efficiency and thus it can be applied to small samples.

Stated choice experiments can be designed as labeled or unlabeled alternative surveys. Labeled alternative surveys are used when the

Fig. 1. Bicycle sharing system's density in the city of Mashhad.
Source: Mashhad Comprehensive Public Bicycle Portal (2017)

alternatives –to be selected by the respondents– are distinguishable from each other and the aim of the study is to determine the market share or the probability of selecting each alternative by estimating utility functions for each specific alternative. For instance, car and bicycle are two alternative modes of transportation which are distinctly selected by individuals with distinct probabilities. Unlabeled alternatives, on the other hand, are used when the alternatives are identical in nature and the aim of study is to evaluate the impact of system attributes (contributing factors) on selecting one single alternative by estimating one utility function for that alternative. The objective of this study is to estimate the public preferences towards the utility (attributes) of BSS irrespective of other alternatives. Thus, an unlabeled experimental design was chosen in this study. In an unlabeled design, the total number of possible alternatives is calculated as (Huber & Zwerina, 1996):

$$\text{Total number of possible alternatives} = L^{a1} \times L^{a2} \quad (1)$$

where L is the number of attribute levels and a is the number of attributes. This equation will result in large number of alternatives in an experiment with multiple attributes each with several levels. Such a large number of choice sets is obviously difficult for respondents to answer. It may also influence the reliability of responses in the survey (Hensher et al., 2005). On the other hand, reducing the number of choice sets will result in the reduction of estimators' efficiency –that is unbiasedness of estimators with minimum variances. To reduce the number of choice sets at the highest level of efficiency, a combination of two common methods in designing choice experiments were used including *factorial design* and *blocking design* (Huber & Zwerina, 1996). Additionally, cyclical design was used to hold the assumptions of orthogonally, minimal overlap and level balance to achieve the highest level of efficiency (Hensher et al., 2005; Huber & Zwerina, 1996). The orthogonality assumption ensures the lack of correlation between attributes so that the influence of each variable on outcomes can be independently estimated. The minimal overlap assumption minimizes the repetition of the same level of an attribute across alternatives in a choice set. Finally, the assumption of level balance ensures that none of the alternatives is naturally preferred to others (Hensher et al., 2005).

4. Data

The stated preference data used in this study consists of the contributing factors to the public preferences towards BSS within two categories: BSS attributes and respondents' attributes. These attributes are first defined based on a systematic search through the literature as well as interviews with experts and frequent BSS users in a focus group. Attribute levels are then defined and SCE surveys are designed accordingly. The details of data collection process are presented in the following sections.

4.1. Attributes and attribute levels

In the preliminary phase of data collection, a comprehensive review was conducted on the existing studies about bicycle sharing systems around the world with especial focus on important attributes influencing BSS mode share. A summary of the reviewed studies is presented in Table 1. Our review found that *number of bicycles*, *number of bicycle lanes*, *number of bicycle stations* and *cost* were significant common attributes that have been considered in the empirical studies.

In the complementary phase of data collection, interviews were conducted with transportation experts from Mashhad city council as well as frequent customers of the current bicycle-sharing system. Respondents were asked about their perception of a convenient bicycle sharing system and any further recommendations to improve the current BSS. The interviews were analyzed using an open coding technique (Miles, Huberman, & Saldana, 2014) in searching for the answer to the question *"which attributes are able to improve the demand for the bicycle sharing system"*. The extracted responses were compared to the BSS attributes collected from the literature review. Interestingly, the two sets of attributes were similar in about 95% of all cases, representing contributing BSS attributes in four main categories: safety, accessibility and economic factors. The findings were discussed in a focus group meeting –consisting of 5 experts– through which the attributes and their associated levels were ultimately concluded:

- The type of cycling facility representing safety factor contributing to the public preference towards BSS. This variable has two levels: 1) shared bicycle lane, and 2) separated bicycle lane.
- The implementation of bicycle training programs representing the safety factor contributing to the public preference towards BSS. This variable has two levels: 1) no training programs, and 2) implementation of training programs.
- The distribution of bicycle stations representing spatial accessibility of the BSS over the study area. This variable has three levels 1) every 5 km, 2) proximity to parking lot, and 3) proximity to bus stop.
- The bicycle fare representing economic factor contributing to the public preference towards BSS. The current fare is free for the first hour of usage, and 2000 Iranian Rials for every hour of excess usage[1]. To determine the fare levels, we conducted a pilot study based on which we defined 10,000 Rials as the highest fare level, 5000 Rials as the medium fare level and 2000 Rials as the current fare level.
- The bicycle quality and the pavement quality (i.e. the quality of pavement along cycling facility), representing convenience of the BSS. The former variable has two levels: 1) fair, and 2) excellent and the latter variable has also two levels: 1) uneven pavement, and 2) even pavement.

The details of the selected BSS attributes are described in Table 2.

4.2. Survey design

Using SAS software, twelve choice sets in three blocks each of which contains four choice sets with three alternative profiles was generated. The *D-efficiency* of the design was 98.53 indicating that the choice sets were optimally balanced, orthogonal and efficient. In every choice set, the two first profiles corresponded to scenarios providing some improvements in the bicycle sharing system. The last alternative profile was referred to the conventional scenario indicating "no-improvement". Herein, this is referred to the *"status quo"* alternative or *"neither improvement scenario"* indicating the system attributes at their current level.

Furthermore, to investigate the impact of socio-demographic attributes and their interactions with other attributes on the public preferences, additional questions were added to the choice cards. Respondents' awareness of the bicycle sharing system, whether they use the system and if so, their purposes of using the system were among other questions added to the questionnaire. In order to test the appropriateness of the attributes' explanations, preliminary interviews were conducted at two bicycle stationeries and modifications were applied based on respondents' recommendations.

The SCE survey was carried out at five different bicycle stations during June and July of the year 2014. Respondents were selected randomly from the vicinity of the selected bicycle stations. The interviewers did not leave the respondents while completing the choice sets and elaborated on cards in case of any ambiguities. In the end, 92 questionnaires were completed from which two questionnaires were excluded from the study because the respondents accomplished less

[1] This fare is equal to USD $0.06 –which is equivalent to 3% of the minimum hourly wage in Iran.

Table 1
Common Bicycle Sharing System Attributes Used in the Literature.

Author (s)	Year	Study Region	Attributes considered in the study	Reference
De Chardon, C.M., Caruso, G. and Thomas, I.	2017	Austria, Belgium, France, Italy, Ireland, Lithuania, Luxembourg, Norway, Slovenia, Spain, Sweden, UK Israel, U.S.A., Canada, Brazil, Australia	Station density, Transportation infrastructure (cycling infrastructure density, bus stop density, railway, subway and tram stop density),BSS attributes(name/number of operator, open hours/days, cost, number of docks per station, ratio of bicycles to station, ratio of docks to bikes), Helmets requirement law for cyclists, Weather(temperature, wind, precipitation, humidity)	(De Chardon et al., 2017)
Zhao, P. and Li, S.	2017	Beijing, China	Number of bicycle lanes, types of bicycle trails, lanes and paths, bicycle parking and provision of transit services, cost of BSS and other alternative transport modes, density of green spaces, convenience stores and restaurants	(Zhao & Li, 2017)
Faghih-Imani, A. and Eluru, N.	2016	Montreal, Canada	Number of BSS stations, BSS capacity, Transportation network infrastructure, land use, Temporal characteristics (time of day, day of week and month)	(Faghih Imani & Eluru, 2016a)
Faghih-Imani, A. and Eluru, N.	2016	New York, U.S.A.	Number of BSS stations, Station capacity, Length of bicycle facilities, Land use (population and job density), Point of interests (presence of subway stations, restaurants, businesses and universities)	(Faghih Imani & Eluru, 2016b)
Karki, T. K. and Tao, L.	2016	Suzhou city, China	Ease of renting, ease of returning, slots' availability, Quality of bike, E-card tapping system	(Kumar Karki & Tao, 2016)
Mateo-Babiano, I., Bean, R., Corcoran, J. and Pojani, D.	2016	Brisbane, Australia	Length of bikeway, Bikeway type (shared pathway, bicycle lane, bicycle awareness zone, bicycle path, bicycle road, connect, informal off road, informal on road and separated pathway)	(Mateo-Babiano, Bean, Corcoran, & Pojani, 2016)
Faghih-Imani, A. And Eluru, N.	2015	Chicago, USA	Travel distance, land use, environment, access to public transportation and infrastructure	(Faghih Imani & Eluru, 2015)
Faghih-Imani, A., Eluru, N., El-Geneidy, A.M., Rabbat, M. and Haq, U.,	2014	Montreal, Canada	Bicycle infrastructure, length of bicycle lanes and bicycle paths, capacity of bicycle station, distance between the station and central business district, walk score, presence of metro and bus station near to the bicycle station, number of restaurants, number of commercial enterprises, presence of university near to the bicycle station	(Faghih Imani et al., 2014)
Paul, F. and Borgenberger, K.	2014	Munich, Germany	Fleet size, number and spatial distribution of docking stations, pricing system, user registration possibilities	(Paul & Bogenberger, 2014)
Büttner, J., and Peterson, T.	2011	Austria, Belgium, Czech Republic, France, Germany, Italy, Poland, Spain, Sweden, United Kingdom	Physical design (hardware, technology and service design), Institutional design (type of operator, contracts and ownership, financing sources and employment opportunities)	(Bütner et al., 2011)

Table 2
Bicycle Sharing System Attributes and Attribute Levels Used in the Stated Choice Experiment.

Category	Attribute	Level 1	Level 2	Level 3
Safety	Bicycle Lane	Shared Bicycle Lane	Separated Bicycle Lane	
	Bicycle Training Programs	No	Yes	
Accessibility	Bicycle Stations	Every 5 kilometers	Proximity to Parking	Proximity to Bus Stop
Cost	Bicycle Fare (IR-Rial)	2000[1]	5000	10,000
Convenience	Bicycle Quality	Fair	Excellent	
	Pavement Quality	Uneven Pavement	Even Pavement	

Table 3
Socio-demographic and Economic Attributes of the Respondents.

Dummy Variable	Sample frequency	Sample share (%)
Age		
Younger than 25	43	48
Older than 25	47	52
Gender		
Female	33	37
Male	57	63
Employment Status		
Employed	46	51
Unemployed	44	49
Student Status		
Student	36	40
Non-student	54	60
Level of Education		
University graduate	11	12
Non-university graduate	79	88
Trip Purpose		
Recreational, work and\or shopping	17	19
Only recreational	40	44
Others	33	37

than half of the questionnaires. Every questionnaire included four choice sets each with three alternatives resulting in 12 records by every questionnaire leading to the total sample size of 1080 observations for this study. A detailed summary of the socio-demographic attributes of the respondents is presented in the Table 3.

5. Model specification

Discrete choice models are widely used in the literature as the modelling approach to estimate the effects of causal factors (e.g. BSS attributes) on individuals' choice (i.e. choosing BSS) (Huber & Zwerina, 1996). These models are based on the *random utility* theory, according to which the utility of choosing an alternative consists of a deterministic (systematic) term and a random (error) term (ε). Let i $(i = 1, 2, 3, \ldots, N)$ be an index to represent individuals and j $(j = 1, 2, 3, \ldots, J)$ be an index to represent alternatives, the utility of choosing alternative j by a given decision maker (U_{ij}) can be estimated by:

$$U_{ij} = \beta_0 + \beta_j X_{ij} + \varepsilon_{ij} \tag{2}$$

where U_{ij} is the utility of alternative j, $\boldsymbol{\beta_j}$ is the vector of parameters for alternative j, $\boldsymbol{X_{ij}}$ is the vector of explanatory variables (i.e. BSS attributes). $\boldsymbol{\beta_0}$ that is known as "alternative specific constant" represents the impact of all unobserved (yet systematic) factors on the utility (Hensher et al., 2005). ε_{ij} is the random term describing the random part of the utility. Assuming that ε_{ij} are generalized extreme value distributed (Mcfadden, 1981), the probability of choosing alternative j presented by $P_i(j)$ can be stated as:

$$P_i(j) = \frac{EXP\,[\beta_j X_{ij}]}{\sum_{j=1}^{J} EXP\,[\beta_j X_{ij}]} \tag{3}$$

The likelihood of choosing alternative j across all individuals can then be determined by the product of Eq. (4) over the entire observations. Such a model specification is referred to as Multinomial Logit (MNL) model (Hensher et al., 2005). One shortcoming of the MNL is the independent alternative assumption indicating that alternatives are independent and have no correlation. To check for this assumption, we tested the null hypothesis on alternative independency using Hausman and McFadden tests (Hausman & Mcfadden, 1984). The test rejected the null hypothesis, indicating the possibility of alternative dependency, and thus alternative models (i.e. mixed logit) was used to account for this correlation across alternatives.

Another shortcoming of the MNL model is that model parameters in the utility function (βj) are fixed across individuals. This assumption ignores the possible heterogeneity among individuals in the sample. In fact, the effects of attributes (socio-demographic and\or bicycle sharing attributes) may not be homogeneous across the observations. This phenomena is referred to as "unobserved heterogeneity" in the sample (Hensher et al., 2005) and needs to be accounted for within choice models. Latent class and mixed modelling methodologies have been introduced as promising approaches to capture the unobserved heterogeneity in data (Greene & Hensher, 2003). Latent class multinomial logit and mixed multinomial logit models are the two most common modelling techniques to capture unobserved heterogeneity. The details of these two models are presented in the following.

In a mixed logit model specification, model parameters are allowed to vary across observations (βij) and thus follow probability distributions. Furthermore, the random terms are allowed to co-vary across alternatives accounting for possible correlation among alternatives. The marginal probability of choosing alternative j in a mixed logit model is presented as:

$$P_i(j) = \int \frac{EXP\,[\beta_{ij} X_{ij}]}{\sum_{j=1}^{J} EXP\,[\beta_{ij} X_{ij}]} f(\beta|\mu)\, d\beta \tag{4}$$

where f(β|μ) is the density function of model parameters (β) with μ being the vector of hyper parameters (mean and variance) and the rest of notations are the same as previously stated. Such density function for model parameters captures the unobserved heterogeneity across individuals. This model is referred to as the Mixed Multinomial Logit (MMNL) model in the literature (Greene & Hensher, 2003). The likelihood function in a MMNL model is attained by integrating Eq. (4) over the entire observations.

In a latent class logit model specification, it is assumed that there could be finite number of classes over the population and thus observations are allowed to belong to different classes with different probabilities. This mechanism accounts for possible unobserved heterogeneities that may exist in data. Assuming that there are S number of classes over the population, the probability of observations belonging to each distinct class can be computed using a logit model with the following specifications:

$$P(C_s) = \frac{e^{U_s}}{\sum_{s=1}^{S} e^{U_s}} \text{ and } U_s = \Omega_s Z_s \tag{5}$$

where Ω is the vector of parameters and $\boldsymbol{Z}$ is the vector of class specific covariates. Such covariates determine the probabilities of observations being assigned to each specific class. Within each class, the probability of each observation belonging to alternative j can be computed using Eq. (3). Applying the rules of conditional probabilities, the marginal probability of each observation belonging to alternative j can be stated as:

$$P_{it}(j) = \sum_{s=1}^{S} P_{it}(j|C_s) \times P(C_s) \quad (6)$$

where $P_{it}(j)$ is the probability of belonging to alternative j, $P_{it}(j|\ C_s)$ is the conditional probably of belonging to alternative j in class C_s (same as Eq. (4)) and $P(C_s)$ is the probability of class C_s. Finally, the likelihood of choosing alternative j across observations can be determined by replacing Eq. (3) in Eq. (6) and summing over the entire sample size.

The likelihood function –whether in the mixed model or in the latent class model, does not have a closed form and so the conventional Maximum Likelihood Estimation (MLE) approach cannot be used. Alternatively, a Maximum Simulated Likelihood Estimation (MSLE) approach is employed where random draws (e.g. from Halton sequences) are used to simulate the likelihood function and estimate the model (Washington, Karlaftis, & Mannering, 2004).

Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are employed for the means of selecting the superior model in terms of fit (Washington et al., 2004):

$$AIC = -2LL + 2P \quad (7)$$

$$BIC = -2LL + PLog(N) \quad (8)$$

where LL is the log likelihood value of the estimated model, P is the number of estimated parameters and N is the number of observations (sample size); the model with a lower AIC and BIC value outperforms the other models.

Following the selection of the superior model among all other candidates, Willingness to Pay (WTP) values are estimated to investigate tangible impact of attributes ($\boldsymbol{X_i}$) relative to each other. WTP is a measure of impact that is helpful in making inferences about model attributes. As the name infers, WTP for each attribute is the maximum monetary value that each individual is willing to sacrifice to achieve the preference per one unit change in the attribute (Hensher et al., 2005). The WTP can be calculated as the ratio of the estimated coefficient for the attribute (β_{X_k}) and the estimated coefficient for cost ($\beta_{\cos t}$):

$$WTP = \frac{\beta_{X_k}}{\beta_{\cos t}} \quad (9)$$

Computation of the WTP can be challenging within the mixed models because the model parameters may be random and have a statistical distribution rather than a point estimate. This problem is even exacerbated if the parameter for cost is random with a distribution around zero. Furthermore, the WTP values are conditional and so each respondent has a unique WTP with a mean and standard deviation. The interested reader is referred to (Hensher et al., 2005) for further discussion on WTP calculations in such circumstances.

6. Results and discussion

The MNL model was estimated using direct maximum likelihood estimation while the MMNL and LCMNL models were estimated using maximum simulated likelihood estimation. In the MMNL model, several types of probability density functions $f(\boldsymbol{\beta}|\boldsymbol{\mu})$ were considered for model parameters (Eq. (3)) including normal, lognormal, uniform and triangular distributions. In the LCMNL model, different number of classes were tested for the observations. 200 Random draws were then employed from Halton sequences in order to estimate both models. The three models were then compared by AIC and BIC measures of fit. Table 4 presents the comparison of goodness of fit among the three model candidates.

According to Table 4, the comparison of goodness of fit measures among the models shows that the MMNL model has the lowest AIC and BIC (590.1 and 628.9, respectively) and thus outperforms the other models in terms of fit. This model was then selected as the superior model to make inferences about the BSS attributes contributing to the public preference. The estimation results of the MMNL model are presented in Table 5.

Table 4
Comparison of Goodness of Fit: Multinomial Logit (MNL), Mixed Multinomial Logit (MMNL) and Latent Class Multinomial Logit (LCMNL) Model.

	MNL	MMNL	LCMNL
Number of estimated parameters	6	10	15
Number of observations	360	360	360
Log Likelihood	−327.9	−285.0	−289.1
AIC	667.8	590.1	608.3
BIC	691.1	628.9	666.5

Table 5
Parameter Estimates of the Mixed Multinomial Logit (MMNL) Model.

Variable	Mean	Standard Error	t-statistic	P – Value
Non-random Parameters				
BSS attributes				
Bicycle Fare (cent)	−0.196	0.086	−2.27	0.023
Cycling Facility – Separated Bicycle Lane	1.228	0.186	6.61	0.000
Bicycle Quality	0.683	0.159	4.29	0.000
Pavement Quality – Even Pavement	0.607	0.160	3.78	0.000
Accessibility – Proximity to Bus Stop	0.508	0.163	3.12	0.002
Bicycle Training Programs	0.353	0.166	2.13	0.033
Mean of Random Parameters				
Respondents Attributes				
Gender – Female	1.120	0.912	1.23	0.219
Employment Status – Employed	0.523	0.792	0.66	0.509
Standard Deviation of Random Parameters				
Respondents Attributes				
Gender – Female	2.335	0.808	2.89	0.004
Employment Status – Employed	2.421	0.748	3.23	0.001

According to the MMNL model, eight variables are significant with 95% certainty. Out of these eight variables, six variables are related to the BSS attributes and two variables are related to the respondents' socio-demographics and economic attributes. The significant variables –which all have intuitive coefficient estimates include bicycle fare, separated bicycle lane, bicycle quality, pavement quality, proximity of bicycle stations to bus stops, bicycle training programs, gender and employment status of respondents. While the parameters for the BSS attributes are fixed across the observations, the parameters for gender and employment status are random and capture the unobserved heterogeneity in data.

To facilitate the interpretation of parameter estimates, willingness to pay (WTP) was calculated for the significant BSS attributes within the MMNL model (Table 6). Since the exchange rate of Iranian Rial to U.S. dollar is too small, the WTP values presented in dollars (or cents)

Table 6
Willingness to Pay for the BSS Attributes in the Mixed Multinomial Logit Model.

Attribute	WTP	Equivalent WTP: Percentage of the Current Fare	Equivalent WTP: Percentage of the Minimum Wage
Separated Bicycle Lane	6.26	104.3	3.4
Bicycle Quality	3.48	58.0	1.9
Pavement Quality – Even Pavement	3.10	52.7	1.7
Accessibility – Proximity to Bus Stop	2.59	43.2	1.4
Bicycle Training Programs	1.80	30.0	1.0

might not provide tangible information for readers. Thus, to provide more tangible interpretation of WTPs, they are also reported as the equivalent percentage of the current bicycle fare and the equivalent percentage of the minimum wage in Iran.

6.1. Bicycle fare

The negative parameter for bicycle fare (-0.196) in the MMNL model indicates that this variable has decreasing effect on the probability of selecting BSS as the primary mode of transport. This finding is intuitive implying that the public preference shifts towards other modes of transport if the bicycle fare increases. Although the current fare is only a small fraction (3%) of the minimum hourly wage in Iran, our findings show that even this cheap fare significantly affects public preferences towards BSS in Mashhad. Bearing in mind that bicycle fare is the main source of revenue for BSS operators, several fare types and \or levels such as integrated multimodal fare cards (Bachand-Marleau, Lee, & El-Geneidy, 2012) may be considered prior to the BSS development plans and policies.

6.2. Separated bicycle lane

The positive parameter for separated bicycle lane (1.228) shows that this variable has increasing effect on the probability of selecting BSS. The WTP for this variable indicates that people are willing to pay 6.26 cents (3.4% of the minimum wage) to be provided with a cycling facility that is totally separated from the road. This willingness to pay is equivalent to 104% increase in the current fare. A comparison of the WTP for separated bicycle lane with the WTPs for all other variables shows that separated bicycle lane is the most determining factor considered by the public when selecting bicycle sharing system as their primary mode of transport. This finding reflects the importance of safety from the public perspective in Mashhad when selecting BSS as their primary mode of transport. Separated bicycle lanes provide a safe route that is segregated from traffic and thus reduce the probability of crashes (Reynolds, Harris, Teschke, Cripton, & Winters, 2009). This important finding is in line with previous studies in the literature emphasizing the safety effects of separated bicycle lanes (Lusk et al., 2011). In addition, a number of bicycle related studies conducted in Iran also revealed the effects of separated bicycle lanes as a promising solution for increasing bicycle ridership (Ahmadi & Karimi, 2017; Askari & Rahimi, 2017; Hamidi & Chavoshi, 2018; Khalili, Khaksar, & Nikkar, 2012; Mokhtari, 2011; Nikoukheslat, Badri Aazarin, Shahin, Fathollahi, & Faridfathi, 2017).

6.3. Bicycle quality

The positive parameter for bicycle quality (0.683) indicates that high quality bicycles are associated with higher probability of selecting BSS as the primary mode of transport. The WTP for this variable indicates that the respondents are willing to pay 3.48 cents –equivalent to 1.9% of the minimum wage and about 58% of the current fare– to receive high quality bicycles. This finding is consistent with the findings on bicycle quality from another study conducted in Iran (Mokhtari, 2011). An earlier study in China has also shown that improving the quality of bicycles could significantly contribute to the mode share for bicycle sharing programs (Kumar Karki & Tao, 2016). Based on the bicycle market price in Iran, replacing the current bicycles with high quality bicycles costs around 115 dollars per bicycle. Assuming that a bicycle is averagely used six hours a day, the WTP estimated for the bicycle quality indicates that the investment for replacing the bicycle hardware will pay off in about two years.

6.4. Pavement quality

The positive parameter for pavement quality (0.683) shows that the probability of selecting BSS increases with improvement in pavement quality on bicycle lanes. Respondents are willing to pay 3.10 cents –equivalent to 1.7% of the minimum wage and 52.7% of the current fare– to be provided by a high quality pavement. Similar findings have been reported for the pavement quality in other major cities of Iran such as Tehran (Azadi, Kermanshahi, & Moemeni, 2017), Tabriz (Nikoukheslat et al., 2017) and Orumia (Ahmadi & Karimi, 2017). Rough pavement and uneven surface may result in more crash rates and severe injuries (Pucher, Komanoff, & Schimek, 1999) and thus can be a discouraging factor among the public to use BSS. This finding is consistent with previous studies (Stinson & Bhat, 2003) suggesting that smooth pavement is more preferred among cyclists.

6.5. Proximity of bicycle stations to bus stops

The proximity of bicycle stations to bus stops has positive parameter (0.508) showing that the probability of selecting BSS increases if BSS stations are close to bus stops. Respondents are willing to pay 2.59 cents – equivalent to 1.4% of the minimum wage and 43.2% of the current fare– to be provided by the BSS stations close to bus stops. This finding highlights the importance of BSS accessibility to other modes of public transport and is consistent with another study conducted in Kish Island in Iran (Batenipour, Khodadadeh, & Mohammadpour, 2013) addressing ease of access to bicycles as the major factor influencing transport decisions. Studies from other parts of the world (De Chardon, Caruso, & Thomas, 2017; Faghih Imani & Eluru, 2016a; Paul & Bogenberger, 2014) also highlighted the importance of BSS accessibility and emphasized the effects of spatial distribution of bicycle stations on individual decisions about choosing BSS (Faghih Imani & Eluru, 2015; Faghih Imani et al., 2014).

6.6. Bicycle training programs

The positive parameter estimated for bicycle training programs (0.353) shows that the probability of selecting BSS increases if consumers are provided with bicycle training programs. The willingness to pay for participation in such programs is 1.8 cents –equivalent to 1% of the minimum wage and 30% of the current fare. This finding is indicative of the need among people in Mashhad to receive appropriate training courses. Past studies have found similar findings on the effectiveness of bicycle training programs on the BSS mode share. The study conducted by (Van Der Kloof, Bastiaanssen, & Martens, 2014) investigated the social aspects of bicycle training courses and found that such courses improve the public knowledge about their environment and may increase bicycle usage. Another study conducted by (Ducheyne, De Bourdeaudhuij, Lenoir, & Cardon, 2013) showed that bicycle training courses may reduce bicycle-related accidents and thus increase bicycle usage. Examples of bicycle training courses implemented around the world are “Master on your bike” in Belgium (Observatory, 2014), “Bikeability” in the United Kingdom (Transport, 2017), and “Bike tours” in the United States (Tours, 2017).

6.7. Employment status

The estimated parameter for employment status is random with mean 0.523 and standard deviation 2.421 indicating that the effect of this variable is heterogeneous across the sample. Since we have assumed a normal distribution for this parameter, the results imply that the probability of selecting bicycle sharing system is higher among 58.6% (the cumulative probability corresponding with the positive values of the parameter) and is lower among 41.4% (the cumulative probability corresponding with the negative values of the parameter) of the employed respondents. This finding suggests that the relationship between employment status and BSS is not homogenous across people and may depend on other factors such as income and type of employment. While some studies concluded that lower income is associated with lower bicycle usage (Parkin, Wardman, & Page, 2008), other studies (Pucher et al., 1999; Stinson & Bhat, 2005) found a positive relationship between income and bicycle usage. Also, previous research (Boumans & Harms, 2005) has shown that part-time employees tend to use bicycle more frequently than full-time employees. Further exploration of the public socio-demographic characteristics (which is not available for this study) is required to shed more light on the effects of employment status on the public preferences towards BSS.

6.8. Gender

The estimated parameter for gender is random with mean 1.120 and standard deviation 2.335 suggesting that the impact of gender on the probability of selecting BSS is heterogeneous across the sample. Because we assumed a normal distribution for the parameter of gender, the above mean and standard deviation for this parameter imply that among females, 68.5% (the cumulative probability corresponding with the positive values of the parameter) prefer BSS over the other transport modes whereas among males, only 31.5% (the cumulative probability corresponding with the negative values of the parameter) prefer BSS over the other transport modes. This finding may be indicative of unobserved factors among females\males that are associated with their preferences towards BSS. For example, cultural factors –particularly in Mashhad which is a religious city, may have strong impact on women's preferences to use bicycles in general. Interestingly, previous research has shown that in some countries men have greater tendency towards cycling (Dickinson, Kingham, Copsey, & Hougie, 2003) whereas in other countries women are more likely to use bicycle for daily commute (Wardman, Tight, & Page, 2007; Witlox, 2004) and thus the effects of gender on bicycle usage is region specific (Heinen, Van Wee, & Maat, 2010). Some other studies (Raudsepp, 2001; Xiao & Mccright, 2014) suggested that women have higher levels of environmental concern and thus have greater intention towards pro-environmental behavioural adjustments (Hunter, Hatch, & Johnson, 2004).

7. Implications

The findings of this study have important implications to cost-benefit analysis of bicycle sharing system development plans in Mashhad. Separated bicycle lane is found to be a key safety factor contributing to the public preference towards BSS and thus allocating budget to separate bicycle lanes (currently shared with vehicles) from the traffic may significantly increase BSS usage in Mashhad. Interestingly, such an increase in BSS usage may in turn lead to gradual decrease in bicycle-related crashes (Jacobsen & Rutter, 2012), remove the perceived barriers to cycling among the public (Askari & Rahimi, 2017; Daley & Rissel, 2011), and ultimately leads to sustainable transportation infrastructure in the long term. We also found that people become more inclined towards BSS if bicycle stations are close to bus-stops. This finding could be a great guidance for selecting future locations of BSS stations. We found that training programs increase the willingness of the public towards BSS. For instance, strategies and training programs may include: training-supportive programs aiming to train cyclists on how to cycle on arterial streets and dark roads (Soltani & Shariati, 2014), training-supportive programs aiming to train drivers on cycling rules and regulations (Nabizadeh et al., 2011), and cycling training modules within driver license programs (Toorzani & Habibian, 2016). Our finding about the impact of employment status on the public tendency towards BSS has interesting cultural implication: the greater tendency towards BSS among the larger proportion of the employed respondents could be indicative of elimination of the conventional belief in Iran, a developing country, that bicycle is associated with low social status. Past research has shown that the use of certain transport modes (e.g. bus versus private car) in some developing countries is not only about meeting a need for transportation, but also is seen as a hierarchy of social status (Currie et al., 2010; Lusk et al., 2011). The findings of our study could be a sign that this conventional attitude may have been moderated –at least for a major proportion of the population in Mashhad. Similarly, the implication of our finding on the impact of gender is highlighted considering that cycling is prohibited for women in Mashhad (due to safety and religious concerns); yet our finding shows that the tendency to use bicycle sharing system is higher among larger proportion of females. Providing suitable services and facilities for women, thus, could increase the BSS usage among females in Mashhad. Several previous studies (Andreopoulos, Damigos, Comiti, & Fischer, 2015; Pucher & Buehler, 2012; Van Der Kloof et al., 2014) also found that safe infrastructure and suitable bicycle accessories for women with children are effective incentives to attract women to BSS.

8. Conclusions

The required infrastructure for bicycle sharing systems (BSS) is often developed with limited knowledge on the public preferences towards this green mode of transportation. Such knowledge can identify important BSS attributes considered by the public in choosing bicycle sharing system as their primary mode of transportation and thus can be helpful in increasing BSS mode share. This study aimed to shed more light on such attributes and their economic impacts on the likelihood of selecting bicycle sharing systems. We designed a stated choice experiment and applied a mixed multinomial logit choice model to examine factors contributing to the public preferences towards bicycle sharing system in Mashhad, Iran.

Findings show that employment status, gender, bicycle fare, separated bicycle lane, bicycle quality, pavement quality, proximity of BSS stations to bus stops and bicycle training programs are significantly associated with the probability of selecting BSS as the primary mode of transport in Mashhad. Among these factors, gender and employment status have heterogeneous impact on the public preferences in selecting BSS. More enriched socio-demographic data may be required to find the causes of such heterogeneity before decision making processes, development plans and action policies.

We found that improvement in cycling infrastructure and facilities can significantly increase public preferences towards BSS. More specifically, separated bicycle lanes, high quality bicycles, high quality pavement and accessibility to bus stops are the contributing design factors that can increase the BSS mode share. This finding supports budget allocation and economic investments to improve BSS infrastructure. In addition, we found that bicycle training courses significantly influence the public demand for the BSS. Such training courses can improve the public skills to cycle in the presence of heavy traffic and contribute to their safety. Additionally, exclusive training programs for people with disability (e.g. instructions on how to use hand-propelled bicycles) and children (e.g. compulsory at-school programs on how to control a bicycle and how to interact with motor vehicles and pedestrians) may further increase BSS preference among these vulnerable road users. Finally, we found that the majority of men and a large proportion of unemployed population in Mashhad have less intention towards BSS. Certain policy incentives such as concession fares or evening unlimited trips may help increasing the mode share among this proportion of the population in Mashhad.

An important limitation of our study is that the sample of stated preference data (sample size of 90) is fairly small and may not be representative of the population in Mashhad and so the results must be interpreted with caution. In addition, applying the proposed models to other samples\datasets can be helpful in validating the findings of this study. Another limitation of this study is that we only used one attribute (i.e. type of cycling facility – separated\shared bicycle lane) to describe BSS safety for the respondents. Although a few studies have investigated other attributes related to cycling safety in Iran (e.g. traffic control devices and lane markings, flashing warning lights and luminescent paint lights across cycling facility (Nikoukheslat et al., 2017), we only used the type of cycling facility to avoid confusing the respondents. Similarly, we only used one BSS attribute (i.e. proximity of BSS to bus-stops) to represent accessibility in our study. However, we acknowledge that other BSS attributes such as number of bicycles at bicycle stations (De Chardon et al., 2017) may reflect accessibility as well. Although we expect that the impact of bicycle supply on the public preferences towards BSS would be negligible due to its under-capacity operation (as discussed earlier), incorporating bicycle supply into the models could be an interesting line of inquiry. Finally, we did not analyse the impact of cultural factors on the public preferences towards BSS. Public perception of poverty and the attitude towards public transport are examples of cultural factors that may influence the public preferences towards BSS. Future research may be directed towards understanding of cultural factors and the corresponding barriers against BSS adoption in developing countries.

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