

World Conference on Transport Research - WCTR 2023 Montreal 17-21 July 2023

## A Joint Model of Cyclist Choice of Bicycle Parking Facilities

David Kohlrautz<sup>a,\*</sup>, Tobias Kuhnimhof<sup>a</sup>

<sup>a</sup>*RWTH Aachen University, Chair and Institute of Urban and Transport Planning, 52074 Aachen, Germany*

---

### Abstract

More and better bicycle parking facilities are essential to promote cycling, and understanding parking behavior is a key factor in addressing their needs. Therefore, this paper analyzes the parking preferences of cyclists with respect to facility type and location (i.e., with respect to access and egress distances), as well as the influence of bicycle parking fees and user-specific factors.

This analysis is based on a stated-preference experiment ( $n = 2,960$ ) on bicycle parking choice behavior among university students and employees of RWTH Aachen University, one of the largest universities in Germany. We use a mixed logit model to examine the influence of facility types, facility's placement-related cycling detours and walking distances, and the price of a parking facility. The results indicate that bicyclists are more than twice as sensitive to walking distances than to cycling detours. While cyclists prefer bicycle parking stations and covered over uncovered parking racks, they avoid taking bicycles into buildings to store them, e.g., in offices. Furthermore, they are reluctant to conduct fly parking, such as at street furniture. The study reveals that student and employee status and the resale value of the bicycle are important user-specific factors influencing the choice between parking facilities. Furthermore, there is a considerable, largely varying willingness to pay for bicycle parking, especially among those with expensive bicycles.

© 2024 The Authors. Published by ELSEVIER B.V.

This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0>)

Peer-review under responsibility of the scientific committee of the 16th World Conference on Transport Research

**Keywords:** Bicycle parking; Cycling; Stated preference survey; Mixed Logit; Mobility behavior; University mobility

---

---

\* Corresponding author. Tel.: +49 241 80 26212

E-mail address: [kohlrautz@isb.rwth-aachen.de](mailto:kohlrautz@isb.rwth-aachen.de)

## 1. Introduction

An often-cited publication on bicycle parking is by Hunt and Abraham (2007). They found for Edmonton (CA) that secure parking at the destination had the same effect on the utility of cycling as a mode as a reduction of 26.5 min in time spent on a roadway in mixed traffic. 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). Relevant locations for bicycle parking are work and study locations, as the average parking time there is the longest, with the exception of home parking. Due to the long parking time, these locations are vulnerable to theft, specifically if there are no 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. 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 less space is required for parking a bicycle than for parking cars. Parking a car requires about 25-30 m<sup>2</sup> (FGSV, 2005). While the area needed for parking 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 around 2.5-3.0 m<sup>2</sup> 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 attractive bicycle parking facilities are often considered essential to working toward these goals. 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.

Overcrowded bicycle parking facilities are a common sight at universities. At the same time, there are often other facilities nearby with free capacity. This indicates an inefficient placement of facilities that do not meet user needs. To promote cycling effectively, it is necessary to gain a deep understanding of bicycle parking preferences. However, previous literature lacks a detailed consideration of bicycle parking facility types. Previous studies have primarily focused on the general impact of bicycle parking provision on mode choice, without consideration of facility quality and position (e.g., Hunt and Abraham (2007), Handy and Xing (2011), Buehler (2012)).

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:

- 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?

Next, 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, such as Hunt and Abraham (2007) and Bueno et al.

(2017), found the level of influence to be very high, while others found it to be low or even statistically insignificant, especially for showers and clothing lockers (Handy and Xing, 2011; Stinson and Bhat, 2004).

Table 1: Literature findings regarding bicycle parking facilities

| Authors                                                 | Citation                | Methods                  | Survey period | Survey area               | Key findings                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------------------------------------|-------------------------|--------------------------|---------------|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Buehler, R.                                             | Buehler (2012)          | Household surveys        | 2007-2008     | Washin gton D.C. (US)     | <ul style="list-style-type: none"> <li>Results indicate that bicycle parking and clothes lockers or cyclist showers are related to higher levels of bicycle commuting.</li> <li>The combined supply of bicycle parking, clothes lockers, and showers increases bicycle commuting more than the provision of bicycle parking only.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Bueno, P. C.; Gomez, J.; Peters, J. R.; Vassallo, J. M. | Bueno et al. (2017)     | Household surveys        | 2010-2011     | N. Y. and New Jersey (US) | <ul style="list-style-type: none"> <li>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.</li> <li>Bicycle-related benefits are the most important factor explaining the decision to cycle to work.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Handy, S.; Xing, Y.                                     | Handy and Xing (2011)   | Quantitati ve Survey     | 2006          | Small cities (US)         | <ul style="list-style-type: none"> <li>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.</li> </ul>                                                                                                                                                                                                                       |
| Hunt, J. D.; Abraham, J. E.                             | Hunt and Abraham (2007) | Stated preference survey | 1994          | Edmont on (CA)            | <ul style="list-style-type: none"> <li>The estimates indicate that secure parking is much more important than showers.</li> <li>Secure parking has the same effect on utility as a decrease of 26.5 min in time spent on a roadway in mixed traffic.</li> <li>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.</li> <li>For the lowest three cost groups, secure parking becomes relatively more attractive as 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 place a higher value on showers.</li> </ul> |
| Lusk, A. C.; Xu, W.; Zhou, L.                           | Lusk et al. (2014)      | Quantitati ve survey     | 2012          | Hangzh ou (CN)            | <ul style="list-style-type: none"> <li>Parking sheds were the most used and highly preferred by both genders.</li> <li>Some of the bicyclists in Hangzhou parked their bicycles in a home or office room. However, both bicyclists and non-bicyclists did not prefer this, with women preferring this option even less.</li> <li>The uses and preferences of bicyclists who cycled more than three days per week compared</li> </ul>                                                                                                                                                                                                                                                                                                                                                     |

to all bicyclists, and for bicyclists and non-bicyclists, were similar.

|                                        |                              |                                                       |            |                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------------------------------------|------------------------------|-------------------------------------------------------|------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Molin, E.; Maat, K.                    | Molin and Maat (2015)        | Stated preference survey                              | 2012       | Delft (NL)        | <ul style="list-style-type: none"> <li>If parking price or walking time increases, the utility of the bicycle parking facility decreases.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Moskovitz, D. A., Wheeler, N. M.       | Moskovitz and Wheeler (2011) | Utilization analysis via time series Photography      | 12 h, 2009 | Portland (US)     | <ul style="list-style-type: none"> <li>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.</li> <li>A preference for parking sheds by all study participants is statistically significant.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Noland, R. B.; Kunreuther, H.          | Noland and Kunreuther (1995) | Quantitative survey                                   | 1991       | Philadelphia (US) | <ul style="list-style-type: none"> <li>Bicycle parking facilities at places of employment are necessary to enhance the convenience of the mode.</li> <li>Those respondents with safe bicycle parking available have a statistically significant higher mean perception of bicycling convenience than those without parking available.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Stinson, M.; Bhat, C.                  | Stinson and Bhat (2004)      | Quantitative survey                                   | 2002       | US and CA         | <ul style="list-style-type: none"> <li>Bicycle racks or locker facilities at the workplace increase the likelihood of commuting by bicycle. However, neither the presence of showers nor clothing lockers was statistically significant.</li> <li>In summary, while commuter bicyclists (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.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Wardman, M.; Tight, M. R.; Page, M.    | Wardman et al. (2007)        | Stated preference survey and revealed preference data | 1998       | GB                | <ul style="list-style-type: none"> <li>Outdoor cycle parking facilities are equivalent to 2.5 minutes of less time spent cycling.</li> <li>Due to improved security, indoor cycle parking facilities were valued more highly at 4.3 minutes. Showers, changing facilities, and indoor bicycle parking combined were valued at 6.0 minutes.</li> <li>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.</li> <li>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.</li> <li>Providing work-related facilities, particularly showers and indoor parking, improves cycle market shares. However, the impact on other modes is limited.</li> </ul> |
| Yuan, C.; Sun, Y.; Lv, J.; Lust, A. C. | Yuan et al. (2017)           | Utilization analysis                                  | 2011       | Beijing (CN)      | <ul style="list-style-type: none"> <li>The occupancy rate for shed spaces is higher than for racks indicating that cyclists prefer sheds.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

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 and 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 choice of bicycle parking. They also analyzed the variables that influence the affiliation of people to the segments and found that only age was statistically significant. 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.

Furthermore, the abilities to store a bicycle vary 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 regarding bicycle parking habits, e.g., the proportion of bicycles parked in parking facilities versus decentralized parking on the street, at lamp posts, etc. For more information on previous literature on bicycle parking, we refer to the review by Heinen and Buehler (2019).

Overall, there is a lack of knowledge about quantifiable preferences for different parking facility types and their interaction with walking distances, cycling detours, and parking fees. For walking distances and parking fees, previous research is limited to railway stations, and cycling detours have not been the subject of research. In addition, most findings focus on a few facility types, such as sheds versus parking racks, and do not consider the variety of possible combinations of parking facility attributes. 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.

### 3. Method

#### 3.1. Stated preference experiment

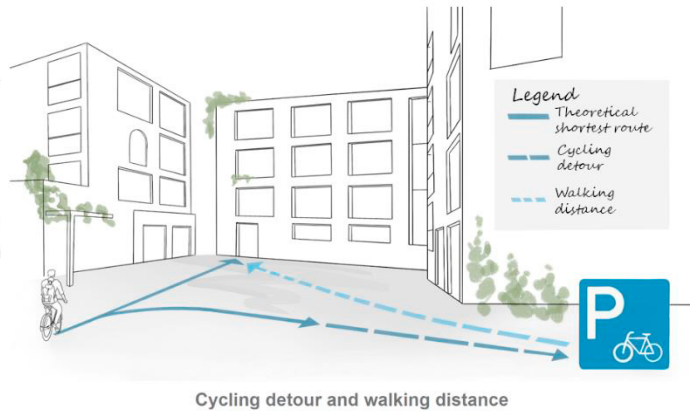
For our analysis, we conducted a survey including a stated preference experiment among employees and students of RWTH Aachen University in July 2022 (i.e., during a period when COVID-19-related restrictions had been eased). In the stated preference part of the survey, participants were asked to choose between parking options in hypothetical choice situations (i.e., choice sets). Each person received eight of these selected from a total of 64 generated choice sets. We generated the choice sets using Ngene, applying an efficient design that minimizes the d-error using coefficients from a pre-test. 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.

Figure 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. First, there were two attributes related to the location of the respective bicycle parking facility: the cycling detour and the 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). Second, the bicycle parking station sometimes had a daily charge (measured in €). Table 2 shows the ranges of these attributes. As can be seen, not all attribute values were combined with all types of bicycle parking facilities in order to create 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. Similarly, since public bicycle parking is usually free of charge, we assumed daily fees only for the high-quality ‘bicycle parking station’.

### Which parking facility do you choose in the following situation?

- Usual commute to the workplace with the bicycle
- *Indoor parking* circumstance is the same as the status quo for bicycle parking in the building of your workplace
- Access to the bicycle parking station is limited to registered users
- Cycling detour is the additional cycling distance compared to the theoretical shortest route
- Walking distance is the distance of the walking path between the parking facility and the destination
- **Cycling detour, walking distance, and parking fee** of the parking facilities vary between the situations



| Indoor parking        | Post of a traffic sign | Uncovered bicycle parking rack | Covered bicycle parking rack | Bicycle parking station  |
|-----------------------|------------------------|--------------------------------|------------------------------|--------------------------|
| Cycling detour 0 m    | Cycling detour 100 m   | Cycling detour 50 m            | Cycling detour 50 m          | Cycling detour 100 m     |
| Walking distance 0 m  | Walking distance 0 m   | Walking distance 200 m         | Walking distance 300 m       | Walking distance 50 m    |
| Daily parking fee 0 € | Daily parking fee 0 €  | Daily parking fee 0 €          | Daily parking fee 0 €        | Daily parking fee 1.00 € |
| <input type="radio"/> | <input type="radio"/>  | <input type="radio"/>          | <input type="radio"/>        | <input type="radio"/>    |

Figure 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 |

Participants were instructed that the ‘indoor parking’ alternative corresponded to their current situation of parking a bicycle indoors at their place of work or study. Consequently, those who could take a bicycle with them into 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). Furthermore, the description of the ‘bicycle parking station’ clarifies that only registered users would have access to the parking station, ensuring a high level of security against theft.

### 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, 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’, or a rule prohibiting bringing bicycles into the building or storing them 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 contains professors, scientific employees (mostly Ph.D. students), and administrative and technical staff (ATS). The shares displayed refer to the population according to RWTH statistics.

Table 3: Sample overview

| Group                                 | Male   |          |       | Female |          |       | N.I.<br>/Diverse | Electric-<br>bicycle<br>share |
|---------------------------------------|--------|----------|-------|--------|----------|-------|------------------|-------------------------------|
|                                       | Sample | In total | Share | Sample | In total | Share |                  |                               |
| Students                              | 1 036  | 27 082   | 4%    | 524    | 11 923   | 4%    | 23               | 4 %                           |
| Professors                            | 59     | 290      | 20%   | 18     | 88       | 20%   | 3                | 31 %                          |
| Scientific<br>employees               | 590    | 3 783    | 16%   | 238    | 1 411    | 17%   | 15               | 12 %                          |
| Administrative<br>and technical staff | 192    | 1 944    | 10%   | 256    | 1 685    | 15%   | 6                | 48 %                          |
| $\Sigma$                              | 1 877  | 33 099   | 6%    | 1 036  | 15 107   | 7%    | 47               | 14 %                          |

While professors and administrative and technical staff are usually long-term employees, most scientific employees' employment duration is limited to around 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 doing their Bachelor's and Master's degrees or both. The length of a typical stay on campus on a regular work or study day varies between groups. 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 July 6, 2022, 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 s-pedeles, cargo bikes, folding bikes, etc. However, the shares of e-bikes differ between the groups. As a result, the distribution of expensive bicycles is also quite disproportionate. Furthermore, as expected, the total number of professors in the survey is low compared to the other groups.

Figure 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 group, 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 has a different composition than RWTH in general and beyond because we know from another mobility survey we conducted at RWTH two weeks earlier that the share of cycling at RWTH is lower.

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.

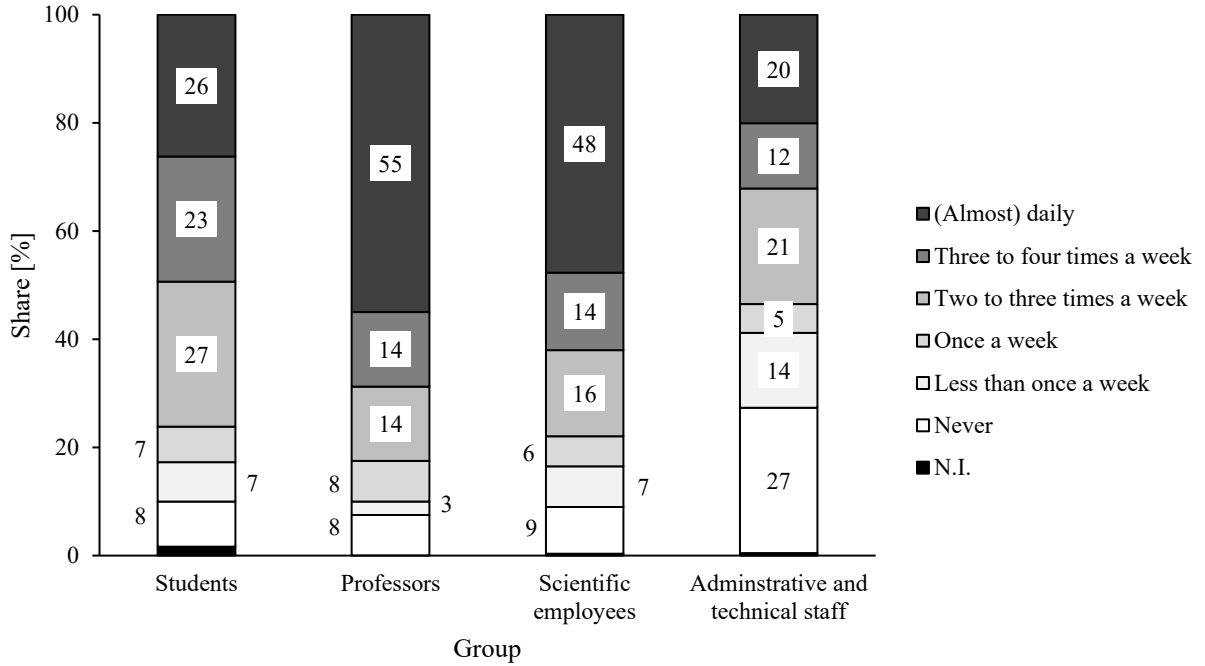


Figure 2: Survey participants by frequency of bicycle use to commute to RWTH

### 3.4. Model Estimation

To analyze participants' preferences for parking facility types, cycling detours, walking distances, and willingness to pay, we ran a mixed logit model using the Apollo package in R. For more information, see Hess and Palma (2022). Logit models are a standard method for modeling choices between different alternatives. They are based on random utility theory. Multinomial logit modeling is an established method for decisions with more than two alternatives. Individuals ( $q$ ) in a given situation ( $t$ ) choose the alternative ( $i$ ) that maximizes their utility ( $U_{itq}$ ). In our case, each alternative represents a combination of parking facility type, cycling detour, walking distance, and parking fee. In addition to the objective utility, calculated as a linear combination of the coefficients ( $\beta_q$ ) multiplied by the parameters of the alternative and the respondent ( $X_{itq}$ ), there is an additional error term ( $\varepsilon_{itq}$ ) representing the variation of individual preferences. This gives the following utility function:

$$U_{itq} = \beta_q X_{itq} + \varepsilon_{itq} \quad (1)$$

Additional assumptions concern the distribution of the error term (they should be independent and identically distributed according to the Gumbel distribution (McFadden, 1974; Profillidis and Botzoris, 2019)) and the independence of irrelevant alternatives (McFadden, 1974). This allows for relative comparisons between odds and makes logit models useful for comparing the influence of different attributes, such as cycling detours and walking distances.

Because each respondent faced eight choice sets, we chose a mixed logit model. We added random coefficients for each type of bicycle parking facility ( $Y_{iq}$ ) to allow for correlation with individuals and alternatives.

$$U_{itq} = \beta_q X_{itq} + \eta_{iq} Y_{iq} + \varepsilon_{itq} \quad (2)$$

The following formula defines the coefficients  $\eta_{iq}$ , where  $\mu_{(\beta)}$  is the mean,  $\sigma_{(\beta)}$  is the standard deviation and  $\xi_{iq}$  is an error term:

$$\eta_{iq} = \mu_{\beta} + \sigma_{\beta} \cdot \xi_{iq} \quad (3)$$

For the error term, we drew numbers 500 times using the Modified Latin Hypercube Sampling' method and applied normal distributions. This was done because they led to a better model fit (BIC,  $r^2$ , log-likelihood) in our example than other distributions. Finally, the probability of each alternative is given by the following formula:

$$p(i, t) = \frac{e^{U_{itq}}}{\sum_i U_{itq}} \quad (4)$$

In terms of interpreting the results, the coefficients  $\beta_q$  describe the logarithm of the odds of the variables' influence. For more information on mixed logit models, see Hensher and Greene (2003).

Dividing the coefficient for an attribute  $k$  ( $\beta_k$ ) by the cost coefficient ( $\beta_{c_g}$ ) estimates the average willingness to pay for the attribute, as the influence of the attribute has the same effect on the probability of the alternative as a price change of that magnitude (Bliemer and Rose, 2013). In our example, the cost coefficient differentiates by group affiliation ( $g$ ). As a result, the following formula estimates the willingness to pay:

$$\text{Willingness to pay}_k = \frac{\beta_k}{\beta_{c_g}} \quad (5)$$

## 4. Results

### 4.1. Descriptive analysis of bicycle parking preferences

The following figures show the selected bicycle parking facilities based on the stated preference experiment. It has to be borne in mind that this is an analysis of hypothetical choice sets and does not represent revealed real-world choices. Figure 3 shows the shares of the bicycle parking facilities by respondent groups. Evidently, there are substantial differences between groups; e.g., the percentage of indoor parking is much lower for students than for the other groups.

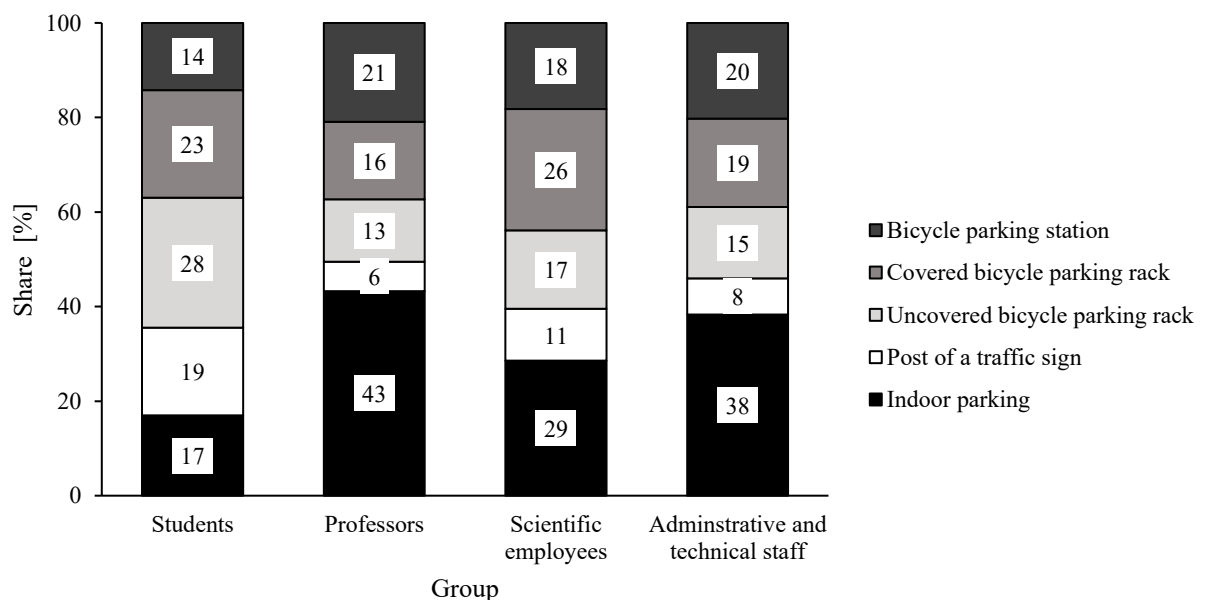


Figure 3: Choice of bicycle parking facility by respondent group

Figure 4 illustrates the relationship between commuting distance and the choice of a bicycle parking facility. There is a clear tendency to choose higher-quality bicycle parking facilities (bicycle parking station, indoor parking) with increasing commuting distance. Similarly, but not shown, the tendency to select higher-quality bicycle parking increases with a longer duration of stay on campus and higher bicycle resale value as well as for electric bicycles.

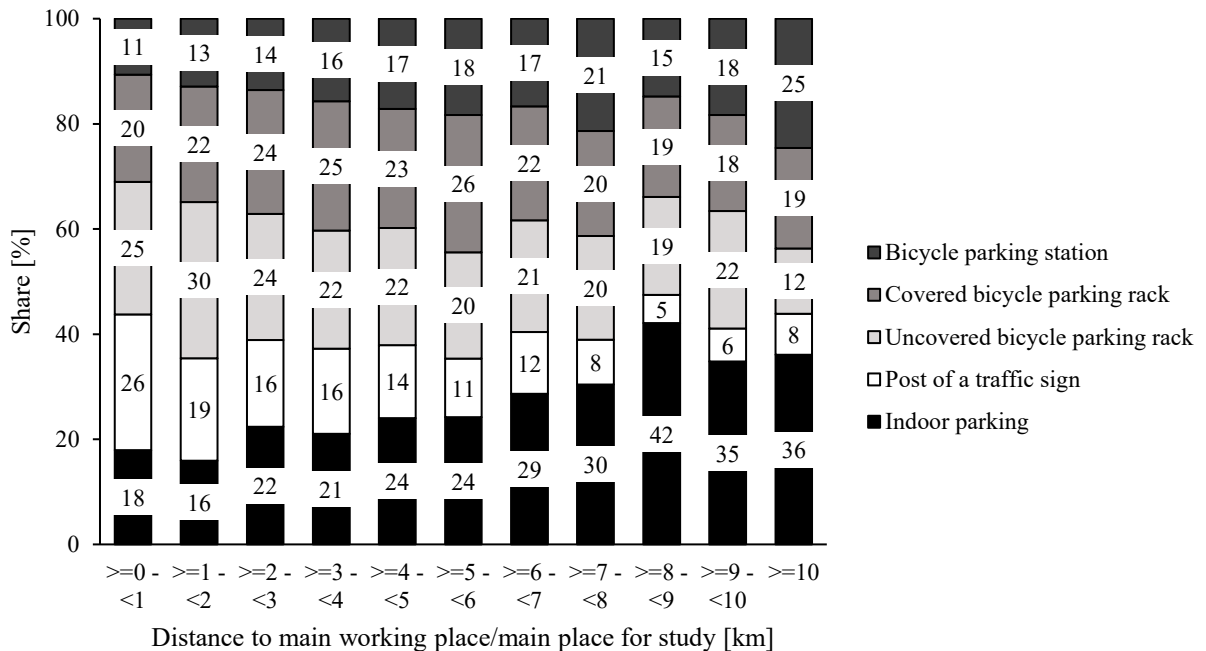


Figure 4: Choice of bicycle parking facility by commuting distance

#### 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 -22,633 and a pseudo- $r^2$  of 0.394. This value indicates the complexity of bicycle parking behavior and suggests the potential influence of additional unobserved factors or the occurrence of inconsistent choices made by respondents. Table 4 shows the model's coefficients using the scientific employees and the uncovered bicycle parking rack as the reference category. All displayed coefficients are significant, at least on a 0.05 p-value level. The p-values were calculated using the Apollo package based on classical standard errors.

While the  $\beta$  correspond to standard logit coefficients, the  $\mu_{(\beta)}$  and  $\sigma_{(\beta)}$  are coefficients for each facility type.  $\mu_{(\beta)}$  is the mean and  $\sigma_{(\beta)}$  represents the standard deviations. Ignore whether  $\sigma_{(\beta)}$  is positive or negative, as the multiplier  $\xi_{iq}$  is symmetrically distributed around zero.

There is a general preference for bicycle parking stations. The probability increases further along with the resale value of the bicycle and the commuting distance. However, the preference for bicycle parking stations is less pronounced among students and administrative and technical staff. Furthermore, respondents prefer covered to uncovered bicycle parking racks, especially when the resale value of the bicycle is higher than 500 €. This demonstrates the benefits of weather protection. On-street parking, as represented by the post of a traffic sign, is viewed very negatively, probably due to the higher risk of theft and vandalism.

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, these barriers to indoor bicycle parking further reduce the utility and, thus, the likelihood of indoor parking. For students, indoor parking is particularly unlikely. On the contrary, being a member of the administrative and technical staff or owning a bicycle with a resale value of more than 500 € increases the likelihood. However, the  $\sigma$ -estimate for indoor parking is relatively high, suggesting that the perception of this parking option varies.

Table 4: Coefficients mixed logit model

|                                                          |                 | Est.   | Std. err. | t-ratio | p-value  |
|----------------------------------------------------------|-----------------|--------|-----------|---------|----------|
| Indoor parking                                           | $\mu(\beta)$    | -3.052 | 0.279     | -10.956 | <2E-12   |
|                                                          | $\sigma(\beta)$ | 5.084  | 0.156     | 32.537  | <2E-12   |
| Indoor parking <sub>Student</sub>                        | $\beta$         | -2.447 | 0.266     | -9.199  | <2E-12   |
| Indoor parking <sub>ATS</sub>                            | $\beta$         | 1.902  | 0.309     | 6.156   | 7.48E-10 |
| Indoor parking <sub>RV &gt; 500 €</sub>                  | $\beta$         | 2.282  | 0.247     | 9.245   | <2E-12   |
| Indoor parking <sub>No designated space</sub>            | $\beta$         | -0.838 | 0.235     | -3.571  | 0.00036  |
| Indoor parking <sub>Indoor parking forbidden</sub>       | $\beta$         | -0.744 | 0.193     | -3.860  | 0.00011  |
| Pole of a traffic sign                                   | $\mu(\beta)$    | -2.035 | 0.073     | -27.884 | <2E-12   |
|                                                          | $\sigma(\beta)$ | 1.966  | 0.075     | 26.336  | <2E-12   |
| Uncovered bicycle parking rack                           | $\mu(\beta)$    | Fixed  |           |         |          |
|                                                          | $\sigma(\beta)$ | 1.375  | 0.065     | 21.081  | <2E-12   |
| Covered bicycle parking rack                             | $\mu(\beta)$    | 0.659  | 0.063     | 10.499  | <2E-12   |
|                                                          | $\sigma(\beta)$ | -1.553 | 0.063     | -24.506 | <2E-12   |
| Covered bicycle parking rack <sub>RV &gt; 500 €</sub>    | $\beta$         | 0.862  | 0.103     | 8.395   | <2E-12   |
| Bicycle parking station                                  | $\mu(\beta)$    | 0.904  | 0.180     | 5.015   | 5.29E-07 |
|                                                          | $\sigma(\beta)$ | 2.906  | 0.087     | 33.559  | <2E-12   |
| Bicycle parking station <sub>Student</sub>               | $\beta$         | -0.575 | 0.179     | -3.210  | 0.00133  |
| Bicycle parking station <sub>ATS</sub>                   | $\beta$         | -0.581 | 0.237     | -2.454  | 0.01412  |
| Bicycle parking station <sub>RV &gt; 500 €</sub>         | $\beta$         | 2.042  | 0.160     | 12.783  | <2E-12   |
| Bicycle parking station <sub>Distance to RWTH [km]</sub> | $\beta$         | 0.049  | 0.013     | 3.748   | 0.00018  |
| Cycling detour [m]                                       | $\beta$         | -0.006 | 0.000     | -22.185 | <2E-12   |
| Cycling detour <sub>Student</sub> [m]                    | $\beta$         | -0.002 | 0.000     | -6.934  | 4.11E-12 |
| Cycling detour <sub>Professor</sub> [m]                  | $\beta$         | -0.002 | 0.001     | -2.603  | 0.00924  |
| Cycling detour <sub>ATS</sub> [m]                        | $\beta$         | 0.001  | 0.000     | 2.522   | 0.01168  |
| Walking distance [m]                                     | $\beta$         | -0.016 | 0.000     | -50.150 | <2E-12   |
| Walking distance <sub>Student</sub> [m]                  | $\beta$         | -0.002 | 0.000     | -6.448  | 1.13E-10 |
| Walking distance <sub>Professor</sub> [m]                | $\beta$         | 0.004  | 0.001     | 4.040   | 5.35E-05 |
| Walking distance <sub>ATS</sub> [m]                      | $\beta$         | 0.006  | 0.001     | 11.310  | <2E-12   |
| Parking fee                                              | $\beta$         | -6.751 | 0.132     | -51.297 | <2E-12   |
| Parking fee <sub>Student</sub>                           | $\beta$         | -1.540 | 0.171     | -9.023  | <2E-12   |
| Parking fee <sub>Professor</sub>                         | $\beta$         | 1.580  | 0.303     | 5.207   | 1.91E-07 |
| Parking fee <sub>ATS</sub>                               | $\beta$         | 1.922  | 0.181     | 10.620  | <2E-12   |

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. While students are less willing to accept walking distances than scientific employees, professors, and administrative and technical staff are more willing. Students and professors are more sensitive to cycling detours than scientific employees, while administrative and technical staff are the least sensitive.

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

Table 5 shows the willingness to pay for a parking facility in relation to a parking rack without a cover, with a cycling detour and a walking distance of zero length. The row ‘Indoor parking’ refers to the case where participants neither reported that there is no designated space for bicycle parking nor that indoor parking is prohibited. Overall, there is a positive willingness to pay for covered bicycle parking racks and parking stations for the reference case of a bicycle resale value below 500 €. However, the order of the two alternatives depends on the group membership. The other facility types, cycling detour, walking distance, and daily parking fee, have a negative willingness to pay value.

Table 5: Willingness to pay for different parking facilities in € per day for a bicycle resale value below 500 €

| RV < 500 €               | Ref. (Scientific employees) | Students | Professors | ATS     |
|--------------------------|-----------------------------|----------|------------|---------|
| Indoor parking           | -0.45 €                     | -0.66 €  | -0.59 €    | -0.24 € |
| Post of a traffic sign   | -0.30 €                     | -0.25 €  | -0.39 €    | -0.42 € |
| Covered parking rack     | 0.10 €                      | 0.08 €   | 0.13 €     | 0.14 €  |
| Bicycle parking station  | 0.13 €                      | 0.04 €   | 0.17 €     | 0.07 €  |
| Cycling detour [100 m]   | -0.09 €                     | -0.10 €  | -0.10 €    | -0.10 € |
| Walking distance [100 m] | -0.24 €                     | -0.23 €  | -0.25 €    | -0.22 € |

The willingness to pay for indoor parking is negative for all groups, although neither the negative impact of no designated space nor a rule prohibiting indoor parking is considered. Similarly, the willingness to pay for the post of a traffic sign is negative for all groups. Students have the smallest negative value here because they are likely to have the least expensive bicycles, the shortest length of stay, and the lowest income. The same factors may explain why students are much less willing to pay for covered parking racks and bicycle parking stations. Similar calculations are possible for the willingness to cycle and walk to access a parking facility. Although the coefficients in the model showed significant differences for the groups, their willingness to pay for a shorter cycling detour or walking distance is almost at the same level.

Table 6 shows the willingness to pay for the facilities assuming a bicycle with a resale value of more than 500 €. The willingness to pay for indoor parking has changed as the negative value became smaller and even positive for administrative and technical staff. In addition, the willingness to pay doubled for covered parking racks and tripled for bicycle parking stations compared to the case where the bicycle has a resale value below 500 €. The willingness to pay for a bicycle parking station is now at the current price level of a car parking permit at RWTH, which is 9.50 € per month or about 0.5 € per working day.

Table 6: Willingness to pay for different parking facilities in € per day for a bicycle resale value above 500 €

| RV > 500 €              | Ref. (Scientific employees) | Students | Professors | ATS    |
|-------------------------|-----------------------------|----------|------------|--------|
| Indoor parking          | -0.11 €                     | -0.39 €  | -0.15 €    | 0.23 € |
| Covered parking rack    | 0.23 €                      | 0.18 €   | 0.29 €     | 0.31 € |
| Bicycle parking station | 0.44 €                      | 0.29 €   | 0.57 €     | 0.49 € |

## 5. Discussion

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 (Lusk et al., 2014; Moskovitz and Wheeler, 2011; 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). For owners of expensive bicycles, higher quality parking facilities could compensate for the influence of longer walking distances and cycling detours, e.g., to reach a centrally located bicycle parking station.

Molin and Maat (2015) found that cyclists can be grouped according to their parking preferences. While they only identified age as a significant influence on group membership, we were able to estimate other influential parameters: student status, belonging to different groups of university employees, and the bicycles' resale value turned out to be important factors in the choice of a bicycle parking facility and influence the willingness to pay. Therefore, it is evident that parking habits differ between groups and individuals, specifically when it comes to priced parking. This suggests that providing different types of bicycle parking facilities for heterogeneous user groups may be a good solution, e.g., people with an expensive e-bike can pay for a limited high-quality parking facility or accept a detour. Conversely, cyclists with less valuable bicycles should be able to use at least uncovered, but preferably covered, bicycle parking racks near their destination. Otherwise, cyclists will use street furniture as posts for traffic signs instead if access and egress times for racks are too long (Gamman et al., 2004).

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 contains mainly participants who often use bicycle parking facilities. Therefore, our results are likely less valid for current non-cyclists. However, according to Lusk et al. (2014), the preferences of cyclists and non-cyclists regarding bicycle parking are similar.

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

Due to the general rarity of bicycle parking stations, most survey respondents are likely to have limited experience with one or a few examples of them. Because bicycle parking stations differ in terms of accessibility, opening times, or surveillance, the perception and definition of bicycle parking stations may also vary among our respondents. Likewise, indoor parking opportunities differ between institutes, companies, and even offices. This could explain why the  $\sigma$  coefficient for indoor parking is relatively high.

Many of the possible parameters in our model are correlated. The analysis showed that, e.g., group membership, 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 group membership and resale value because they provided the most significant results, and adding other factors did not improve the model much.

Unfortunately, linking our results to mode choice decisions is not possible. As a result, we cannot directly calculate the increase in cycling shares as a result of 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 a

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.

We included student and employee group status because we estimated parking preferences for different groups at RWTH. It is necessary to consider the composition of users while 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

Improving bicycle parking facilities is an essential measure to encourage employees, students, and guests to commute by bicycle. Our results show a remarkable willingness to pay for higher-quality parking facilities, particularly among owners of bicycles with higher resale values. The results also show that preferences and willingness to pay for parking facilities differ between groups. The main findings are:

- Bicycle parking stations are the preferred parking facility in most cases.
- Cyclists prefer covered to uncovered parking racks.
- 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); the latter applies even when indoor parking is generally available.
- Indoor parking at the workplace is primarily an option for people with high-value bicycles.
- Cyclists are about two and a half times more sensitive to walking distances than to cycling detours.
- The willingness to pay for bicycle parking depends on group membership and indirectly on the bike's resale value.

A good bicycle parking infrastructure takes these aspects into account and provides a range of options when bicycle parking stations cannot be provided for everyone in every location. Therefore, an open question is the design of an optimal parking infrastructure within financial constraints.

The calculated willingness to pay rates provide a basis for analyzing the theoretical benefits of measures to increase bicycle parking. Since parking facility types require different levels of investment, the quantitative user benefits could be used to decide between them and to evaluate acceptable detours resulting from placement strategies. Since all groups are more sensitive to walking distances than cycling detours, bicycle parking infrastructure should be accessible by cycling without sections where cyclists have to push their bikes.

Overall, to design parking facilities according to user needs, good parking facilities should be provided close to destinations. If it is not possible to provide bicycle parking stations in all buildings, it is recommended to combine them with parking racks, which should be covered if possible. The use of indoor parking or parking at the post of a traffic sign appears to be a fallback behavior that is practiced when there is no suitable alternative.

As the bicycle fleet in Germany is changing and the share of e-bikes increases, it is also important to consider how this affects 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.

## 7. Author contributions and acknowledgments

The authors confirm their contribution to the paper as follows: research, analysis, and interpretation: David Kohlrantz. Supervision and advisory: Tobias Kuhnimhof. All authors reviewed the results and approved the final version of the manuscript.

RWTH Aachen University financed this research to improve its bicycle parking facilities.

## 8. References

- Bliemer, M.C., Rose, J.M., 2013. Confidence intervals of willingness-to-pay for random coefficient logit models. *Transportation Research Part B: Methodological* 58, 199–214. <https://doi.org/10.1016/j.trb.2013.09.010>.
- Buehler, R., 2012. Determinants of bicycle commuting in the Washington, DC region: The role of bicycle parking, cyclist showers, and free car parking at work. *Transportation Research Part D: Transport and Environment* 17, 525–531. <https://doi.org/10.1016/j.trd.2012.06.003>.
- Bueno, P.C., Gomez, J., Peters, J.R., Vassallo, J.M., 2017. Understanding the effects of transit benefits on employees' travel behavior: Evidence from the New York-New Jersey region. *Transportation Research Part A: Policy and Practice* 99, 1–13. <https://doi.org/10.1016/j.tra.2017.02.009>.
- ChoiceMetrics, 2018. Ngene User Manual & Reference Guide, 241 pp.
- FGSV, 2005. Empfehlungen für Anlagen des ruhenden Verkehrs. Forschungsgesellschaft für Straßen- und Verkehrswesen, Köln.
- FGSV, 2012. Hinweise zum Fahrradparken. FGSV Verlag, Köln.
- Gamman, L., Thorpe, A., Willcocks, M., 2004. Bike Off! Tracking the Design Terrains of Cycle Parking: Reviewing Use, Misuse and Abuse. *Crime Prev Community Saf* 6, 19–36. <https://doi.org/10.1057/palgrave.cpcs.8140199>.
- Handy, S.L., Xing, Y., 2011. Factors Correlated with Bicycle Commuting: A Study in Six Small U.S. Cities. *International Journal of Sustainable Transportation* 5, 91–110. <https://doi.org/10.1080/15568310903514789>.
- Hartog, J.J. de, Boogard, H., Nijland, H., Hoek, G., 2010. Do the health benefits of cycling outweigh the risks? *Environmental health perspectives* 118, 1109–1116. <https://doi.org/10.1289/ehp.0901747>.
- Heinen, E., Buehler, R., 2019. Bicycle parking: a systematic review of scientific literature on parking behaviour, parking preferences, and their influence on cycling and travel behaviour. *Transport Reviews* 39, 630–656. <https://doi.org/10.1080/01441647.2019.1590477>.
- Hendriksen, I.J.M., Simons, M., Garre, F.G., Hildebrandt, V.H., 2010. The association between commuter cycling and sickness absence. *Preventive Medicine* 51, 132–135. <https://doi.org/10.1016/j.ypmed.2010.05.007>.
- Hensher, D.A., Greene, W.H., 2003. The Mixed Logit model: The state of practice. *Transportation*, 133–176. <https://doi.org/10.1023/A:1022558715350>.
- Hess, S., Palma, D., 2022. Apollo: a flexible, powerful and customisable freeware package for choice model estimation and application, 227 pp.
- Hunt, J., Abraham, J., 2007. Influences on bicycle use. *Transportation* 34, 453–470. <https://doi.org/10.1007/s11116-006-9109-1>.
- Lusk, A.C., Wen, X., Zhou, L., 2014. Gender and used/preferred differences of bicycle routes, parking, intersection signals, and bicycle type: Professional middle class preferences in Hangzhou, China. *Journal of transport & health* 1, 124–133. <https://doi.org/10.1016/j.jth.2014.04.001>.
- McFadden, D., 1974. Conditional logit analysis of qualitative choice behavior, in: Zarembka, P. (Ed.), *Frontiers in Econometrics*, pp. 105–142.
- Molin, E., Maat, K., 2015. Bicycle parking demand at railway stations: Capturing price-walking trade offs. *Research in Transportation Economics* 53, 3–12. <https://doi.org/10.1016/j.retrec.2015.10.014>.
- Moskovitz, D.A., Wheeler, N., 2011. Bicycle Parking Analysis with Time Series Photography. *Transportation Research Record: Journal of the Transportation Research Board* 2247, 64–71. <https://doi.org/10.3141/2247-08>.
- Noland, R.B., Kunreuther, H., 1995. Short-run and long-run policies for increasing bicycle transportation for daily commuter trips. *Transport Policy* 2, 67–79. [https://doi.org/10.1016/0967-070X\(95\)93248-W](https://doi.org/10.1016/0967-070X(95)93248-W).
- Profillidis, V.A., Botzoris, G.N., 2019. Econometric, Gravity, and the 4-Step Methods, in: *Modeling of Transport Demand*. Elsevier, pp. 271–351.
- Rose, J.M., Bliemer, M.C.J., 2013. Sample size requirements for stated choice experiments. *Transportation* 40, 1021–1041. <https://doi.org/10.1007/s11116-013-9451-z>.
- RWTH Aachen University, 2022. Facts and Figures. <https://www.rwth-aachen.de/cms/root/Die-RWTH/Profil/~enw/Daten-Fakten/?lidx=1> (accessed 22 November 2022).
- Stinson, M.A., Bhat, C.R., 2004. Frequency of Bicycle Commuting: Internet-Based Survey Analysis. *Transportation Research Record: Journal of the Transportation Research Board* 1878, 122–130. <https://doi.org/10.3141/1878-15>.

- Wardman, M., Tight, M., Page, M., 2007. Factors influencing the propensity to cycle to work. *Transportation Research Part A: Policy and Practice* 41, 339–350. <https://doi.org/10.1016/j.tra.2006.09.011>.
- Yuan, C., Sun, Y., Lv, J., Lusk, A.C., 2017. Cycle Tracks and Parking Environments in China: Learning from College Students at Peking University. *International journal of environmental research and public health* 14. <https://doi.org/10.3390/ijerph14080930>.