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

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SHORT SUMMARY

Bicycle parking management is a strategy to address congestion in cities with high levels of cycling. One approach to tackle this issue is to construct bicycle parking stations that provide weather and theft protection. However, due to their high cost and limited capacity, a pricing strategy to manage occupancy may be useful. Nevertheless, there is a shortage of quantitative studies that analyze improvements in bicycle parking and specifically measure the impact of parking fees. This paper examines the effect of parking fees on the utility of planned bicycle parking stations at RWTH Aachen University using a synthetic population. The study uses a mixed logit model that is based on a stated preference experiment on bicycle parking (n = 2,960). The results suggest that parking fees can reduce parking facility occupancy while generating substantial revenues and profits.

Keywords: Bicycle Parking, Discrete Choice Modelling, Logsum, Parking Demand Management, Pricing

1. INTRODUCTION

Bicycle parking management is an increasingly important issue in countries with rising bicycle traffic, such as Denmark, the Netherlands, and Germany (van der Spek & Scheltema, 2015). At train stations, in particular, the demand for bicycle parking often surpasses the available capacity, resulting 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). This is a problem not only in urban planning but also an obstacle for pedestrians and people with reduced mobility (van der Spek & Scheltema, 2015). For this reason, several studies have already investigated how cyclists choose between parking facilities at train stations (Arbis et al., 2016; Jonkeren & Kager, 2021; Molin & Maat, 2015) and whether they are willing to pay for secure bicycle parking (Fournier et al., 2023; van Lierop et al., 2012). Molin & Maat, 2015 also examined the effect of pricing on bicycle parking choice. The researchers concluded that issues with high demand for bicycle parking are not limited to train stations. They suggest that analyzing bicycle parking preferences and the trade-offs between facility quality, cost, and other factors in various locations that attract many visitors is an important topic for further research. This also applies to universities, where staff and students frequently compete for limited bicycle parking space.

One solution to address the high demand is to construct bicycle parking stations (BPS), also known as bicycle parking garages. They offer several benefits to users, including protection from weather and theft, as only registered users have access to them. They can help reduce the demand for bicycle parking in the neighborhood due to their attractiveness (van der Spek & Scheltema, 2015). In Germany, the number of e-bikes has more than doubled from 4.5 million in 2018 to 9.8 million in 2022 (ZIV, 2023). Secure bicycle parking is becoming increasingly important because e-bikes are expensive, making the construction of bicycle parking stations more useful.

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, so it is important to prevent overcrowding by cyclists who do not appreciate their benefits in order to maximize the utility of bicycle parking stations. Personal attributes and the resale value of the bicycle determine the level of benefit from parking stations (Hunt & Abraham, 2007; van Lierop et al., 2012). Therefore, it is 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 research found that parking fees at train stations and public transit hubs in Germany can be up to 2 € per day or 20 € per month, while in city centers, they can reach up to 8 € per day or 25 € per month. Lower-quality parking facilities are often additionally available and free to use at these locations as an alternative for cyclists who are unwilling to pay and to prevent fly-parking. However, quantifiable data on the benefits and impacts of parking charges are lacking, particularly for locations other than train stations.

Against this background, we analyze the benefits of 17 planned bicycle parking stations in a case study at RWTH Aachen University. We use the logsum approach to estimate the economic benefits of parking facilities based on a stated preference experiment that included parking fees. Additionally, we calculate the revenues of different parking fee levels and take into account the decreasing attractiveness of parking facilities due to crowding effects.

2. METHODOLOGY

To model the demand for bicycle parking stations, we used the approach outlined in Figure 1. We generated a *synthetic bicycle commuter population* using a *mobility survey*, *student and employee statistics,* and *building locations and space usage* data from all university buildings.

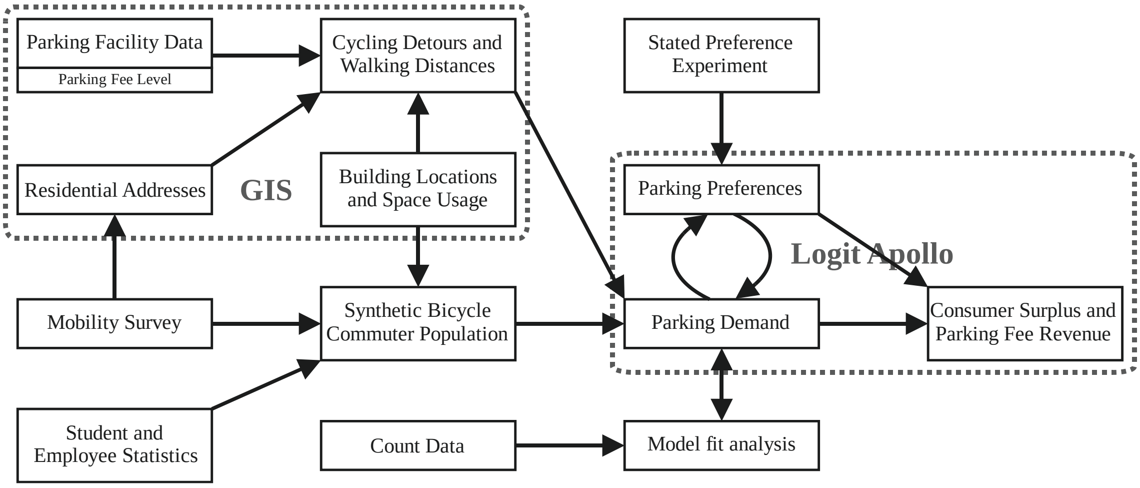

Figure 1: Overview of the modeling approach

The synthetic population consists mainly of students, as shown in Table 1, although weighting by the commuting frequency reduced their dominance.

Table 1: User composition of synthetic population

Students	Professors	Scientific employees	Administrative and technical staff
9,873	154	1,983	520

For each building, we calculated cycling detours and walking distances based on *residential addresses* from the mobility survey and the location of parking facilities. 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 17 parking stations planned have a total capacity of 597 spaces, including 101 spaces planned inside one building. Additionally, the existing bicycle parking station already provides 543 spaces. We also considered alternative parking options, such as bringing bicycles into offices and fly parking. We varied the fees for parking at the bicycle parking stations in the simulations while leaving all other facilities free to use.

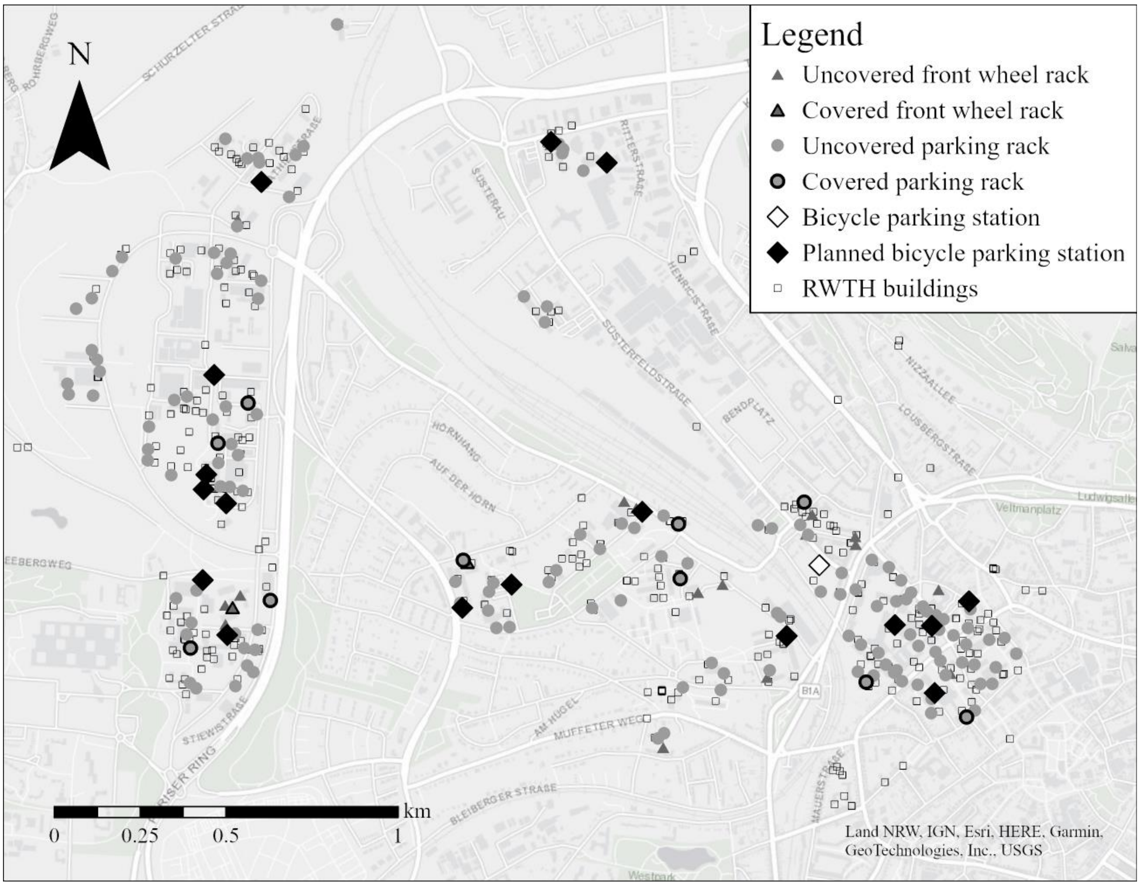

Figure 2: Overview of parking facilities at RWTH Aachen University

Using a mixed logit model, we estimated *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 construction, we performed a *model fit analysis* based on *count data*. 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. For further details on the modeling approach, please refer to Kohlrautz & Kuhnimhof, 2024.

Stated preference experiment

The stated preference experiment (n = 2,960) took place in July 2022. We invited each university member to participate via email. Participants could choose between indoor parking, such as bringing the bicycle into the office, if feasible in the status quo, the post of a traffic sign representing fly parking, uncovered or covered u-racks, and bicycle parking stations. Except for 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. An example choice set is displayed in Figure 3. To analyze the stated preference experiment, we used a mixed logit model that also included interactions between student and employment status, the resale value of the bicycle, and indoor parking barriers with the parking preferences of cyclists. For more information on the stated preference experiment, we refer to Kohlrautz & Kuhnimhof, 2023.

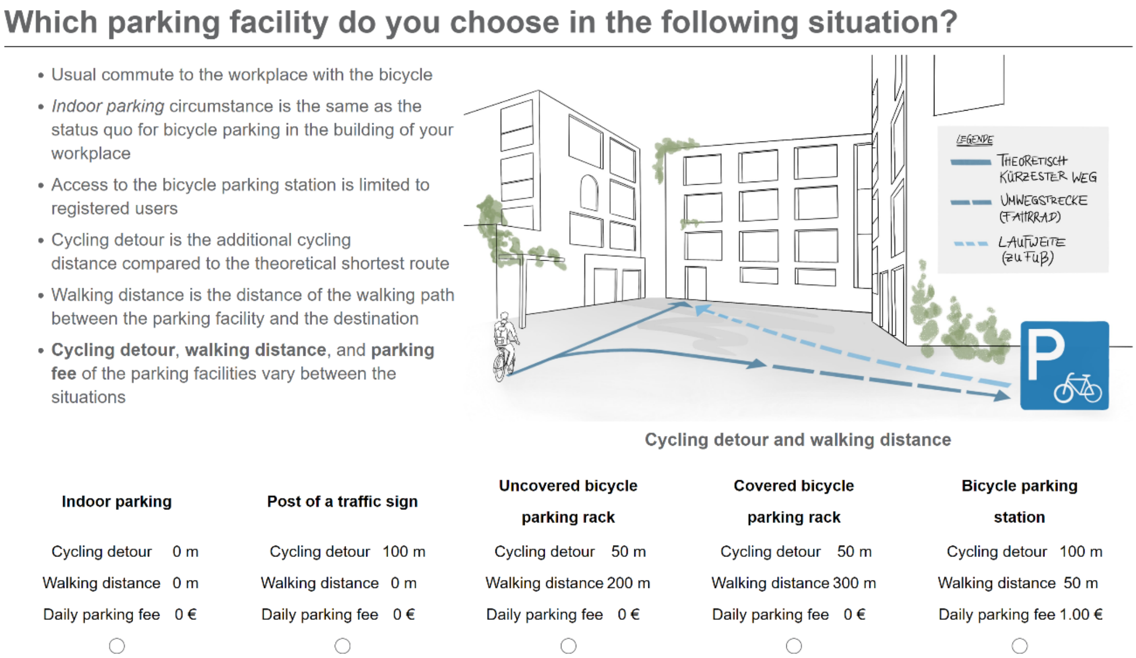

Figure 3: Example of a choice set

Consideration of occupancy effects

To consider the effect of overcrowding on the choice of parking facilities, we applied the following capacity restraint function to the utility function of parking facilities:

$$f = -0.5 \cdot \left(\frac{Parking\ Demand_{Modeled}}{Capacity} \right)^2 \tag{1}$$

This allows for overcrowding, which is common in the real world, as facilities such as u-racks are often used to park more bicycles than intended during periods of high demand.

Modelling the profits from parking fees

Since the bicycle parking stations should be accessible only to registered users, operating costs will be incurred even if these are free to use. Therefore, we assume comparable low additional operating costs for the transaction of the parking fee of 0.05 € per parked bicycle per day. Consequently, we define the benefit of bicycle parking stations (B_{BPS}) as the sum of the price-sensitivity-weighted consumer surplus $\left(\Delta E\left(CS_q\right)\right)$ and the profits from their operation ($Profit_{BPS}$):

$$B_{BPS} = \Delta E\left(CS_q\right) + Profit_{BPS} = \frac{1}{\alpha_q}\left[ln\left(\sum_{j=1}^{J^1} e^{V_{qi}^1}\right) - ln\left(\sum_{j=1}^{J^0} e^{V_{nj}^0}\right)\right] + Profit_{BPS} \qquad (2)$$

$$Profit_{BPS} = Number_{Parking\ processes} \cdot \left(Fee_{Parking} - 0.05\ €\right) \qquad (3)$$

To calculate benefit-cost ratios, we divide the benefits by the construction costs of the bicycle parking stations. We are comparing two scenarios: one where the parking fee is applied to all parking stations, including the currently free-to-use one, and another where the two large bicycle parking stations, including the existing one, are excluded from the parking fee because the stations are not expected to be overcrowded.

We assume a usage period of 30 years, 205 work (or study) days (220 work days minus sick days) per year, an interest rate of 2 % per annum, and assume a temporal overlap of parking events for 0.4 for students and 0.8 for employees, taking into account commuting frequency, duration of stay, and vacation.

3. RESULTS AND DISCUSSION

Table 2 presents the benefit-cost ratios, which are calculated by dividing the consumer surplus and parking profits by the construction costs of the parking stations in relation to the parking fee level. Additionally, the table displays the revenue and profit generated from parking fees, the number of crowded bicycle parking stations, and the median occupancy rate of bicycle parking stations. As we did not consider mode shift effects, the benefit-cost ratio of the bicycle parking stations is only about 0.2 without a parking fee. As parking fees increase, the number of crowded bicycle parking stations and median occupancy decreases.

The benefit-cost ratios are higher when only the parking facilities with limited capacity charge parking fees. In fact, applying a parking fee to these facilities can actually increase the ratio, as the fee mitigates the negative effects of congestion. However, high parking fees result in lower benefit-cost ratios as the parking stations remain unused due to the high price. Additionally, if the price is too high, profits decrease because not enough cyclists are willing to pay the fee. Applying the parking fee to all parking stations, including the one that is currently free, can result in negative benefit-cost ratios. This is because the current station would have a lower utility than it currently has, and the reduced use of the station would also result in overcrowding at nearby alternative facilities. These factors would negate the benefits of the newly constructed bicycle parking stations. Furthermore, the results indicate a lower willingness to pay for secure bicycle parking at the workplace than in a study by Fournier et al., 2023, which estimated about one Canadian $ per day.

Table 2: Cost ratios for different parking fee levels

	Parking fees for all parking stations					**Parking fees for 15 of 17 parking stations**				
Parking fee per day	**Benefit-cost ratio**	**Parking fee revenues [in k€]**	**Parking fee profit [in k€]**	**No. of crowded BPS**	**Median occupancy of BPS**	**Benefit-cost ratio**	**Parking fee revenues [in k€]**	**Parking fee profit [in k€]**	**No. of crowded BPS**	**Median occupancy of BPS**
0	0.23	0	0	6	0.85	0.23	0	0	6	0.85
0.05	0.19	347	0	5	0.77	0.20	263	0	5	0.77
0.1	0.16	616	308	4	0.69	0.24	469	235	4	0.69
0.2	0.11	961	720	3	0.55	0.29	741	556	3	0.58
0.5	0.02	1022	919	0	0.24	0.27	829	746	0	0.25
1	-0.02	337	320	0	0.05	0.10	291	276	0	0.06
2	-0.03	14	13	0	0.00	0.02	12	12	0	0.00

Molin & 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 at a university based on stated preference data. The findings indicate that parking fees can reduce the occupancy of bicycle parking facilities. Nevertheless, most bicycle parking stations in the Netherlands offer free parking for at least the first 24 hours despite high demand (van der Spek & Scheltema, 2015).

The model provides an economic basis for deciding on the implementation and level of parking fees. For the case study, the highest economic benefit is achieved with no parking fee, if it is applied to all parking stations. However, with moderate levels of parking fees, applied to stations that are likely to suffer from crowding, it is also possible to manage parking occupancy and generate revenue from parking fees. Over the course of 30 years of use, the annual profit is estimated to be approximately 25,000 € for a parking fee of 0.50 € per day.

The 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. Nevertheless, the assumed transactional cost level and the applied capacity restraint function influence the results. However, a steeper capacity restraint function provided similar results.

Furthermore, mode choice effects are not considered. Parking fees might discourage potential cyclists from cycling to the university. However, the same is true for overcrowded facilities. If the aversion to paying parking fees is more important than the fear of overcrowding, this supports the result that parking fees should not be applied in our case.

While we used daily parking fees, it is likely that in the case of a university with frequent users, the implementation of a monthly billing system is more realistic. This would change the utility functions. However, we believe that the relationships would be similar.

Overall, the results indicate that parking charges should only be implemented when demand is high relative to supply and a bottleneck is unavoidable. Therefore, it would make sense to charge only in these cases. 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.

4. CONCLUSIONS

This paper examines the impact of bicycle parking fees on the utility of bicycle parking stations at a university and demonstrates that operating these stations has the potential to generate profits. However, the introduction of parking fees diminishes the overall benefits of the parking stations if applied to a heterogeneous set of parking stations despite reducing overcrowding of facilities. Therefore, we recommend implementing bicycle parking fees only when overcrowding of facilities is unavoidable and cannot be solved by expanding current existing ones or constructing alternative facilities. This is particularly relevant at train stations and in historic city centers, especially when the mode share of cycling is high. However, further research is required for other locations with user compositions that differ from universities, as this may result in varying levels of willingness to pay for secure bicycle parking.

ACKNOWLEDGEMENTS

RWTH Aachen University provided financial support for this research to improve its parking facilities.

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