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Cyclists' heterogeneous parking preferences and their implications for bicycle parking facilities

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ABSTRACT

Understanding bicycle parking behavior is essential when planning bicycle parking facilities. This is necessary in order to meet the needs of cyclists, to effectively promote cycling, and to prevent fly parking of bicycles. Therefore, this paper analyzes cyclists' parking preferences regarding the type and placement of bicycle parking facilities. The study is based on a stated preference experiment (n = 2,960) on the bicycle parking choice behavior of university students and employees of RWTH Aachen University, one of the largest universities in Germany. The analysis employs a mixed logit model to estimate the influence of facility type and user-specific factors, the willingness to pay for parking facilities, and the relevance of cycling detours and walking distances. The results indicate that cyclists are more than twice as sensitive to walking distances than to cycling detours. Furthermore, they have a general preference for bicycle parking stations and covered versus uncovered parking racks, as well as a reluctance to use informal parking facilities. While previous research has shown that groups of cyclists have different preferences and parking behaviors, it has been unclear what factors influence group membership. This paper shows that student and employment status and the resale value of the bicycle are important user-specific factors influencing the choice between parking facilities. Furthermore, there is a notable willingness to pay for bicycle parking, especially among those with expensive bicycles. The considerable variation in preferences among cyclists underscores the importance of considering the heterogeneity of cyclists when planning parking facilities to optimize their utility.

1. Introduction

An often-cited publication by Hunt and Abraham (2007) found for Edmonton (CA) that secure parking at the destination had the same effect on the utility of cycling as a mode as reducing the time spent on a roadway in mixed traffic by 26.5 min. Even if this value seems unrealistically high, at least from a European perspective, it shows the importance of bicycle parking in promoting cycling. Nevertheless, bicycle parking is an undervalued topic in the literature, as most studies in this area focus on infrastructure for moving bicycle traffic, such as bike lanes and bike paths (Heinen and Buehler, 2019). Moreover, most studies analyzing the impact of bicycle parking facilities use secure bicycle parking only as an abstract concept (e.g., Hunt and Abraham, 2007; Handy and Xing, 2011; Buehler, 2012) and do not operationalize what it actually means, leaving research gaps regarding the preferences for specific facility types and their attributes.

Relevant locations for bicycle parking are work and study locations, as the average parking time there is the longest, with the

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exception of home parking. Due to the long parking time, these locations are vulnerable to theft, especially in the absence of secure parking facilities. Therefore, this paper focuses on bicycle parking facilities at universities, which are major commuting destinations for both students and a wide range of university employees, including academic and non-scientific staff.

Universities and other employers have an interest in a substantial share of their employees cycling to work by providing a good bicycle parking supply. One reason is the employee's health, as cycling commuters are less likely to be absent due to illness (Hartog et al., 2010; Hendriksen et al., 2010). Another reason is that parking a bicycle takes up less space than parking a car, which is about 25–30 m^2 (FGSV, 2005). While the space required to park a bicycle is more difficult to estimate due to the wide variety of parking infrastructure designs, it is clear that parking a bicycle requires only a fraction of the space required to park a car. German guidelines estimate about 2.5–3.0 m^2 per bicycle (FGSV, 2012).

Furthermore, cycling-friendliness can also be an image factor for companies and universities. Even beyond greenwashing, a growing number of employers aim to increase their sustainability and reduce their climate impact. Employee mobility and commuting behavior are important factors in this context and beyond the individual employer perspective, there is a political and societal interest in a growing share of bicycle commuters due to the overall environmental and health benefits of cycling compared to driving. Consequently, both employers and society have a vested interest in promoting cycling.

While bicycle parking management is becoming increasingly important as cycling rates increase (van der Spek & Scheltema, 2015), overcrowded bicycle parking facilities are already a common sight at universities. At the same time, other nearby facilities often have available capacity. This points to an inefficient placement of facilities that do not meet the needs of users (Gamman et al., 2004). To optimize bicycle parking provision, it is essential to gain a comprehensive understanding of parking behavior. This would support the effective promotion of cycling and prevent fly-parked bicycles. However, there is a paucity of literature that focuses on facility types and facility placement.

Against this background, we conducted a stated preference survey among employees and students at RWTH Aachen University, one of the largest universities in Germany, with approximately 47,000 students and 10,000 university employees (RWTH Aachen University, 2022). The study aimed to investigate the influence of both the characteristics of bicycle parking facilities and their placement in terms of access and egress (quantified by the required cycling detour distance and walking distance). We used a mixed logit model to analyze the preferences and the willingness to pay for secure bicycle parking. The following research questions guided these analyses, as they are relevant to the planning of bicycle parking facilities:

- Who prefers what type of bicycle parking facility?
- How do the bicycle parking facility location, associated cycling detours, and walking distances influence the choice of bicycle parking facilities?
- How much are cyclists willing to pay for bicycle parking?

This paper defines bicycle parking facilities as any facility used to park bicycles, including designated parking racks, as well as locking to street furniture or taking the bicycle to the office. First, we provide a literature review before describing our survey and model estimation. We then present our results before moving on to a discussion and drawing conclusions.

2. Literature review

Several studies analyze bicycle parking at the workplace, such as parking racks and sheds, but also related facilities, such as showers, lockers, and changing rooms, as shown in Table 1. Most found that these positively influenced the likelihood of cycling to work. Some North American studies found the level of influence to be very high (Bueno et al., 2017; Hunt & Abraham, 2007), while others found it to be low or even statistically insignificant, particularly for showers and clothing lockers (Stinson and Bhat, 2004; Handy and Xing, 2011). Fournier et al. (2023) found that the level of interest in secure bicycle parking varied by cycling frequency and location, being highest near metro stations and at work. Hunt and Abraham (2007) found that secure bicycle parking becomes more important as the purchase price of the bicycle increases.

Wardman et al. (2007) concluded that the impact of cycling facilities on mode choice is limited, at least in their study area in England. They found that a daily payment of £2 to employees to encourage them to cycle to work was more effective in increasing cycling than improved bicycle parking facilities.

There is considerably less literature on user preferences for specific bicycle parking facilities. However, studies from different locations have found that cyclists prefer bicycle sheds to bicycle parking racks (Lusk et al., 2014; Moskovitz & Wheeler, 2011; Yuan et al., 2017). Furthermore, in Hangzhou, China, on-street parking appears to be the less preferred option (Lusk et al., 2014). Lusk et al. (2014) also found that some people park their bicycles inside their homes or offices, even though this is not their preferred parking option. In their analysis, the preferences of cyclists and non-cyclists were similar.

Molin and Maat (2015) conducted a stated preference experiment on bicycle parking at train stations in the Netherlands. They found negative influences of parking prices and walking times, as well as different segments of cyclists in terms of their parking preferences. They labeled these segments 'free facility', 'price sensitive', 'walking time-sensitive', and 'paid facility' and identified different utility functions for them that guide their bicycle parking behavior. They also analyzed the variables that influence a cyclist's affiliation to the segments and found that only age was statistically significant. Furthermore, they concluded that bicycle parking is not only an issue at railway stations and that examining bicycle parking preferences is an important topic for future research. Similarly, Egan et al. (2022) also clustered parking preferences, comparing the preferences for open, locked, and guarded parking.

Another study on walking distances found that an increase of 100 m reduced the use of bicycle lockers at train stations by 20 %

Table 1
Literature findings regarding bicycle parking facility choice.

Citation	Methods	Survey period	Survey area	Key findings
Buehler (2012)	Household surveys	2007–2008	Washington D.C. (US)	• Results indicate that bicycle parking and clothes lockers or cyclist showers are related to higher levels of bicycle commuting. • The combined supply of bicycle parking, clothes lockers, and showers increases bicycle commuting more than the provision of bicycle parking only.
Bueno et al. (2017)	Household surveys	2010–2011	N. Y. and New Jersey (US)	• Compared to individuals receiving no subsidies, individuals with cyclist showers, lockers, or bicycle parking at work are 50 times more likely to commute by bicycle. • Bicycle-related benefits are the most important factor explaining the decision to cycle to work.
Fournier et al. (2023)	Quantitative survey	2021	Montréal (CA)	• Interest in secure bicycle parking depends on location, which is the highest at metro stations and work. • Dedicated cyclists are most interested in secure parking, while leisure cyclists are most willing to pay and walk for secured bicycle parking.
Handy and Xing (2011)	Quantitative Survey	2006	Small cities (US)	• Surprisingly, having bicycle facilities (racks, showers, etc.) close to the workplace does not significantly influence bicycle commuting, suggesting that although they may be a welcome amenity, they do not seem to be a determining factor for bicycle commuters. Possible explanations are that bicycle commuters find adequate places to park their bicycles even without racks and that bicycle commutes over short distances and at moderate speeds do not generate enough sweat to necessitate a shower.
Hunt and Abraham (2007)	Stated preference survey	1994	Edmonton (CA)	• Secure parking has the same effect on utility as a decrease of 26.5 min in time spent on a roadway in mixed traffic. • The provision of showers at the destination has a more modest yet significant positive effect on the attractiveness of cycling, equivalent to a reduction of 3.6 min cycling in mixed traffic. • For the lowest three cost groups, secure parking becomes relatively more attractive as the bicycle purchase price increases. The result for the highest price group does not follow this trend. • There are indications that those with a higher level of cycling experience value showers more.
Lusk et al. (2014)	Quantitative survey	2012	Hangzhou (CN)	• Parking sheds are the most used and highly preferred by both genders. • Some of the cyclists in Hangzhou park their bicycles in a home or office room. However, both cyclists and non-cyclists do not prefer this option, and women prefer it even less. • The uses and preferences of cyclists who cycle more than three days a week are similar to those of all cyclists, and the same is true for cyclists and non-cyclists.
Molin and Maat (2015)	Stated preference survey	2012	Delft (NL)	• If parking price or walking time increases, the utility of the bicycle parking facility decreases.
Moskovitz and Wheeler (2011)	Utilization analysis via time series photography	2009	Portland (US)	• One-third of all bicycle parking events at the PSU last less than two hours, 23 % for two to four hours, and 43 % for longer than four hours. • A preference for parking sheds by all study participants is statistically significant.
Noland and Kunreuther (1995)	Quantitative survey	1991	Philadelphia (US)	• Bicycle parking facilities at places of employment are necessary to enhance the convenience of the mode. • Those respondents with safe bicycle parking available have a statistically significant higher mean perception of cycling convenience than those without parking available.
Stinson and Bhat (2004)	Quantitative survey	2002	US and CA	• Bicycle racks or locker facilities at the workplace increase the likelihood of commuting by bicycle. However, neither the presence of showers nor clothing lockers is statistically significant. • In summary, while commuter cyclists (and others who exercise en route to work) would likely welcome showers and clothing lockers at the workplace, such facilities do not appear to impact the frequency of commuting by bicycle.
Wardman et al. (2007)	Stated preference survey and revealed preference data	1998	UK	• Outdoor cycle parking facilities are equivalent to 2.5 min of less time spent cycling. • Due to improved security, indoor bicycle parking facilities are valued more highly at 4.3 min. The combination of showers, changing facilities, and indoor bicycle parking is valued at 6.0 min.

(*continued on next page*)

Table 1 (*continued*)

Citation	Methods	Survey period	Survey area	Key findings
				• A 10-percentage point increase in the proportion of the population cycling to work would have the same effect on demand as a one-minute cycle time reduction. • A £2 per day payment to commuters rewarding them for cycling to work is not far from doubling the share of cycling. It has a larger impact than the ideal but unachievable scenario of cycling to work being spent entirely on thoroughly segregated cycleways. • Providing work-related facilities, particularly showers and indoor parking, improves cycle market shares. However, the impact on other modes is limited.
Yuan et al. (2017)	Utilization analysis	2011	Beijing (CN)	• The occupancy rate for shed spaces is higher than for racks, indicating that cyclists prefer sheds.

(Arbis et al., 2016). A commonly observed behavior is that cyclists practice 'fly parking', locking their bicycle to street furniture not intended for bicycle parking, or even wildly without locking to anything. This behavior occurs when the designated parking facilities are too unattractive, usually due to inappropriate placement too far away from destinations (Gamman et al., 2004; Larsen, 2015). However, studies quantifying the critical distance are lacking, and none of the aforementioned studies analyze the influence of cycling detours required to access a specific parking facility.

Furthermore, the ability to store a bicycle varies by bicycle type. For example, typical bicycles in China have kickstands and built-in locks, similar to the Netherlands and in contrast to the US (Yuan et al., 2017). Even within Germany, there are differences between cities in terms of bicycle parking habits, such as the proportion of bicycles parked in designated parking facilities versus fly parking. For more information on previous literature on bicycle parking, we refer to the review by Heinen and Buehler (2019).

In summary, there is a lack of knowledge about quantifiable preferences for different parking facility types because most studies use secure parking only as an abstract concept or consider only a few facility types, such as sheds versus parking racks. Research on possible combinations of parking facility types and their interaction with pricing and placement-related factors, such as cycling detours and walking distances, is limited. For parking fees and walking distances, previous research has focused only on railway stations, and cycling detours have not been the subject of research. Furthermore, the influence of socio-demographic factors and the value of the bicycle on the choice of a bicycle parking facility has not yet been analyzed in detail. Therefore, this study focuses on the influence of facility types, cycling detours, walking distances, and pricing on bicycle parking facility choice and analyzes the interactions between these influences and user characteristics.

3. Method

3.1. *Stated preference experiment*

For our analysis, we conducted a survey with a stated preference experiment among employees and students of RWTH Aachen University in July 2022 (i.e., during a period when COVID-19-related restrictions had been relaxed). In the stated preference part of the survey, participants were asked to choose between parking options in hypothetical choice situations (i.e., choice sets). Each person received eight of these, selected blockwise from a total of 64 generated choice sets to avoid unbalanced groups of choice sets. We generated the choice sets using Ngene, applying an efficient design that minimizes the d-error using coefficients from a pretest. For more information, see Rose and Bliemer (2013) and ChoiceMetrics (2018). We later adjusted some choice sets when the given values resulted in dominant alternatives.

Fig. 1 shows an example choice set translated from German to English. Each choice set consisted of the five alternatives 'indoor parking', 'post of a traffic sign', 'uncovered bicycle parking rack', 'covered bicycle parking rack', and 'bicycle parking station'. Due to the gaps in the literature so far, we chose three attributes to characterize the alternatives in addition to the facility type. Two attributes were related to the location of the respective bicycle parking facility: cycling detour and walking distance. These factors (measured in meters) characterized the additional distance that users would have to cover in order to access the facility by bicycle (cycling detour) or to walk from the facility to their final destination (walking distance). Moreover, the bicycle parking station sometimes had a daily charge (measured in €).

Participants were instructed that the indoor parking alternative corresponded to their current situation of parking a bicycle within the building at their place of work or study. Consequently, those who could take a bicycle with them to their office were instructed to consider this as an option. The post of a traffic sign represents 'fly parking' to realistically reflect parking behavior, where cyclists use street furniture that is not intended for parking when the other options are too poor (Gamman et al., 2004). As bicycle parking racks (also known as u-racks) are the standard type of parking facility in Germany, we included them both with and without covering. Furthermore, the description of the bicycle parking station (also known as parking garage) clarifies that only registered users would have access to the parking station, thus ensuring a high level of security against theft.

Table 2 shows the attribute ranges. As can be seen, not all attribute values were combined with all types of bicycle parking facilities in order to create balanced and realistic choice situations. For example, in the case of parking the bicycle at the post of a traffic sign, the detour was limited to 100 m because, in reality, such opportunities to park the bicycle close to the trip destination are common.

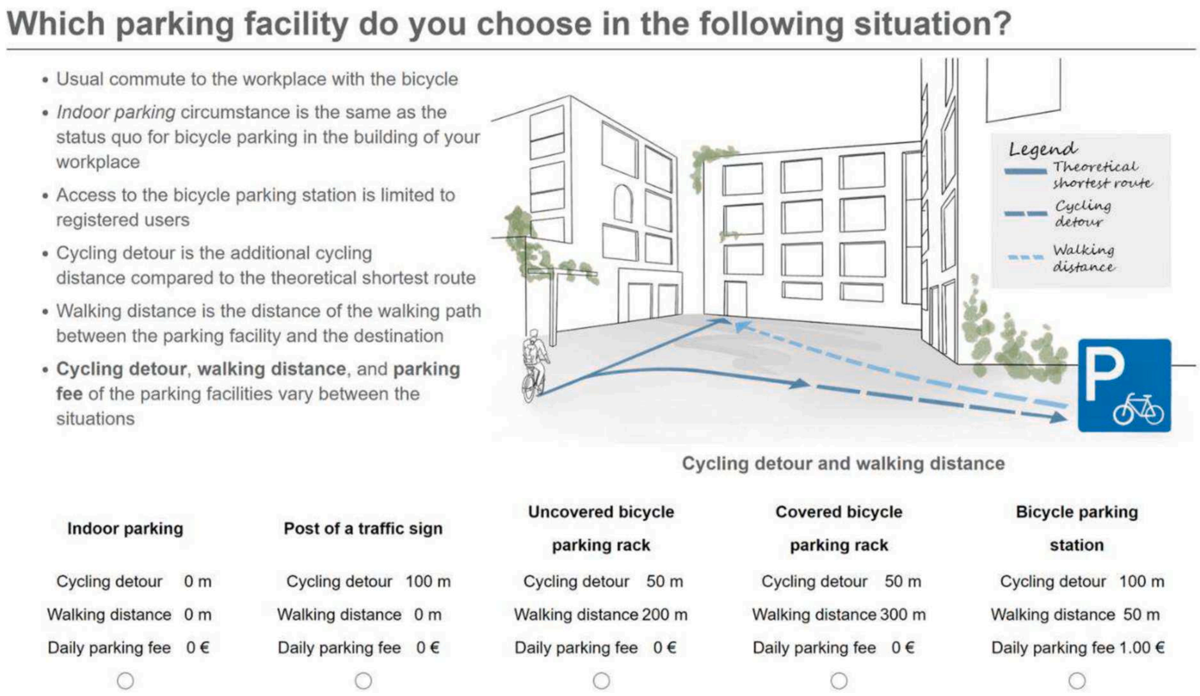

Fig. 1. Example of a choice set.

Table 2
Parameter range relating to the bicycle parking facility type.

Alternative	Cycling detour [m]	Walking distance [m]	Fee per day [€]
Indoor parking	0	0	0
Post of a traffic sign	0, 50, 100	0, 50, 100	0
Uncovered bicycle parking rack	0, 50, 100, 200	0, 50, 100, 200	0
Covered bicycle parking rack	0, 50, 100, 200, 300	0, 50, 100, 200, 300	0
Bicycle parking station	0, 50, 100, 200, 300	0, 50, 100, 200, 300	0, 0.10, 0.20, 0.50, 1

Similarly, since public bicycle parking is usually free of charge, we assumed daily fees only for the high-quality bicycle parking station.

3.2. Additional questions

In addition to the stated preference part, we collected data on the type of employment at RWTH, the distance between home or place of residence and the main place of work or study at the university, and the frequency of commuting in general and by bicycle. We also asked questions about the bicycle type (standard bicycle, e-bike, speed-e-bike, other bicycle types with or without electric motor) and the resale value (RV) of the bicycle. Respondents were also asked how long, on average, they park at the university during a typical work or study day.

Another focus of the survey was on barriers to indoor parking in the specific university building. Respondents could choose between the alternatives of ‘no barriers’, ‘no designated space’, a rule prohibiting bringing bicycles into the building or storing them in their department, and others. The model later used the reported barriers as factors influencing parking choice.

3.3. Sample

Our sample includes both 1,583 RWTH students and 1,377 RWTH employees, as shown in Table 3. The second group includes professors, scientific employees (mostly Ph.D. students), and administrative and technical staff (ATS). The response rates displayed refer to the population according to RWTH statistics.

While professors and administrative and technical staff tend to be long-term employees, most scientific employees’ employment is limited to about six years. Many of the scientific employees were previously students at RWTH. Students are typically enrolled at RWTH for 2–5 years, depending on their program and whether they are pursuing a bachelor’s or master’s degree or both. The length of a typical stay on campus on a regular work or study day depends on student and employment status. In particular, students stay shorter. In addition, the average income is typically lowest for students and highest for professors.

The entire population of RWTH students and employees received an email inviting them to participate in the survey on 6 July 2022,

Table 3
Sample overview.

Student and employment status	Male			Female			N.I. /Diverse	Electric-bicycle share
	Sample	In total	Response rate	Sample	In total	Response rate		
Students	1,036	27,082	4 %	524	11,923	4 %	23	4 %
Professors	59	290	20 %	18	88	20 %	3	31 %
Scientific employees	590	3,783	16 %	238	1,411	17 %	15	12 %
Administrative and technical staff	192	1,944	10 %	256	1,685	15 %	6	48 %
∑	1,877	33,099	6 %	1,036	15,107	7 %	47	14 %

during the summer semester, toward the end of the lecture period (for administrative and technical reasons, it was impossible to split the survey across different days). The response rate is around 4 % for students and 10 to 20 % for employees. 85 % of the cyclists in our sample use conventional bicycles and 13 % standard e-bikes. The remaining percentages are speed-e-bikes, cargo bikes, folding bikes, etc. However, the shares of e-bikes differ between students and employee groups. As a result, the distribution of expensive bicycles is also quite disproportionate. Furthermore, as expected, the total number of professors in the sample is low.

Fig. 2 shows that most survey participants frequently commute to RWTH by bicycle. Due to the COVID-influenced work-from-home-friendly policy, a cycling frequency of three times per week often includes every commute. The cycling frequency depends on the employment status, as the share of daily cycling commuters is much higher for scientific employees and professors than for administrative and technical staff and students. The sample composition differs from that of RWTH and in general, as another mobility survey conducted two weeks earlier at RWTH showed a lower share of cycling.

After the stated preference part of the survey, we asked the participants if they would commute more often by bicycle if secure bicycle parking were available at the university (yes-share: 64 %) and the same for showers (yes-share: 40 %). They also had to answer whether they would buy a more expensive bicycle if secure bicycle parking were available at RWTH (yes-share: 60 %). According to their previous answers, more than half of the people who want to cycle more often already cycle every time they commute. This and the high yes-shares indicate that the desire for improved bicycle parking infrastructure was a motivating factor for participating in the survey.

3.4. Model estimation

To analyze participants' preferences and willingness to pay for bicycle parking, we ran a mixed logit model using the Apollo package in R. For more information, see Hess and Palma (2022). Mixed logit models represent a standard approach for modeling choices among alternatives in stated preference experiments as they allow for systematic heterogeneity in taste variation. In a given situation (t), an individual (q) selects the alternative (i) (in this case, a parking facility type) that maximizes their utility (U_{iqt}). Each alternative represents a combination of parking facility type, cycling detour, walking distance, and parking fee. In addition to the objective utility, there is an additional error term (ε_{iqt}), representing the unobserved variation in preferences. Further assumptions pertain to the distribution of the error term (it should be independent and identically distributed according to the Gumbel distribution) and the independence of irrelevant alternatives. This allows for relative comparisons between odds. Moreover, mixed logit models

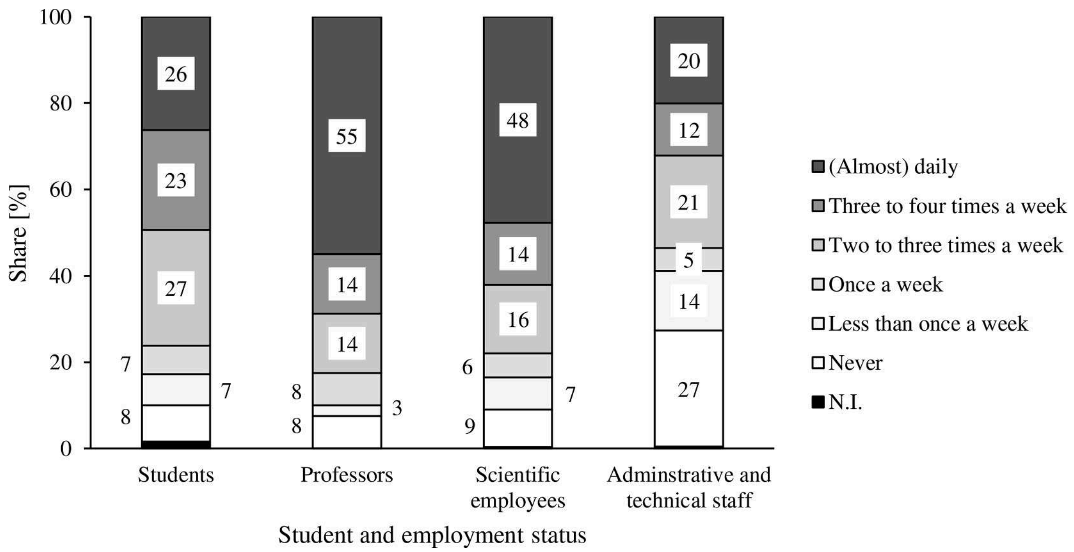

Fig. 2. Frequency of bicycle commuting by student and employment status.

incorporate error terms that allow for correlation in unobserved factors among choices of an individual, which were asked repeatedly. The estimated model includes classical logit coefficients (β_c) multiplied by parameters of the alternative and the respondent $\left(X_{ciqt}\right)$, random coefficients $\left(\alpha_{iq}\right)$ for the facility type $\left(Y_i\right)$, and error coefficients $\left(\gamma_{jiq}\right)$ to capture the correlation between different groups (j) of facility types. Consequently, the utility function is defined as follows:

$$U_{iqt} = \sum_{c=1}^{C} \beta_c X_{ciqt} + \left(\alpha_{iq} + \sum_{j=1}^{J} \gamma_{jiq}\right) Y_i + \varepsilon_{iqt} \quad (1)$$

α_{iq} is defined as follows, where μ_i is the mean, σ_i is the standard deviation, and ξ_{iq} is an error term distributed symmetrically around zero:

$$\alpha_{iq} = \mu_i + \sigma_i \cdot \xi_{iq} \quad (2)$$

Furthermore, we defined error components γ_{jiq} for the following groups of facility types: fallback facilities (indoor parking, pole of a traffic sign), parking racks (uncovered bicycle parking rack, covered bicycle parking rack), covered facilities (indoor parking, covered bicycle parking rack, bicycle parking station), and designated high-quality parking facilities (covered bicycle parking rack, bicycle parking station). Consequently, these components capture the correlation between different facility types with similar characteristics. We also applied a ξ_{jiq} that is distributed symmetrically around zero:

$$\gamma_{jiq} = \sigma_{ji} \cdot \xi_{jiq} \quad (3)$$

To simulate the distribution of ξ_{iq} and ξ_{jiq} values, we draw 500 times numbers using 'Modified Latin Hypercube Sampling'. We chose normal distributions because they gave a better model fit (BIC, r2, log-likelihood) in our example than other distributions. Finally, the following formula calculates the conditional probability of each alternative for given values of the distributed parameters:

$$L_{iqt} = \frac{e^{U_{iqt}}}{\sum_{i=1}^{I} e^{U_{iqt}}} \quad (4)$$

The following formula provides the unconditional probability:

$$P_{iq} = \int_{\eta_{iqt}} L_{iqt} f\left(\eta_{iqt}\right) d\eta_{iqt} \quad (5)$$

Here, η_{iqt} represents all distributions of random parameters. The formula weights the likelihood of an alternative with the frequency of the parameters of the situation to occur.

The influence of cycling detour, walking distance, and price is accounted for with classical coefficients. Furthermore, the model considers systematic heterogeneity and non-linear effects by analyzing the influence of facility types and distances joint with user-specific attributes. Therefore, we crossed most of the variables with the employment and student status and the resale value of the bicycle by creating dummy variables. For example, the parameter of 'Indoor parking $_{\text{Student}}$' is zero if the alternative is not indoor parking or the participant is not a student. If both conditions are true, the parameter is one.

The reference category is generally a scientific employee with a bicycle with a resale value of less than 500 €. The coefficients are applied in an additive manner. Consequently, a resale value exceeding 1,000 € necessitates the application of both the coefficients for 'over 500 €' and 'over 1,000 €'. While section 4.1 will show that student and employment status and commuting distance are correlated with each other and a greater preference for higher quality parking facilities, we found that these parameters are also correlated with the length of stay and the resale value of the bicycle. Since student and employment status and the resale value of the bicycle proved to be the most significant variables, we focused on them. For example, the additional inclusion of length of stay did not substantially improve the model fit and led to insignificant results. Therefore, we excluded this variable.

The coefficients of the model represent the influence of an increase of the correspondent variable by one on the utility of an alternative. Thus, it is possible to estimate the average willingness to pay values for attributes by considering the price sensitivity of respondents based on the estimates for the price coefficients. For more information on mixed logit models, see Hensher and Greene (2003).

4. Results

4.1. Descriptive analysis of bicycle parking preferences

The following figures show the bicycle parking facilities selected in the stated preference experiment. It is important to note that these figures display the results for the hypothetical choice sets and do not represent revealed real-world choices. Fig. 3 shows the proportions of the bicycle parking facilities by student and employment status. Obviously, there are substantial differences, e.g., the percentage of indoor parking is much lower for students than for the employee groups.

Fig. 4 illustrates the relationship between commuting distance and the choice of a bicycle parking facility. There is a clear tendency to choose bicycle parking facilities that provide a high level of protection against theft (bicycle parking station, indoor parking) as commuting distance increases. Similarly, but not shown, the likelihood of choosing these facilities increases with a longer duration of

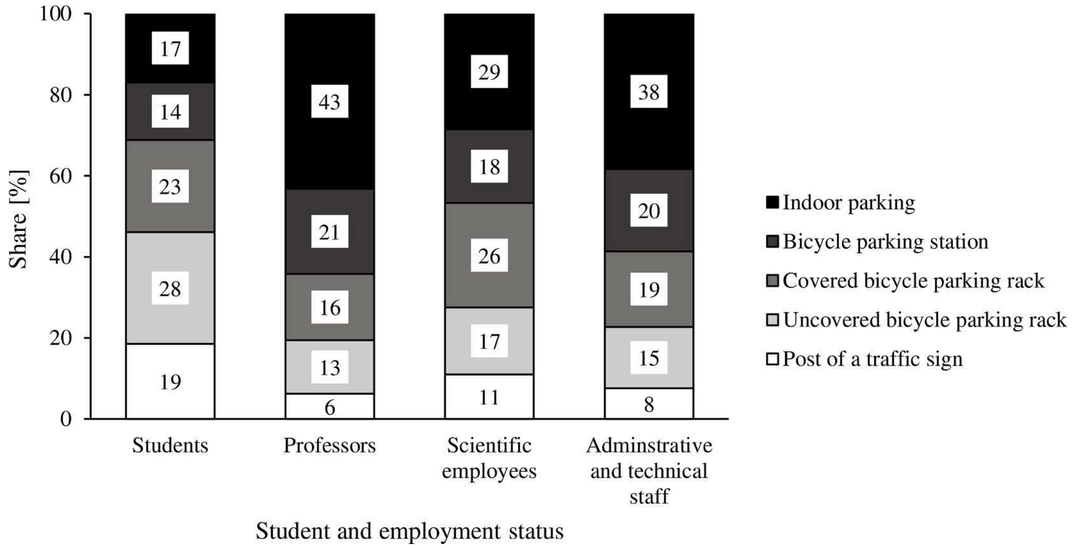

Fig. 3. Reported choice of bicycle parking facility by student and employment status in the choice experiment.

stay on campus, ownership of an e-bike, or a higher resale value of the bicycle in general.

4.2. Multivariate analysis of bicycle parking choice

We ran a mixed logit model for the choice of bicycle parking facilities and obtained a log-likelihood of –22,452 and a McFadden's pseudo R2 of 0.40, as illustrated in Table 4. This R^2 value is comparable to that observed in the latent class model utilized by Molin and Maat (2015) (0.44). Nevertheless, it indicates that there are additional unobserved factors or that some inconsistent choices have been made which the random coefficients and error terms of our model could not capture.

Table 5 shows the model's coefficients using the scientific employees and the uncovered bicycle parking rack as the reference category. The coefficients displayed are significant, at least at the 0.1p-value level, except for the indoor parking barriers, which are less significant. The p-values were calculated using the Apollo package based on classical standard errors.

The β_c values correspond to standard logit coefficients. For the facility type, μ_i represents the mean and σ_i the standard deviation, while σ_{ji} values represent error components for different facility types. It is irrelevant whether σ_i or σ_{ji} are positive or negative, as the

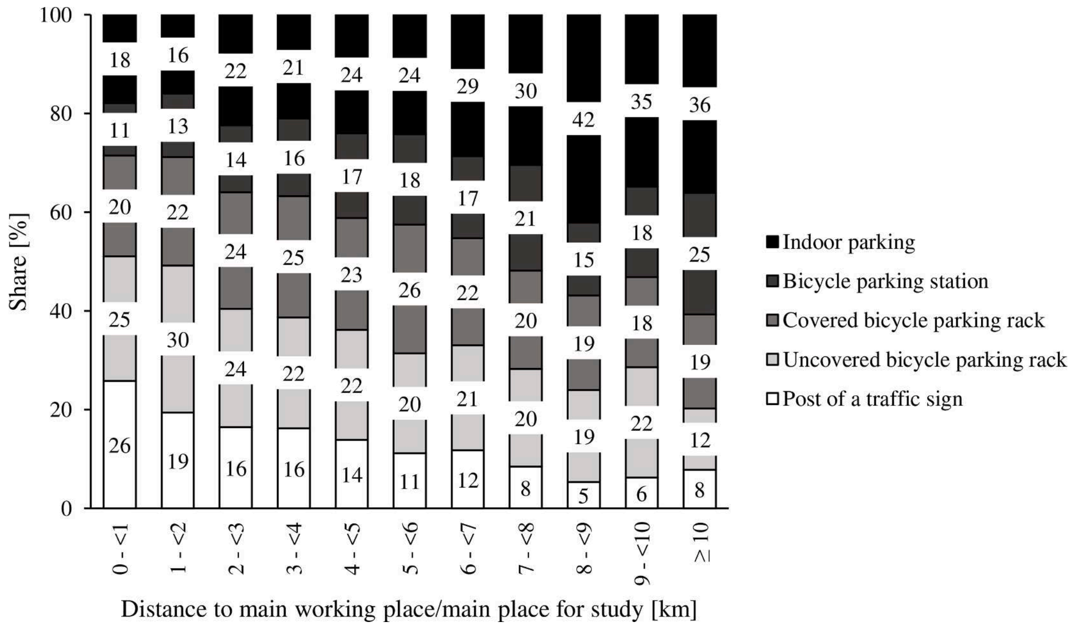

Fig. 4. Reported choice of bicycle parking facility by commuting distance in the choice experiment.

Table 4
Model fit results.

Model parameter	Result
LL (start)	−84,181
LL (final)	–22,452
R^2	0.40
AIC	44,978
BIC	45,276

Table 5
Coefficients mixed logit model.

Coefficient		Est.	Std. err.	t-ratio	p-value	
Indoor parking	μ_i	−3.032	0.335	−9.059	<2E-12	***
	σ_i	4.912	0.159	30.815	<2E-12	***
Indoor parking $_{\text{Student}}$	β_c	−2.323	0.320	−7.261	<2E-12	***
Indoor parking $_{\text{ATS}}$	β_c	1.556	0.333	4.670	3.01E-06	***
Indoor parking $_{\text{RV} > 500\ €}$	β_c	1.817	0.283	6.411	1.44E-10	***
Indoor parking $_{\text{RV} > 1000\ €}$	β_c	1.696	0.386	4.401	1.08E-05	***
Indoor parking $_{\text{No designated space}}$	β_c	−0.853	0.274	−3.117	0.002	**
Indoor parking $_{\text{Indoor parking forbidden}}$	β_c	−0.766	0.498	−1.539	0.124	
Indoor parking $_{\text{Forbidden at the department}}$	β_c	−0.851	0.646	−1.319	0.187	
Pole of a traffic sign	μ_i	−1.945	0.075	–25.860	<2E-12	***
	σ_i	−1.051	0.213	−4.925	8.42E-07	***
Uncovered bicycle parking rack	μ_i	fixed				
	σ_i	−0.903	0.110	−8.243	<2E-12	***
Covered bicycle parking rack	μ_i	0.779	0.068	11.451	<2E-12	***
	σ_i	0.444	0.232	1.912	0.056	.
Covered bicycle parking rack $_{\text{RV} > 500\ €}$	β_c	0.961	0.112	8.577	<2E-12	***
Bicycle parking station	μ_i	0.584	0.126	4.645	3.40E-06	***
	σ_i	−2.570	0.088	−29.296	<2E-12	***
Bicycle parking station $_{\text{ATS}}$	β_c	−0.321	0.014	–23.014	<2E-12	***
Bicycle parking station $_{\text{RV} > 500\ €}$	β_c	1.658	0.199	8.338	<2E-12	***
Bicycle parking station $_{\text{RV} > 1,000\ €}$	β_c	1.257	0.230	5.473	4.42E-08	***
Bicycle parking station $_{\text{Distance to RWTH}}$ [km]	β_c	0.054	0.013	4.236	2.27E-05	***
Cycling detour [m]	β_c	−0.006	2.82E-04	–22.125	<2E-12	***
Cycling detour $_{\text{Student}}$ [m]	β_c	−0.002	3.62E-04	−6.315	2.71E-10	***
Cycling detour $_{\text{Professor}}$ [m]	β_c	−0.002	0.001	−3.419	6.29E-04	***
Cycling detour $_{\text{ATS}}$ [m]	β_c	0.001	4.35E-04	2.729	0.006	**
Walking distance [m]	β_c	−0.017	3.64E-04	−45.783	<2E-12	***
Walking distance $_{\text{Student}}$ [m]	β_c	−0.002	4.02E-04	−5.476	4.36E-08	***
Walking distance $_{\text{Professor}}$ [m]	β_c	0.005	0.001	3.897	9.75E-05	***
Walking distance $_{\text{ATS}}$ [m]	β_c	0.006	0.001	9.983	<2E-12	***
Parking fee	β_c	−6.795	0.217	−31.296	<2E-12	***
Parking fee $_{\text{Student}}$	β_c	−1.590	0.292	−5.453	4.96E-08	***
Parking fee $_{\text{Professor}}$	β_c	1.742	0.687	2.534	0.011	*
Parking fee $_{\text{ATS}}$	β_c	1.869	0.281	6.654	2.86E-11	***
Fallback facilities	σ_{ji}	−1.131	0.161	−7.008	2.42E-12	***
Bicycle parking rack	σ_{ji}	−1.089	0.119	−9.154	<2E-12	***
Covering	σ_{ji}	−1.520	0.176	−8.652	<2E-12	***
High-quality parking facility	σ_{ji}	−1.213	0.200	−6.051	1.44E-09	***

multipliers ξ_{iq} and ξ_{jiq} are symmetrically distributed around zero.

Indoor parking in the status quo has a strong negative coefficient even without barriers such as rules prohibiting it or a lack of designated spaces. As expected, rules prohibiting indoor parking in the building or at the department and the lack of designated spaces cumulatively reduce the utility and, thus, the likelihood of choosing indoor parking. Surprisingly, the barriers are less statistically significant than expected. However, the estimated σ_i for indoor parking is relatively high, suggesting that the preference for this parking option varies. This may be related to the fact that although we considered reported barriers, the perception of these barriers also varies. Currently, it depends on the building whether it is allowed to bring bicycles inside; moreover, it is often tolerated even if it is not formally allowed. This gray area may also explain why students are particularly unlikely to choose indoor parking. They have probably never tried to take a bicycle into a lecture hall. Conversely, those who own a bicycle with a resale value of more than 500 € or even 1,000 €, or who are members of the administrative and technical staff are more likely to choose indoor parking. It is probable that members of this employee group have more experience in this matter and are aware of the departmental policy, or even have the authority to decide on it themselves.

On-street parking, as represented by the post of a traffic sign, is disfavored, probably due to the higher risk of theft and vandalism. Additionally, it may be perceived as socially unfavorable parking behavior. Furthermore, respondents prefer covered to uncovered

Table 6
Willingness to pay for different parking facilities in € per day for the reference of an uncovered parking rack.

	RV	Ref. (Scientific employees)	Students	Professors	ATS
Indoor parking	< 500 €	−0.45 €	−0.64 €	−0.60 €	−0.30 €
	> 500 €	−0.18 €	−0.42 €	−0.24 €	0.07 €
	> 1,000 €	0.07 €	−0.22 €	0.10 €	0.41 €
Post of a traffic sign	–	−0.29 €	−0.23 €	−0.38 €	−0.39 €
Covered parking rack	< 500 €	0.11 €	0.09 €	0.15 €	0.16 €
	> 500 €	0.26 €	0.21 €	0.34 €	0.35 €
Bicycle parking station	< 500 €	0.09 €	0.07 €	0.12 €	0.05 €
	> 500 €	0.33 €	0.27 €	0.44 €	0.39 €
	> 1,000 €	0.51 €	0.42 €	0.69 €	0.65 €
Cycling detour [100 m]	–	−0.09 €	−0.10 €	−0.17 €	−0.10 €
Walking distance [100 m]	–	−0.25 €	−0.23 €	−0.24 €	−0.22 €

bicycle parking racks, especially when the resale value of the bicycle is over 500 €. This demonstrates the benefits of weather protection. Probably because of this and a lower perceived risk of theft, there is a general preference for bicycle parking stations with access restricted to registered users. This preference increases further along with the resale value of the bicycle being above 500 € and even more so when the resale value exceeds 1,000 € and also when the commuting distance increases. However, the preference for bicycle parking stations is less pronounced among administrative and technical staff.

The results for the influence of cycling detours and walking distances are intuitive. Both negatively affect the choice of a bicycle parking facility. Furthermore, cyclists are much more sensitive to walking distances than to cycling detours. Students and professors are more sensitive to cycling detours than scientific employees, while administrative and technical staff are less sensitive. While students are less willing to accept walking distances than scientific employees, professors and administrative and technical are more willing.

Unsurprisingly, a daily parking fee substantially impacts parking facility choice. Students are much more price-sensitive than scientific employees, while professors and administrative and technical staff are the least. Income differences are likely to explain these results, at least in part.

The estimates for the error components for different facility types indicate several significant correlations between the considered alternatives. This suggests that the different facility types should not be evaluated independently.

Table 6 presents the mean willingness to pay for the various facility types. For instance, for a scientific employee with a bicycle with a resale value of less than 500 €, the facility type bicycle parking station instead of an uncovered parking rack has on average, the same effect on the utility of a facility as a price decrease of 0.09 €. The values for indoor parking refer to the case in which participants did not report a lack of designated space for bicycle parking or that indoor parking is prohibited. Given the ambiguity surrounding indoor parking, while cyclists are generally reluctant to park indoors, this reluctance decreases as the resale value of the bicycle increases. As a result, those with expensive bicycles prefer indoor parking to uncovered parking racks, with the exception of students.

While cyclists would generally pay a small amount of money to have a covered parking rack instead of an uncovered one, this value more than doubles if the resale value of the bicycle is over 500 €. The same relationship exists for bicycle parking stations. For those who own a bicycle with a resale value of more than 1,000 €, as is often the case for e-bikes, the willingness to pay for such a facility is at the current price level of a car parking permit at RWTH (9.50 € per month or about 0.5 € per working day). However, the willingness to pay for a better parking facility type differs according to student and employment status. Students have the lowest values, probably because they have the least expensive bicycles, the shortest duration of stay, and the lowest income. Similar calculations are possible for the willingness to cycle and walk to access a parking facility. Since cyclists would pay more than 0.20 € per day for a reduction of 100 m in walking distance, this highlights the importance of an adequate placement of parking facilities.

5. Discussion

Our model shows that facility types, cycling detours, walking distances, and pricing are all relevant to the choice of bicycle parking facilities and reveals many individual-specific factors that have an additional influence. The results show that cyclists prefer weather protection and higher security against theft, which is consistent with other literature findings that cyclists prefer sheds over parking racks (Moskovitz and Wheeler, 2011; Lusk et al., 2014; Yuan et al., 2017). Furthermore, the preference is even stronger when the value of the bicycle is higher, confirming other research (Hunt and Abraham, 2007). While Arbis et al. (2016) found that a 100 m increase in walking distance reduces the use of bicycle lockers at train stations by 20 %, our estimates suggest a much stronger sensitivity of cyclists, as a 100 m increase in walking distance approximately reduces the utility of the facility by about 80 %. This may be related to the different approaches (revealed occupancy vs. stated choice). If a facility has a very high utility, an 80 % reduction may mean that it is still the most attractive parking facility. While previous literature has only analyzed the influence of walking distance on parking choice and not the influence of cycling detours, our findings indicate that cyclists are less than half as sensitive to cycling detours as they are to walking distances. A possible explanation is the difference in travel speed between walking and cycling.

Previous studies have found a willingness to pay of 1C$ for secure bicycle parking at workplaces (Fournier et al., 2023). A study by van Lierop et al. (2012) estimated that over 40 % of cyclists would be willing to pay more than 0.50C$ for secured bicycle parking in general. The results of our study indicate that only those with expensive bicycles have a comparably high willingness to pay for secure bicycle parking, as represented by the willingness to pay for bicycle parking stations. This suggests that the actual willingness to pay for bicycle parking may be lower than previously estimated. However, it should be noted that this study focused on a university context in Germany that includes students with a high price sensitivity. Moreover, Fournier et al. (2023) found that the willingness to pay for bicycle parking is higher at train and metro stations than at workplaces.

Several studies have found that segments of cyclists have different parking preferences (Hunt and Abraham, 2007; Lusk et al., 2014; Molin and Maat, 2015; Fournier et al., 2023). Fournier et al. (2023) also found a relationship between household income and the willingness to pay for secure bicycle parking. While Molin and Maat (2015) only identified age as a significant influence on segment membership, we were able to estimate other influencing parameters: student and employment status, as well as the bicycles' resale value, turned out to be important factors in the choice of a bicycle parking facility. It is, therefore, clear that parking habits differ between user groups and individuals, especially when it comes to paid parking. This suggests that providing different types of bicycle parking facilities for heterogeneous users may be a good solution, as people with an expensive e-bike would accept a parking fee for a high-quality parking facility or the detours and walking distances that are required to use a centralized parking station further away from their destination. Conversely, cyclists with less valuable bicycles should be able to use at least uncovered, but preferably covered, bicycle parking racks near their destination that are free to use. Otherwise, if access and egress times for racks are too long, they will use street furniture as traffic sign posts instead, as indicated by the model. This finding corroborates previous research on the phenomenon of fly parking (Gamman et al., 2004; Larsen, 2015). The different levels of willingness to pay for bicycle parking also show that the share of expensive bicycles determines the utility of bicycle parking facilities. As the share of e-bikes increases, this issue becomes more important – both in terms of promoting cycling and in terms of the economic welfare benefits of providing bicycle parking. Therefore, policies to improve bicycle parking facilities should be intensified, and even the costly construction of bicycle parking stations seems reasonable.

Although we considered rules prohibiting indoor parking or lack of space for it as separate factors, our results also confirm that indoor bicycle parking, such as in offices, is not preferred (Lusk et al., 2014). However, this is less evident when the resale value of the bicycle is high.

Given the high proportion of bicycle commuters, our sample is dominated by participants who frequently use bicycle parking facilities. Therefore, our results are likely to be less valid for current non-cyclists. However, according to Lusk et al. (2014), the bicycle parking preferences of cyclists and non-cyclists are similar. Nevertheless, there may be a bias because the interest in better parking facilities was a motivational factor for participating in the survey.

Due to the general rarity of bicycle parking stations, most survey respondents are likely to have limited experience with this type of parking facility. Because bicycle parking stations vary in terms of accessibility, hours of operation, or camera surveillance, the perception and definition of bicycle parking stations may also vary among our respondents, although studies have shown that the influence of camera surveillance, for example, is rather limited (Molin and Maat, 2013). Similarly, indoor parking options and their acceptance vary between institutes, companies, and even individual offices, which could explain the high σ_i coefficient for indoor parking.

Many of the possible parameters in our model are correlated. The analysis showed that, e.g., student and employment status, commuting distance, bicycle type, the resale value of the bicycle, and length of stay correlate with stronger preferences for higher-quality bicycle parking infrastructure as well as with each other. Therefore, other parameters may also be important drivers of behavior. Nevertheless, our model focused on student and employment status and resale value because they provided the most significant results.

Each of the choice sets consisted of five different alternatives. This may have overstrained some of the respondents, so we recommend decreasing the number for further experiments to reduce complexity. As the error components applied to different facility types were statistically significant, it indicates that some of the alternatives are correlated and share unobserved characteristics.

Another limitation of our study is that factors such as the objective risk of theft and its subjective perception influence where a bicycle is parked. These factors vary between countries, regions, and within cities. Therefore, the model estimates may not be fully transferable across regions or countries.

Unfortunately, it is not possible to directly link our results to mode choice decisions. As a result, we cannot calculate the increase in cycling rates due to improvements in bicycle parking facilities. Several studies have addressed this issue, but in most cases, they considered secure bicycle parking only as an abstract concept, independent of any specific facility type. Further research is required to analyze the relationship between the provision of parking facilities and modal shift potentials, considering facility types and their positioning.

In order to estimate parking preferences for different user groups at a university, we included student and employment status. It is necessary to consider the composition of users when transferring our results to companies, hospitals, supermarkets, and other places where cyclists park their bicycles. Further research should investigate whether this transfer is valid or whether preferences differ substantially in other contexts.

6. Conclusion

This paper analyzed bicycle parking preferences and estimated many variables that strongly influence the decision of where to park. The results show that preferences and willingness to pay for parking facilities differ according to student and employment status. We also found a remarkable willingness to pay for higher quality parking facilities, particularly among owners of bicycles with higher resale values, highlighting the importance of improving bicycle parking infrastructure as the share of e-bikes grows rapidly.

The key findings include:

- Bicycle parking stations are the preferred parking facility in most cases.
- Cyclists prefer covered to uncovered parking racks.
- Indoor parking at the workplace is primarily an option for people with high-value bicycles.
- Cyclists are about two times more sensitive to walking distances than to cycling detours.
- Parking preferences and the willingness to pay for bicycle parking vary considerably by student and employment status, and the resale value of the bicycle.

Cyclists tend to avoid parking their bicycles at a post of a traffic sign (or on-street, respectively) and taking the bicycle with them to their place of work or study (indoor parking), even when indoor parking is generally available. Parking indoors or at a post of a traffic sign seems to be a fallback behavior, practiced when there is no suitable alternative.

Since the parking preferences of cyclists emerged to be very heterogeneous, a good bicycle parking infrastructure takes these aspects into account and provides a range of options where bicycle parking stations cannot be provided for everyone in every location. In this case, combining bicycle parking stations with bicycle parking racks near destinations is recommended, which should be covered if possible. Since all user groups in our model were more sensitive to walking distances than cycling detours, bicycle parking infrastructure should be accessible by riding, without sections where cyclists have to walk their bikes.

An open question is how to design an optimal parking infrastructure within financial constraints. The calculated willingness to pay rates provide a basis for analyzing the theoretical benefits of measures to improve bicycle parking. Since different parking facility types require varying levels of investment, the quantitative user benefits could be used to decide between them and to evaluate acceptable detours resulting from placement strategies.

As the bicycle fleet in Germany changes and the share of e-bikes increases, it is also important to consider how this will affect demand and preferences for bicycle parking. For example, questions remain about the charging infrastructure for e-bikes. Other open questions relate to other destinations, trip purposes, and length of stay, e.g., at home or supermarkets.

CRediT authorship contribution statement

David Kohlrautz: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tobias Kuhnimhof:** Supervision, Resources, Funding acquisition.

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Declaration of competing interest

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