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Stated Preference-Based Analysis of the Impact of Bicycle Parking Fees on the Occupancy and Benefits of Bicycle Parking Stations

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Abstract

Cities with high levels of cycling frequently encounter challenges associated with high demand for bicycle parking. One approach to tackle this is the installation of bicycle parking stations that provide weather and theft protection. Due to their high cost and limited capacity, a pricing strategy appears to be useful for managing the occupancy of these facilities. However, there is a shortage of quantitative studies that analyze improvements in bicycle parking and specifically measure the impact of parking fees. Against this background, this paper examines the effect of parking fees on the utility of planned bicycle parking stations at RWTH Aachen University in Germany. The study uses a mixed logit model that is based on a stated preference experiment on bicycle parking (n = 2,960). Based on logsum analysis, the results indicate that parking fees can contribute to bicycle parking demand being spatially more evenly distributed, thereby reducing congestion of parking stations while at the same time generating substantial revenues. In the case study, bicycle parking stations can enhance their benefit-cost ratio by implementing parking fees, provided that facilities with low occupancy are excluded from the parking fee. Therefore, the introduction of a modest fee can be beneficial for single bicycle parking facilities that otherwise face substantial crowding, without compromising, but actually increasing their benefit-cost ratio.

1 Introduction

Bicycle parking management is an increasingly important issue in countries with growing bicycle traffic, such as Denmark, the Netherlands, and Germany (van der Spek and Scheltema, 2015). At train stations, in particular, but also at other locations, such as city centers or universities, the demand for bicycle parking often surpasses the available capacity. This results in overcrowded facilities and issues with fly-parked bicycles, such as those locked to street furniture or haphazardly parked on sidewalks, etc. (Gamman et al., 2004; Larsen, 2015). Consequently, a deficiency in bicycle parking supply is not merely an issue for cyclists and a barrier to the promotion of bicycle traffic; it also has implications for urban design and creates obstacles for pedestrians and individuals with reduced mobility (van der Spek and Scheltema, 2015).

One potential solution to address the high demand for bicycle parking is the construction of bicycle parking stations, also known as bicycle parking garages. These facilities offer several benefits to users, including protection from weather and theft, as only registered users have access. Consequently, they have the potential to channel bicycle parking demand towards these facilities due to their attractiveness and reduce excess demand in the surrounding area (van der Spek and Scheltema, 2015). Moreover, the increasing value of bicycles due to the growing number of e-bikes necessitates improvements to bicycle parking facilities, as secure parking is of particular importance for them (Hunt and Abraham, 2007; Kohlrautz and Kuhnimhof, 2024b). For instance, the number of e-bikes in Germany increased by more than twofold, from 4.5 million in 2018 to 11.0 million in 2023 (ZIV, 2024).

However, bicycle parking stations require more space than conventional facilities and are significantly more expensive to construct. As a result, parking stations usually have a limited capacity. As they are highly attractive to users who benefit considerably from theft protection and to users who do not appreciate their benefits as much, they inherently carry the risk of becoming overused, which in turn reduces the benefits for all users. To optimize the utility of bicycle parking stations, it is therefore reasonable to charge parking fees for bicycles, similar to cars, to manage occupancy. This practice is already common in parking garages at train stations in Germany and other countries (Buehler et al., 2021). Our own, unpublished research revealed that parking fees at train stations and public transit hubs in Germany are up to 2 € per day or 20 € per month. In city centers, rates were as high as 8 € per day or 25 € per month. These bicycle parking stations are typically combined with free, lower-quality parking facilities available in the vicinity to prevent fly-parking, which serve as alternatives for cyclists who are unwilling to pay. Despite the common practice of charging for bicycle parking stations, there is a lack of quantifiable data on the benefits and impacts of parking charges, particularly for locations other than train stations.

In light of the aforementioned gap in the literature, we analyzed the benefits of 17 planned bicycle parking stations in a case study at RWTH Aachen University, Germany. First, we generated a synthetic population of bicycle commuters based on a mobility survey (n = 3,841). We then assigned them to parking facilities based on parking preferences estimated in a stated preference experiment (n = 2,960). Finally, we used the logsum approach to estimate the consumer surplus of parking facilities. The consumer surplus represents the utility of improvements to bicycle parking for cyclists. Furthermore, we calculated the revenues generated by different parking fee levels and considered the decreasing attractiveness of parking facilities due to crowding effects. This article uses the following definitions:

- Parking fee: The daily amount of money that a cyclist must pay for the use of a bicycle parking station
- Net revenues: Total revenue generated by the bicycle parking station operator from parking fees, minus transaction costs (i.e., the cost of user identification and accounting)

- Benefit-cost ratio: The consumer surplus that cyclists obtain from the construction of the bicycle parking stations, taking into account the occupancy and fees, plus the net revenues, divided by the construction costs of the bicycle parking stations

The article commences with a review of the existing literature, before presenting the methodology and results. This is followed by a discussion and a conclusion.

2 Literature review

A number of studies have examined the factors influencing cyclists' choice of parking facilities at train stations and other locations. The findings indicate that cyclists prefer bicycle sheds over bicycle parking racks (Lusk et al., 2014; Moskovitz and Wheeler, 2011; Yuan et al., 2017) and avoid on-street parking (Lusk et al., 2014).

Moreover, several studies have analyzed variations in the preferences of cyclists. One relevant factor is the resale value of the bicycle (Hunt and Abraham, 2007; van Lierop et al., 2012). Other studies have categorized cyclists into different groups, as shown in Table 1.

Table 1. Previous studies categorizing groups of cyclists by parking preferences

Source	Location and context	Method	Groups
Molin and Maat (2015)	Parking at train stations, NL	Latent class modeling	'Free facility', 'price sensitive', 'walking time-sensitive', 'paid facility'
Egan et al. (2022)	General parking preferences, Dún Laoghaire-Rathdown, IE	Cluster analysis	'Informal', 'open', 'any', 'accessible', 'secure'
Fournier et al. (2023)	Parking in different location contexts, Montréal, CA	Cluster analysis	'Leisure cyclists', 'summer cyclists', 'occasional cyclists', 'dedicated cyclists'

Egan et al. (2022) used cluster analysis to categorize cyclists according to their preferences. They identified the bicycle type and the percentage of long-term parking as influencing factors. Fournier et al. (2023) determined trip purpose and cycling frequency as relevant factors. In contrast, Molin and Maat (2015), focusing on train stations, identified age as the only significant factor. The studies demonstrate that bicycle parking behavior is complex and varies, indicating that cyclists gain varying levels of benefits from parking facilities and may behave differently in the case of the introduction of a parking fee. However, none of the studies take the intraindividual variation of parking preferences into account, i.e., that cyclists may show different parking habits due to the specific situation, weather, and mood.

Some studies have focused on the willingness to pay for secure bicycle parking. Fournier et al. (2023) found for Canada that the willingness to pay for secure bicycle parking is highest at metro and train stations, and workplaces. The researchers estimated an average willingness to pay per day of 1.59 CAD in general, 2.25 CAD at train stations, and approximately 1 CAD at workplaces. They further concluded that the duration of stay is relevant. Van Lierop et al. (2012) found that over 40 % of cyclists are willing to pay more than 0.50 CAD per day for secured bicycle parking.

Wardman et al. (2007) conducted a study to assess the impact of daily payments to employees as an incentive to commute by bicycling. Their findings indicated that a payment of 2 GBP was more effective than providing bicycle parking facilities. Conversely, it can be assumed that bicycle parking fees are a disincentive to commuting by bicycle if no free-of-charge parking alternatives are available. Moreover, it is probable that a parking fee would result in a shift in demand to non-designated parking facilities, such as street furniture or parking in offices, which is also an observed practice (Lusk et al., 2014).

Molin and Maat (2015) concluded that the challenges associated with excess demand for bicycle parking are not limited to train stations. They suggest that further research is needed that analyzes bicycle parking preferences and the trade-offs between facility quality, cost, and other factors, covering a diverse set of high-demand destinations. This also includes universities, where staff and students frequently compete for limited bicycle parking spaces.

In conclusion, there is a substantial research gap for empirical, quantitative evidence regarding the impact of bicycle parking fees. While there are general estimates of the willingness to pay, there is no application of these estimates to calculate the impact of such fees. This paper will address this topic with an application to the specific situation of a university campus.

3 Methodology

This section commences with an introduction to the prediction model, after which it proceeds to focus on the stated preference experiment, the consideration of occupancy effects in the model, and the modeling of the revenues from parking fees. Further details on the modeling approach can be found in Kohlrautz and Kuhnimhof (2024a).

3.1 Model overview

To model the demand for bicycle parking stations and the effects of charging fees, we used the approach delineated in Figure 1. First, we generated a *synthetic bicycle commuter population* through the use of cycling mode shares derived from a *mobility survey* conducted at RWTH Aachen University in June 2022. The survey focused on the commuting behavior of university members and was independent of the later applied survey on bicycle parking. We then combined the mode shares with the *student and employee statistics*, and *building locations and space usage* data from all university buildings.

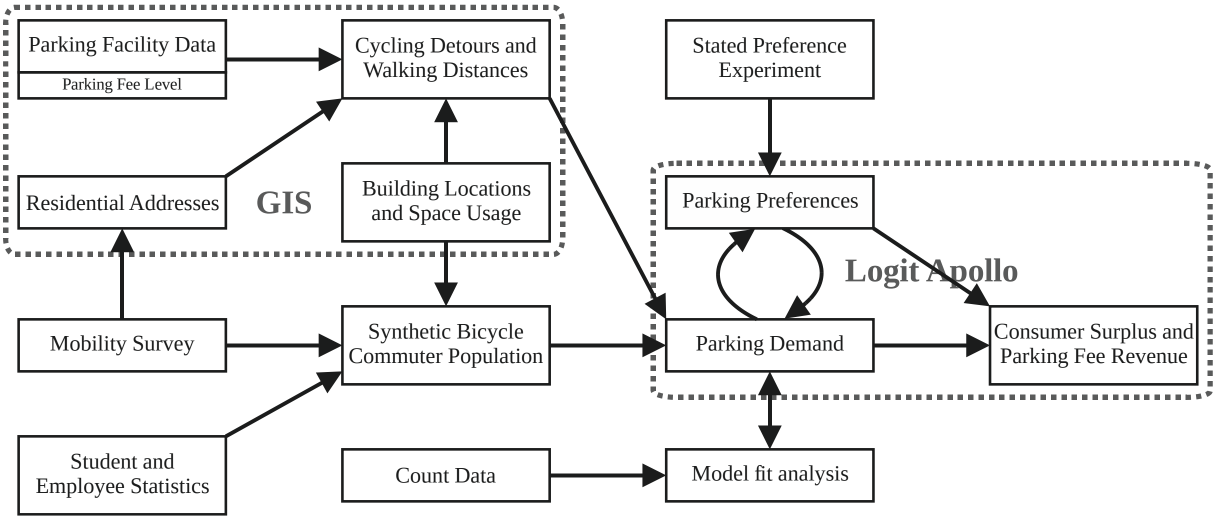

Figure 1. Overview of the modeling approach

As illustrated in Table 2, the synthetic population of bicycle commuters is predominantly composed of students. However, when weighted by the commuting frequency and a temporal overlap factor to estimate the number of parked bicycles, their dominance is reduced. It should be noted that the applied approach only considers current cyclists and does not take into account the effects of parking facility provision on mode choice.

Table 2. Previous studies categorizing groups of cyclists by parking preferences

	Students	Professors	Scientific employees	Administrative and technical staff
Number	9,873	154	1,983	520
Share	79 %	1 %	16 %	4 %
Weighted share	62 %	2 %	29 %	7 %

For each building and based on the location of bicycle parking facilities on the one hand and *residential addresses* on the other, we calculated beeline-based cycling detours and walking distances for cyclists using the respective facilities for parking. The *parking facility data* included all designated bicycle parking facilities at the university, both before and after the construction of the bicycle parking stations (Figure 2). The current infrastructure includes more than 5,000 parking spaces at the university, with over 4,000 of them being uncovered parking racks. The existing, free-to-use bicycle parking station provides 543 spaces.

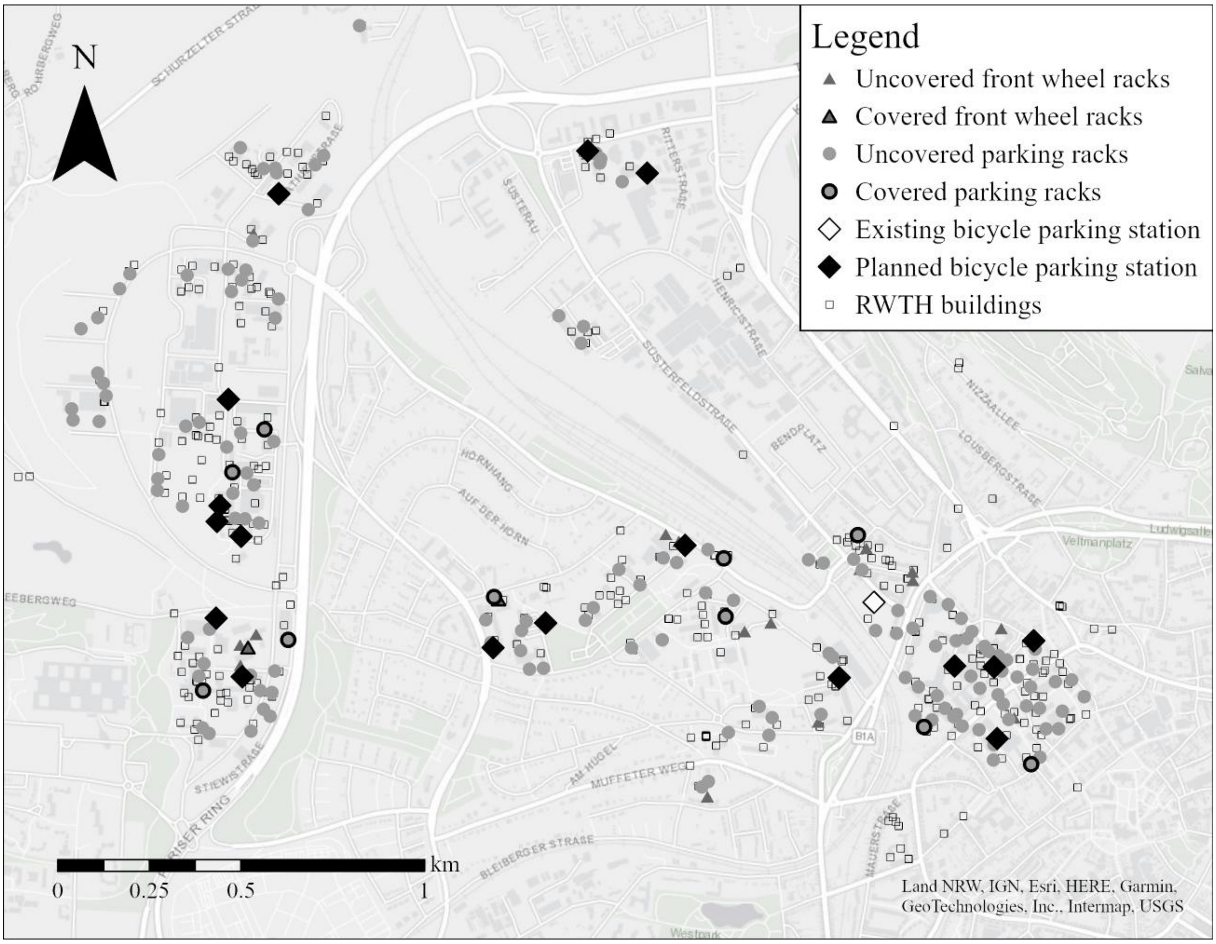

Figure 2. Overview of bicycle parking facilities at RWTH Aachen University

The 17 planned parking stations have a total capacity of 597 spaces, including one parking station with 101 spaces planned within a building. In comparison to the existing situation, the introduction of these parking stations will result in a twofold increase in the number of parking spaces in parking stations, despite the fact that the number of parking stations rises from 1 to 18. The overall total supply of parking facilities will increase by approximately 10 %. The applied bicycle parking prediction model also considered alternative parking options, such as bringing bicycles into offices and fly parking. In the simulations, we varied the fees for the bicycle parking stations while all other facilities remained free to use.

We used a mixed logit model to estimate *parking preferences* based on a *stated preference experiment*. We extended our model to account for occupancy effects. We then predicted the *parking demand* per facility by iteratively applying this model to the bicycle commuter population, allowing cyclists to choose a different parking facility when occupancy changes. For each parking fee, we estimated the *consumer surplus* using the logsum approach. During model development, we performed a *model fit analysis* based on *count data* of parked bicycles. However, we could not include the effect of pricing in the comparison between predicted and counted bicycles due to the current unavailability of paid bicycle parking.

3.2 Stated preference experiment

The stated preference experiment took place in July 2022. All university students and employees received an email invitation to participate. Participants could choose between the following alternatives: indoor parking, such as bringing the bicycle into the office, if that option was available to them in the status quo (it is for some employees while it is not for others); the post of a traffic sign representing fly parking; an uncovered or covered u-rack; and a bicycle parking station. With the exception of indoor parking, each alternative was associated with different cycling detours to reach the facility and walking distances from the facility to the destination. The bicycle parking station was associated with different levels of daily parking fees. The range of parameters depended on the facility type, as displayed in Table 3.

Table 3. Parameter range for the different facility types

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

We generated the choice sets using the software Ngene, applying an efficient design that minimizes the d-error using coefficients from a pretest. Each participant received eight choice sets, which were selected blockwise from 64 choice sets to avoid unbalanced combinations of choice sets. An example choice set is displayed in Figure 3.

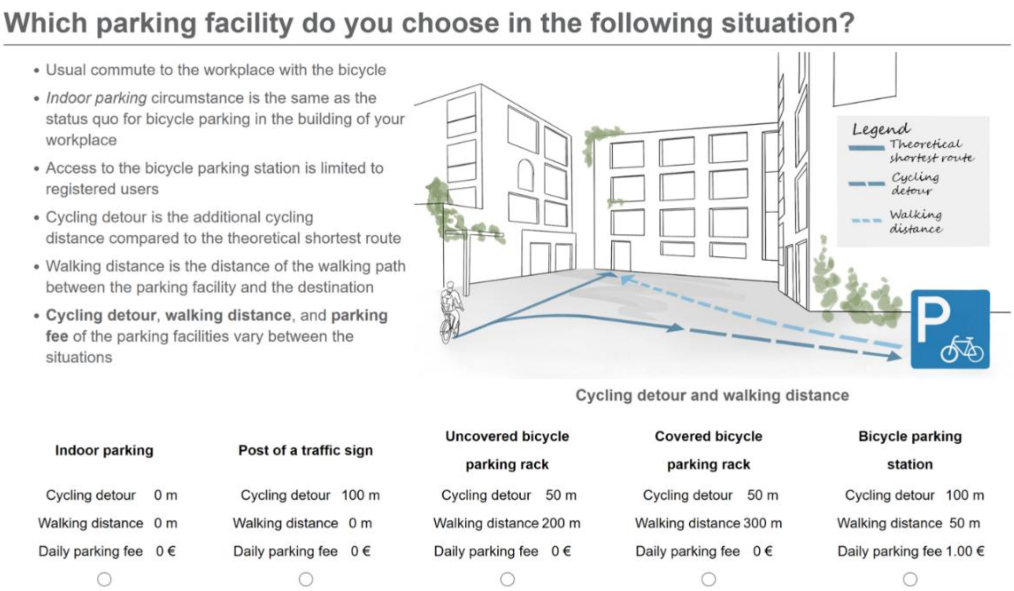

Figure 3. Example of a choice set

To analyze the stated preference experiment, we used a mixed logit model with the following utility function:

$$U_{itq} = \alpha_{iq} X_i + \sum_{p=1}^{P} \beta_p Y_{iqp} + \varepsilon_{itq} \tag{1}$$

The utility U_{itq} of an alternative (i) depends on the situation (t) and the individual (q). β_p are standard logit coefficients, while ε_{itq} represents the unobservable variation in preferences and is a Gumbel-distributed error term. α_{iq} contains an interindividual random coefficient for the facility type (X_i):

$$\alpha_{iq} = \mu_i + \sigma_i \cdot \xi_{iq} \tag{2}$$

The α_{iq} incorporates the mean value (μ_i) for the facility type and a standard deviation (σ_i) that is multiplied by a normally distributed error term (ξ_{iq}) with a mean value of zero.

The estimated coefficients also include interactions between student status and employee group membership $\left(\beta_{p_S}\right)$, the resale value of the bicycle $\left(\beta_{p_{RV}}\right)$, and indoor parking barriers $\left(\beta_{p_B}\right)$, with the parking preferences of cyclists. Table 4 displays the resulting coefficients, where β_λ and β_{λ_S} represent the β_p and β_{p_S} values for the influence of pricing, respectively. The reference category is a scientific employee with a bicycle with a resale value below 500 €. Coefficients are applied in an additive manner. To illustrate, both the general coefficient for bicycle parking stations and that for the combination of student status and bicycle parking stations are applied to the example of a student facing the alternative bicycle parking station. As a different example, for owners of a bicycle with a resale value exceeding 1,000 €, both the influence of a resale value exceeding 500 € and that of a resale value exceeding 1,000 € are valid.

Overall, there is a reluctance to use indoor parking, which represents the informal parking in offices, etc., that is even stronger if it is formally forbidden. In contrast, it is weaker if the resale value of the bicycle is high. Cyclists also hesitate to fly park at street furniture. Relative to uncovered bicycle parking racks (the reference category), cyclists prefer covered parking racks and bicycle parking stations. This preference increases if the resale value of the bicycle is high.

Cyclists are sensitive to cycling detours, and this sensitivity is even more pronounced for walking distances. While there are notable differences between the student and employee groups in terms of distances, there are significant variations in price sensitivity. Students are more sensitive, while professors and administrative and technical staff are comparatively less sensitive. For more detailed information on the stated preference experiment, we direct the reader to Kohlrautz and Kuhnimhof (2025).

Table 4. Coefficients of the mixed logit model

		Estimate	Standard error	t-ratio	p-value	
Indoor parking	μ_i	-2.940	0.299	-9.828	<0.001	***
Post of a traffic sign	σ_i	5.146	0.160	32.237	<0.001	***
Indoor parking Student	β_{p_S}	-2.419	0.271	-8.929	<0.001	***
Indoor parking Administrative and technical staff	β_{p_S}	1.784	0.375	4.758	<0.001	***
Indoor parking Resale value > 500 €	$\beta_{p_{RV}}$	1.740	0.300	5.808	<0.001	***
Indoor parking Resale value > 1000 €	$\beta_{p_{RV}}$	1.304	0.441	2.955	0.003	**
Indoor parking No designated space	β_{p_B}	-0.965	0.287	-3.359	<0.001	***
Indoor parking Indoor parking forbidden	β_{p_B}	-0.894	0.272	-3.282	0.001	**
Indoor parking Forbidden at the department	β_{p_B}	-0.936	0.420	-2.230	0.026	*
Pole of a traffic sign	μ_i	-2.032	0.075	-26.953	<0.001	***
	σ_i	1.945	0.072	26.972	<0.001	***
Uncovered bicycle parking rack	μ_i	fixed				
	σ_i	1.381	0.065	21.104	<0.001	***
Covered bicycle parking rack	μ_i	0.656	0.066	9.899	<0.001	***
	σ_i	-1.547	0.065	-23.936	<0.001	***
Covered bicycle parking rack Resale value > 500 €	$\beta_{p_{RV}}$	0.874	0.104	8.368	<0.001	***
Bicycle parking station	μ_i	0.876	0.164	5.349	<0.001	***
	σ_i	2.864	0.085	33.552	<0.001	***
Bicycle parking station Student	β_{p_S}	-0.495	0.181	-2.733	0.006	**
Bicycle parking station Administrative and technical staff	β_{p_S}	-0.620	0.333	-1.861	0.063	.
Bicycle parking station Resale value > 500 €	$\beta_{p_{RV}}$	1.489	0.199	7.488	<0.001	***
Bicycle parking station Resale value > 1,000 €	$\beta_{p_{RV}}$	1.258	0.254	4.961	<0.001	***
Bicycle parking station Distance to RWTH [km]	β_p	0.045	0.018	2.551	0.011	*
Cycling detour [m]	β_p	-0.006	<0.001	-19.104	<0.001	***
Cycling detour Student [m]	β_{p_S}	-0.002	<0.001	-5.840	<0.001	***
Cycling detour Professor [m]	β_{p_S}	-0.002	0.001	-2.868	0.004	**
Cycling detour Administrative and technical staff [m]	β_{p_S}	0.001	0.001	1.950	0.051	.
Walking distance [m]	β_p	-0.016	<0.001	-38.871	<0.001	***
Walking distance Student [m]	β_{p_S}	-0.002	0.001	-4.380	<0.001	***
Walking distance Professor [m]	β_{p_S}	0.004	0.001	3.147	0.002	**
Walking distance Administrative and technical staff [m]	β_{p_S}	0.006	0.001	8.588	<0.001	***
Parking fee	β_λ	-6.745	0.259	-26.035	<0.001	***
Parking fee Student	β_{λ_S}	-1.515	0.367	-4.127	<0.001	***
Parking fee Professor	β_{λ_S}	1.513	0.667	2.270	0.023	*
Parking fee Administrative and technical staff	β_{λ_S}	1.895	0.367	5.169	<0.001	***

* '.' p-value < 0.1, '*' p-value < 0.05, '**' p-value < 0.01, '***' p-value < 0.001
Reference category: Uncovered bicycle parking rack, scientific employee, bicycle with a resale value < 500 €

3.3 *Consideration of occupancy effects*

Although the stated preference experiment did not include occupancy, it is essential to consider occupancy when modeling the benefits of bicycle parking stations, as their benefits are typically constrained by their capacity. It was thus necessary to consider the temporal overlap of parking events during the estimation of facility occupancy in order to account for commuting frequency, average length of stay, sick leave, and vacation. In the survey, participants reported their commuting frequency by bicycle and the typical duration of their stay at the university. The results indicated that students commute less often and also stay significantly less long at the university. Therefore, we used weightings of 0.4 for students and 0.8 for employees to estimate occupancy based on the number of cyclists parking there. However, it should be noted that these numbers are partly estimated, as time-of-day demand curves have been unavailable.

In order to account for the impact of occupancy on the choice of parking facilities, we manually added the following capacity restraint function (analogous to volume-delay functions) additively to the utility function of parking facilities:

$$f = -\gamma \cdot \left(\frac{Parking\ Demand_{Modeled}}{Capacity}\right)^{\delta} \tag{3}$$

This function accounts for the decreasing probability of selecting a parking facility while simultaneously allowing for overcrowding. I.e., the probability is not zero even if occupancy is above capacity. This is consistent with real-world observations, as the number of bicycles parked in facilities such as u-racks often exceeds capacity during periods of high demand. Therefore, we set $\gamma = 0.5$, and to assess the reliability of our results, we tested the effect of both $\delta = 2$ and $\delta = 4$. We applied both functions to all facility types, with the exception of indoor parking.

Figure 4 illustrates the impact of the considered capacity restraint functions on the probability of a facility being chosen. As occupancy increases, the odds for the facility fall. The turning point is located at full occupancy. A $\delta = 2$ assumes a slow decrease starting earlier, while a $\delta = 4$ starts later to decrease the utility, but then decreases rapidly, resulting in much lower odds for facilities above capacity. A reduction in the probability of a facility being chosen prior to full occupancy is intended to reflect the theoretical risk of crowding, due to fluctuations in demand and the increased effort required to locate and access one of the remaining free parking spaces.

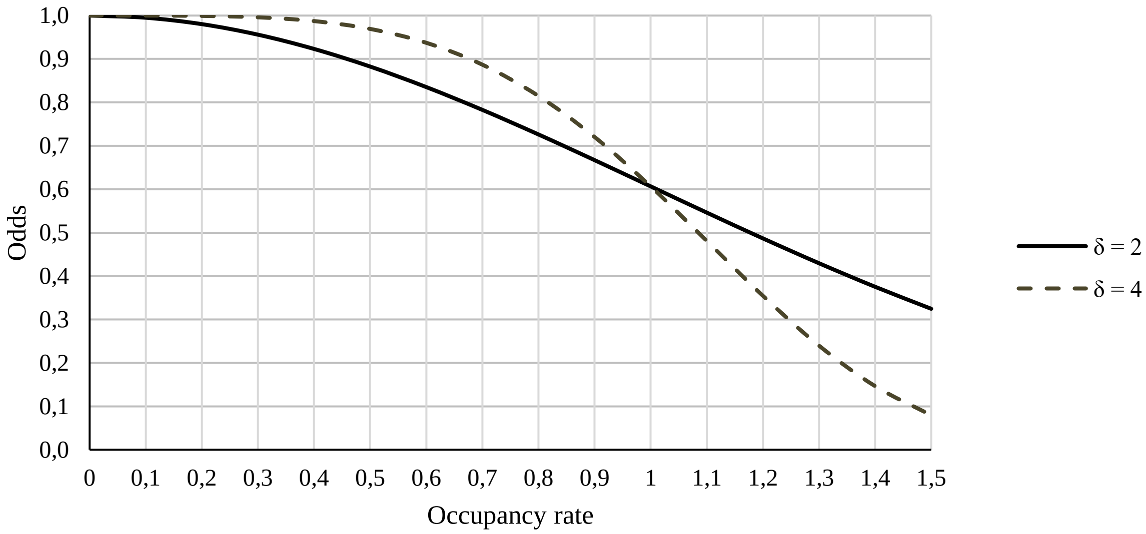

Figure 4. Influence of the occupancy on the odds of a parking facility based on the considered capacity restraint functions

To consider the occupancy, we proceeded in an iterative manner, assigning cyclists to parking facilities, calculating the utility of parking facilities in terms of the predicted occupancy, and reassigning cyclists to the parking facilities. This procedure adheres to Wardrop's principle in terms of route choice, or more generally, the Nash equilibrium.

3.4 *Modeling the revenues from parking fees*

To calculate the benefits of bicycle parking stations $\left(B_{Bicycle\ parking\ stations}\right)$, we estimated their utility from the user's perspective. This is the difference in consumer surplus $\left(\Delta E\left(CS_q\right)\right)$ compared to the scenario without their implementation. We then added the aforementioned value to the net revenue from the parking fee $\left(Net\ revenue_{Bicycle\ parking\ stations}\right)$:

$$B_{Bicycle\ parking\ stations} = \Delta E\left(CS_q\right) + Net\ revenue_{Bicycle\ parking\ stations} \quad (4)$$

The difference in consumer surplus is estimated using the logsum approach:

$$\Delta E\left(CS_q\right) = \frac{1}{\beta_\lambda + \beta_{\lambda_S}}\left[ln\left(\sum_{i=1}^{I^1} e^{V_{qi}^1}\right) - ln\left(\sum_{i=1}^{I^0} e^{V_{qi}^0}\right)\right] \quad (5)$$

V_{qi}^1 represents the quantifiable utility of an alternative for the construction of bicycle parking stations, while V_{qi}^0 denotes the same for the baseline case without their construction. The consumer surplus is monetized by the price coefficient, which is divided into a general (β_λ) and a group-specific part $\left(\beta_{\lambda_S}\right)$. The latter is based on the membership to student and employee groups. This takes into account the differences in price sensitivity between user groups.

To calculate the revenue from implementing a parking fee, we use the following formula:

$$Net\ revenue_{Bicycle\ parking\ stations} = Number_{Parking\ processes} \cdot \left(Fee_{Parking} - 0.05\ €\right) \quad (6)$$

As bicycle parking stations are only accessible to registered users, we posit that the operating costs for the transaction and accounting of the parking fee are 0.05 € per parked bicycle per day.

In order to calculate benefit-cost ratios, we divide the benefits by the construction costs of the bicycle parking stations. We compare two scenarios. In the first scenario (S1), the parking fee is applied to all parking stations, including the one that already exists in the status quo and is currently free of charge. In the second scenario (S2), the two largest bicycle parking stations, including the existing one, are excluded from the parking fee because it is anticipated that these stations will not be overcrowded. Furthermore, we assume a usage period of 30 years, 205 work (or study) days per year (220 work days minus sick days), and an interest rate of 2 %.

4 Results

When the parking fee is applied to all bicycle parking stations (S1), our model suggests that the bicycle parking stations have the highest overall benefit-cost ratio if there is no parking fee, as illustrated in Figure 5. If the two largest stations are excluded (S2), the benefit-cost ratio of the bicycle parking stations is highest at a parking fee level of approximately 0.30 €. The primary reason for benefit-cost ratios that are significantly less than one is the absence of consideration of mode shift effects. This is because the model only takes current cyclists into account and also does not consider that an attractive bicycle parking infrastructure could increase the cycling frequency of current cyclists.

In general, the benefit-cost ratio for S1 declines monotonically with increasing parking fees. At a value of 0.30 €, the benefit-cost ratio is already one-third of the one without parking fees. This is because parking stations remain unused due to the high price, as not enough cyclists are willing to pay the fee. This can also result in negative benefit-cost ratios, as the utility of the existing station that is currently free to use decreases as well and remains unused. Additionally, the utility of nearby alternative facilities decreases as they take up demand and suffer from overcrowding.

The exclusion of the two largest parking stations from the fee (S2) has the effect that the introduction of parking fees leads to an increase in the benefits of parking stations. Furthermore, the results indicate a relatively stable benefit-cost ratio until a fee level of 0.40 €. This demonstrates that the implementation of a fee is capable of regulating demand in order to reduce the crowding of facilities and allows a transfer of benefits associated with less crowding into revenues. Moreover, the discrepancy between the applied CR functions with $\delta = 2$ and $\delta = 4$ is negligible, as the trends of the curves are comparable.

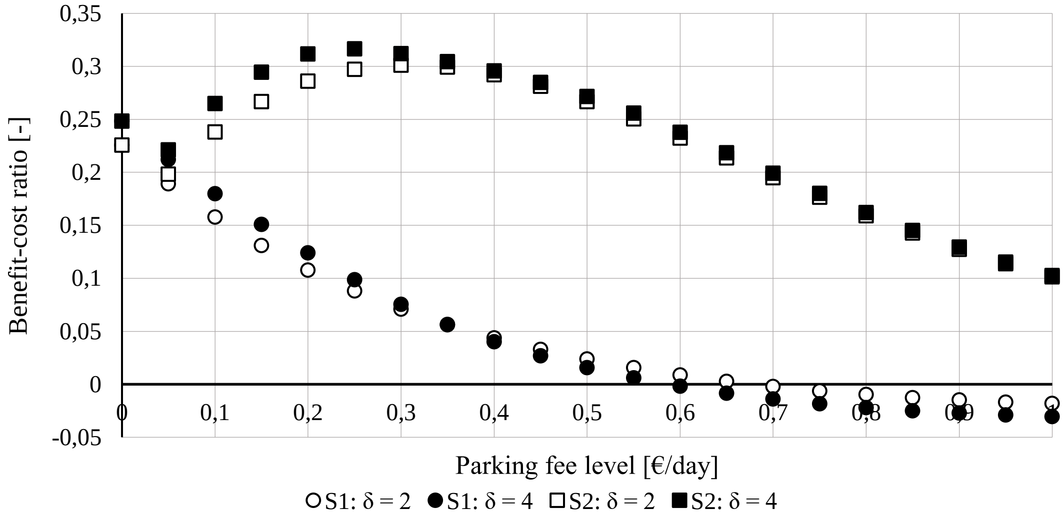

Figure 5. Benefit-cost ratio by parking fee level for the usage period of 30 years

Figure 6 illustrates the potential net revenues that could be generated from the implementation of a parking fee for a usage period of 30 years. The values result from subtracting the transaction costs from the revenues. In all scenarios, the achievable revenues are highest at a parking fee level of 0.40 €. It is not surprising that the net revenues are higher when the parking fees are applied to all parking stations. However, if the two largest stations are excluded, the maximum revenue is approximately three-quarters of the revenues that would result from applying the fee to all parking stations. In this case, less than half of the parking spaces are subject to the fees. This demonstrates that excepting the two largest stations from the fee causes a comparably low decrease in potential revenues. Furthermore, the influence of the different δ in the CR function is negligible.

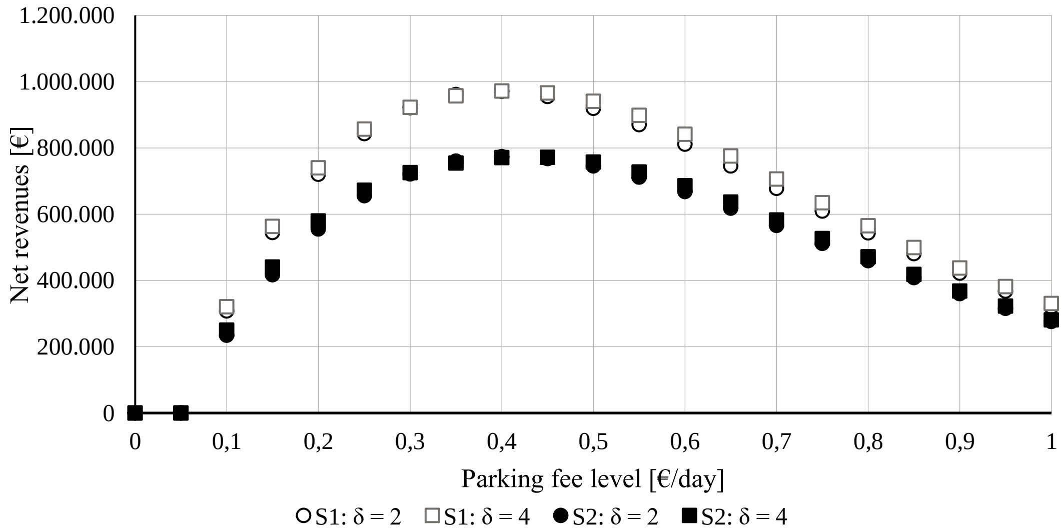

Figure 6. Net revenues relative to parking fee level for the usage period of 30 years

Table 5 illustrates that an increase in parking fees decreases the number of crowded bicycle parking stations and their median occupancy. In the case that the bicycle parking stations are free to use, they are occupied to an average of 0.85, with only six facilities experiencing crowding. Given $\delta = 4$, the occupancy is slightly higher, with seven rather than six crowded stations. This is because the steeper function shifted demand from other crowded facilities to the bicycle parking stations.

Table 5: Number of crowded bicycle parking stations and median occupancy of bicycle parking stations by parking fee level

	S1 $\delta = 2$		S1 $\delta = 4$		S2 $\delta = 2$		S2 $\delta = 4$	
Parking fee per day [€]	Number of crowded facilities	Median occupancy	Number of crowded facilities	Median occupancy	Number of crowded facilities	Median occupancy	Number of crowded facilities	Median occupancy
0	6	0.85	7	0.86	6	0.85	7	0.86
0.10	4	0.69	4	0.70	4	0.69	4	0.70
0.20	3	0.55	3	0.56	3	0.58	3	0.60
0.30	1	0.43	1	0.43	1	0.45	1	0.45
0.40	0	0.32	0	0.32	0	0.34	0	0.34
0.50	0	0.28	0	0.24	0	0.25	0	0.25
1	0	0.05	0	0.05	0	0.06	0	0.06

The data presented in the table indicates that a parking fee of 0.40 € per day is sufficient to prevent all bicycle parking stations from becoming overcrowded. However, at this price level, the median occupancy has already decreased to approximately one-third, resulting in a significant number of spaces remaining unoccupied. This illustrates the disadvantages of implementing a uniform parking fee across a diverse set of different bicycle parking stations with varying occupancy rates. At a parking fee level of 1 €, all parking stations are nearly empty.

5 Discussion

This article examines the impact of introducing parking fees for bicycle parking stations in the context of a planned expansion of bicycle parking supply at a university. The model provides an economic basis for determining the implementation and level of parking fees based on the results of a stated preference experiment. For this case study, the highest economic benefit is achieved depending on whether all parking stations are affected by the parking fee, without a parking fee, or at a parking fee level of 0.30 €. When unoccupied parking stations are excluded, moderate levels of parking fees are able to manage parking occupancy and generate revenues from parking fees. Over the course of a 30-year period, the annual net revenues are estimated to be approximately 25,000 € for a parking fee of 0.30 € per day. Consequently, parking fees could initially be used to manage occupancy and partly finance the ongoing expansion of parking supply, thereby rendering the fees redundant in the long term.

Our findings indicate that the primary influence on the results is the actual demand-supply ratio. In our case study, the overall occupancy was predicted to be 0.85, with a maximum of 7 out of 18 bicycle parking stations being crowded. The results for the scenario where the two largest parking stations were excluded from fees already indicate that parking charges should only be implemented when demand is high relative to supply. A further analysis of which bicycle parking stations should be priced to maximize benefits would also be possible. This analysis could potentially demonstrate that even higher fees can actually increase the benefits of bicycle parking stations significantly. However, implementing differential pricing based on occupancy at a university may face political resistance from employees due to concerns about fairness and equity. In contrast, parking fees at train stations, for example, can be a useful tool to prevent overcrowding of high-quality parking facilities. In conclusion, it is advisable to impose a fee for bicycle parking at the study or workplace only in instances where a shortage of supply is unavoidable. Furthermore, the current model does not take distributional impacts into account. It is debatable whether infrastructure such as bicycle parking should be exclusively for those who are less price-sensitive.

As occupancy was not part of the stated preference experiment, we had to manually choose how to incorporate this factor. The approach with a capacity restraint function and varying the curve of the function demonstrates that the exact form of modeling the effect is less relevant. As long as the function acknowledges a significant decrease in the attractiveness of bicycle parking facilities in the event of crowding, we expect the results to be similar. Furthermore, the current model fails to account for varying levels of occupancy throughout the day. The model only considers general occupancy, whereas bicycle parking facilities typically operate on a first-come, first-served basis. Consequently, cyclists who arrive early find a parking space easily, while those who arrive late must search for a space for a longer period. However, cyclists may avoid using parking facilities that become overcrowded during the day in advance. This is due to the increased likelihood of damage to bicycles by other users when the facility is crowded, as well as the inconvenience of exiting a crowded facility later. Nevertheless, alternative methodologies, such as an incremental assignment in conjunction with blocking occupied facilities or assigning negative utilities based on functions only when facilities are full, are also conceivable.

Furthermore, mode choice effects are not considered. Parking fees may act as a deterrent to potential cyclists who might otherwise choose to cycle to the university. However, the same applies to overcrowded facilities. Consequently, further research is required that investigates the relationships between parking facility occupancy, parking fees, and mode choice, as these should be major considerations within the planning of bicycle parking facilities. Moreover, the applied calculation does not consider the general operating costs of the bicycle parking stations. These costs are similar for all parking fee levels and therefore do not affect the ranking of the results displayed.

While we analyzed daily parking fees, a monthly billing system may be a more realistic implementation in the case of a university with frequent users. This would necessitate a change to the utility functions, but we believe that the relationships would be similar. However, including parking fees in student subscription fees permanently would prevent the intended displacement effects, e.g., that cyclists with inexpensive bicycles use low-quality facilities, which is therefore not advisable.

Molin and Maat (2015) conducted a stated preference experiment to analyze the trade-offs between costs and facility attributes at train stations. Our study demonstrates that these trade-offs can also be modeled on a behavioral level based on stated preference data and using a synthetic population. The findings indicate that parking fees can reduce the occupancy of bicycle parking facilities. Nevertheless, bicycle parking stations in the Netherlands typically offer free parking for at least the first 24 hours, despite high demand (van der Spek and Scheltema, 2015). Our findings indicate a lower willingness to pay for secure bicycle parking at the workplace than in a study by Fournier et al. (2023), which estimated approximately 1 CAD per day.

Further research is necessary to analyze the influence of parking fees at other locations. This includes different demand-supply ratios and user groups. For instance, at less student-dominated locations, such as company sites or train stations, the willingness to pay for bicycle parking is already different. Additionally, parking behavior in terms of parking duration deviates. Therefore, the results are likely to vary. Moreover, further research should investigate the influence of occupancy and crowding on bicycle parking facility choice empirically. Furthermore, the specific transactional costs associated with each parking process can vary considerably, depending on the operational model employed. Consequently, defining this function may have a significant impact on the overall economic profitability of implementing a parking fee, and the influence of the function should be further analyzed.

In our case study, we examined the subsequent addition of bicycle parking stations to an existing supply with conventional bicycle parking facilities. Therefore, cyclists have the option of utilizing either free-to-use facilities or potentially charged bicycle parking stations at all locations. In order to maximize the revenue from parking facilities when planning a new site, it would be rational to only implement charged facilities. However, in this case, the risk of fly parking to occur is high. Consequently, we recommend combining paid facilities with free-to-use conventional facilities to mitigate this risk. This will also prevent high-quality facilities from being overcrowded by users with inexpensive bicycles.

Overall, the results indicate that implementing a uniform parking fee across locations with different levels of demand is an ineffective strategy for managing demand. Instead, a differentiated approach based on local occupancy levels may be more effective. While this may seem implausible in the context of university campuses, it demonstrates the potential of pricing strategies.

6 Conclusions

This study examined the impact of bicycle parking fees on the utility of bicycle parking stations at a university and demonstrated that operating these stations has the potential to generate net revenues. However, the introduction of parking fees diminishes the overall benefits of the parking stations if applied to all bicycle parking stations, despite reducing overcrowding of facilities. Therefore, we recommend implementing bicycle parking fees only when overcrowding of facilities can otherwise not be avoided, e.g., by expanding the current parking supply or constructing alternative facilities. This is particularly pertinent in the context of train stations and historic city centers, especially when the mode share of cycling is high. Consequently, further research is required for other types of locations and situations with other occupancy levels and user compositions.

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