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FINANCIAL DETERMINANTS OF MODE SUBSTITUTION IN RESIDENTS' TRAVEL BEHAVIOUR: A CASE STUDY OF PUBLIC BIKE-SHARING IN LODZ, POLAND

Abstract. Bike-sharing networks have achieved considerable success in many cities worldwide, gaining a growing number of supporters for this mode of transportation. While the existing literature covers various aspects related to bike-sharing, the exploration of the relationship between these networks and the financial benefits for residents when transitioning to cycling has been somewhat limited. Therefore, the main objective of our article is to identify the factors influencing urban residents' decisions to switch to cycling and to understand the significance of financial considerations in shaping changes in travel behaviour.

We assessed the perceived affordability of bike-sharing services by measuring respondent satisfaction (via Computer Assisted Personal Interviews – CAPI) with the rental prices of city bicycles. To examine the relationships between variables, we employed statistical tests, including the Fisher test, the chi-square test of independence, and the Mann-Whitney test. Our research findings confirmed that replacing public transportation with bicycles has the most substantial impact, while substituting car trips has a relatively minor effect. Furthermore, our analysis revealed statistically significant associations between price satisfaction and the decision to abandon car travel in favour of cycling, as well as the motivation to save costs and substituting walking and public transport with bicycle travel.

Key words: bike-sharing, travel behaviour, financial and economical determinants, modal substitution.

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1. INTRODUCTION

The modal substitution of car travel with environmentally friendly low-carbon mobility options represents a pivotal strategy for transitioning towards sustainable urban mobility (Becker and Rudolf, 2018; Zhang *et al.*, 2022). A key expectation associated with public bike-sharing systems is their potential to redirect existing car journeys towards more sustainable modes of transportation, such as bicycles (Fishman *et al.*, 2014; Lu *et al.*, 2018; Shaheen *et al.*, 2016). However, previous research has suggested that shared bikes have not been entirely effective in displacing car travel (Johansson *et al.*, 2019; Fishman *et al.*, 2014; Bieliński *et al.*, 2021). Our understanding of the factors that drive modal substitution remains incomplete (Javaid *et al.*, 2020; Guo and Zhang, 2021; Chen *et al.*, 2022a). Thus, this paper aims to uncover the patterns of modal substitution brought by urban cycling and to underscore the significance of financial considerations in influencing the travel behaviour of urban residents. In our study, we consider modal substitution as potentially permanent, frequent, or occasional and encompassing the replacement of cars, public transport, and pedestrian journeys with shared bicycles.

Our emphasis on financial factors stems from the impact of bicycle rental fees on the adoption of this mobility option in urban settings, a phenomenon well-documented in numerous studies (Ricci, 2015; Podgórniak-Krzykacz *et al.*, 2022; Ji, 2023). The primary contribution of this research to the field lies in its focused investigation into the role of financial factors in shaping modal substitution. By examining perceived cost savings in transportation, the financial accessibility of bike-sharing services, and the income of users, we introduce a novel dimension to the discourse, shedding light on the economic motivations underpinning modal substitution decisions.

The findings of this study could offer valuable insights for policymakers and urban planners seeking to promote sustainable urban mobility and reduce reliance on private vehicles, especially in light of ongoing global efforts to address climate change and urban sustainability.

The analyses conducted in this article pertain to the city of Lodz in Poland. Poland has emerged as a leader among Central and Eastern European countries in the development of shared mobility systems, particularly bike-sharing systems (Kuźma *et al.*, 2022). Lodz, a central Polish city, offers an intriguing context to explore the dynamics of urban mobility. The city's flat topography, coupled with an expanding network of bike lanes and cyclist-friendly infrastructure, creates an ideal setting for bike-sharing activities. Lodz boasts a diverse transportation system, with two traffic peaks, one around 9 a.m. and another at 5 p.m., followed by a gradual decline in travel until 11 a.m. (Borowska-Stefańska *et al.*, 2021). This pattern suggests significant potential for bike-sharing to play a pivotal role in urban mobility and alleviate transportation congestion.

The bike-sharing system in Lodz was inaugurated in 2016, with Nextbike serving as its operator at the time. In its inaugural year, the system achieved a notable success, and in the subsequent years, rental numbers remained relatively stable. Between 2016 and 2019, approximately 1.5 million bike rentals were recorded annually, accompanied by a concurrent doubling of registered users, from 66,000 to 130,000 (Rowerowa Łódź, 2022).

Our survey was conducted among 296 users of the bike-sharing system in Lodz in 2019. This study examines three financial predictors influencing changes in citizens' travel behaviour following the introduction of a bike-sharing service: the role of transport cost savings as a motivation for using bike-sharing services, the perceived financial accessibility of the bike-sharing service, and the income levels of users. The financial conditions for utilising the bike-sharing system in Lodz were favourable for users making short trips, as the first 20 minutes of bike usage were free, and the high density of bike stations, particularly in the city centre and its immediate surroundings (Borowska-Stefańska *et al.*, 2020), which facilitated covering short distances at no cost. As such, our study aims to investigate whether financial factors influenced the substitution of other transportation modes with shared bicycles.

We sought answers to the following research questions:

1. Does the availability of the public bicycle system in Lodz lead to modal substitution where respondents opt for shared bicycles over other means of urban transportation?
2. Is there a correlation between the significance of financial factors for using public bicycles and the frequency of substituting other modes of transportation with bicycles?

The structure of this article is as follows. The following section presents a literature review examining the impact of bike-sharing service availability on residents' travel behaviour, along with the findings of previous studies regarding the determinants of such changes, including financial aspects. The methodology and results sections follow, and the article concludes with a discussion and summary.

2. LITERATURE REVIEW

Shared mobility has become an integral part of urban landscapes worldwide, offering travellers short-term access to various transportation modes, including motor vehicles, bicycles, and scooters, tailored to their specific needs. Bike-sharing represents a prime example of the sharing economy paradigm, offering an innovative solution to transportation challenges (Pawłowska, 2019). Bike-sharing programs have been successfully introduced and implemented in numerous cities globally, serving as policy instruments to mitigate greenhouse gas emissions, alleviate

traffic congestion, and promote physical activity. They have effectively bridged gaps in existing public transportation networks (Shaheen and Chan, 2016). Empirical evidence underscores the substantial positive externalities associated with bike-sharing programs. These programs offer urban residents a convenient and time-efficient mode of travel (Maas *et al.*, 2021) while reducing traffic, lowering energy consumption, minimising harmful emissions, enhancing public health, and stimulating economic growth (Chen *et al.*, 2022b). Bike-sharing holds the potential to play a pivotal role in urban transportation development, providing valuable insights for shaping urban transportation policies (Qiu and He, 2018). Nevertheless, transitioning travel behaviour away from automobiles and towards more sustainable alternatives, such as cycling, has proven to be a formidable challenge. Historical engineering-focused solutions to transportation issues during the 1960s to the 1990s marginalised cycling to the extent that utility trips in the United Kingdom plummeted from 13% in 1952 to around 1% by 1972 (Watson and Shove, 2008).

However, in many cities worldwide, residents, authorities, and other stakeholders have embraced the positive outcomes associated with private or shared bicycles. The surging popularity of cycling serves as evidence that behavioural change is attainable, even in cases of limited or suboptimal infrastructure investments (Pucher *et al.*, 2011). Some research has investigated the transition from other modes of transport to shared bikes (Crisostomi *et al.*, 2015). On average, no significant change was observed when shifting from private cars (Midgley, 2011; Johansson *et al.*, 2019). However, residents more frequently switch from public transport (Jäppinen *et al.*, 2013), a phenomenon often attributed to cultural factors, where public transport is perceived as the least desirable option, offering inadequate service quality. López-Casasnovas (2009) estimated that in Barcelona, most bike-sharing users had previously relied on public transport, implying that bike-sharing has, to some extent, supplanted mass transit systems like buses and subways.

Conversely, Otero *et al.* (2018) demonstrated that, when accounting for control variables and spatial effects, the frequency of public transport use significantly correlated with the number of bike-sharing trips. This positive effect was observed for short and medium-distance trips, but no such relationship was found for long-distance journeys. These findings underscore the relevance of public transport frequency as a determinant of bike-sharing usage, an aspect deserving attention in urban planning (Otero *et al.*, 2018; Radzimski and Dzięcielski, 2021).

Recent developments have introduced unexpected shifts in travel behaviour. Abdullah *et al.* (2021) noted that travel behaviour worldwide underwent significant changes following the outbreak of the COVID-19 pandemic. Researchers confirmed a shift towards personal cars during lockdowns (Abdullah *et al.*, 2021; Ku *et al.*, 2021; Tan and Ma, 2021). Another study explored the spatiotemporal shift in bike-sharing patterns in Chicago during the pandemic, comparing them to other transportation modes. Generalised additive (mixed) models were employed

to identify relationships and non-linear time interactions between daily bike-sharing usage at the station level and various independent variables. The results revealed that stations located in areas with higher income levels experienced a decrease in bicycle use during the pandemic compared to the pre-pandemic period (Li *et al.*, 2021).

According to Campbell *et al.* (2016), research based on a preference survey and multinomial logit analysis suggests that transitioning from existing modes of transport to bike-sharing depends on factors such as travel distance, temperature, precipitation, and air quality. Another study underscores the key factors contributing to bike-sharing success, emphasising the importance of local government experience, well-planned infrastructure, and public education as essential pillars of effective bike-sharing systems (Kwiatkowski and Biegańska, 2021). Zhao and Li (2017) observed that individuals with middle and high incomes were more likely to opt for cars over bicycles, while those with lower incomes preferred buses. Personal attitudes also play a crucial role in mode choice, as individuals who prioritise cost-effective travel are more inclined to choose cycling. Rodriguez-Valencia *et al.* (2021) revealed a connection between experience with public bike-sharing and perceptions of it as a mode of transportation. Less experienced users were more motivated by rational reasons, such as cost savings and dissatisfaction with subpar public transport. In contrast, experienced cyclists linked their use of public bikes to their passion for this mode of transport. Fishman *et al.* (2013) emphasised the paramount importance placed on value for money by bike-share members, a primary motivation for their registration and utilisation of these programs.

Numerous studies have explored the benefits of bike-sharing (Shelat *et al.*, 2018; Nieuwenhuijsen and Rojas-Rueda, 2020; Chen *et al.*, 2022c; Zhi *et al.*, 2022). Otero *et al.* (2018) conducted a health impact assessment study to quantify the health risks and benefits of replacing car travel with the European Bike-Sharing System (BSS). The health benefits of physical activity outweighed the health risks posed by fatal road accidents and air pollution. The level of car travel substitution corresponded to an annual saving of €18 million, primarily due to reduced fatalities. The benefits of shared bikes can also be assessed from an economic perspective. Bullock *et al.* (2017) demonstrated the economic advantages of bike-sharing schemes in Dublin, showcasing individual benefits and public good outcomes.

However, research on the impact of public bicycling on citizens' transport behaviour and the importance of financial factors driving these changes in Central and Eastern European countries remains limited. Analyses of bike-sharing systems in this region underscore their dynamic development and strong user interest (Kuźma *et al.*, 2022). Poland, in particular, stands out with its average annual revenues from bike-sharing services, reaching €21 million in 2019, several times higher than neighbouring countries (Borowska-Stefańska *et al.*, 2020). The development of bike-sharing systems in Poland began in 2010 and proceeded at a rapid pace until the COVID-19 pandemic. During the pandemic, bike rentals in major Polish cities

dropped by almost 50% (Jędrzejewski, 2022). From 2020 to 2022, the shared bike market in Poland experienced renewed growth, with 79 bike-sharing systems operating in 2022, offering approximately 23,700 vehicles (Mobilne miasto, 2023).

In contrast to the prevalence of scooter-sharing systems in Polish cities, constituting 80% of the shared micro-mobility market, 95% of bike-sharing systems are government-owned (docked bike-sharing), with only 5% being commercial systems. Public bike systems in Poland are largely funded by cities, with development often facilitated by European Union funds (Dzięcielski *et al.*, 2020). Due to high maintenance costs, some Polish cities (e.g., Poznań, Olsztyn) have discontinued bike-sharing systems in recent years, while new systems continue to emerge. In 2024, the launch of the largest bike-sharing system in Poland, and the third-largest in Europe, is planned across 31 municipalities in the Górnośląsko-Zagłębiowska Metropolis. The system will include 7,000 bikes and approximately 1,000 stations, offering passengers using public transportation monthly passes the ability to rent bikes for free for up to 30 minutes a day (Metropolia GZM, 2023).

Research on public bicycling in Polish cities has focused on the performance of bike-sharing systems (Bieliński *et al.*, 2019), frequency of use, motivations and determinants of public bicycle use, including financial considerations (Podgórniak-Krzykacz and Trippner-Hrabi, 2021; Podgórniak-Krzykacz *et al.*, 2022), user evaluations (Macioszek *et al.*, 2020), or evaluations of specific application features (Pamuła and Gontar, 2017). However, the issue of modal substitution resulting from the introduction of bike-sharing systems has not been thoroughly examined. Radzimiński and Dzięcielski (2021) conducted a study in the city of Poznań that explored integration and substitution between public bicycles and public transport. The metropolitan bike-sharing system in Poland has also garnered interest, with studies highlighting the various needs of cities, towns, and villages in integrating bike-sharing as a means of transport for residents, tourists, and recreational cyclists (Kwiatkowski, 2021). Consequently, our study addresses this knowledge gap by investigating modal substitution induced by urban cycling in the Polish city of Lodz and seeks to establish the significance of financial factors in driving this change.

3. METHODOLOGY

3.1 Research sample

The operator of the bike-sharing system in Lodz during the survey period was Nextbike Polska, managing a fleet of 1,584 vehicles. In 2019, this system ranked fourth among the 15 largest bike-sharing systems in Poland (as shown in Table 1).

The Lodz public bicycle system followed a station-based operational model, comprising 157 stations. In 2019, the system recorded 1.4 million rentals, making it the third-largest in terms of usage in Poland.

Table 1. Number of bicycles and bike rentals in the 15 largest bike-sharing systems in Poland in 2019

City	Name of the bike-sharing system	Number of bikes	Number of rentals
Warsaw	Veturilo	5,500	5,316,910
Wroclaw	Wrocławski Rower Miejski	2,065	1,817,783
Poznan	Poznański Rower Miejski	1,700	1,134,360
Lodz	Łódzki Rower Publiczny	1,584	1,469,419
Krakow	Wavelo	1,500	839,445
Lublin	Lubelski Rower Miejski	961	658,700
Szczecin	Bike_S	700	410,000
Bialystok	BiKeR	659	539,396
Katowice	City by bike	632	261,836
Bydgoszcz	Bydgoski Rower Aglomeracyjny	590	245,000
Kalisz	Kaliski Rower Miejski	283	118,400
Radom	Radomski Rower Miejski	270	82,800
Czestochowa	Częstochowski Rower Miejski	185	149,200
Gliwice	Gliwicki Rower Miejski	150	84,800
Kolobrzeg	Kołobrzeski Rower Miejski	135	88,000

Source: Mobilne miasto (2020).

The changes in travel behaviour among Lodz residents, influenced by the availability of bike-sharing services and their financial determinants, were investigated through a survey conducted using the Computer Assisted Personal Interview (CAPI) technique. This survey took place from March to June 2019. The survey sample was non-random and purposive, consisting of individuals who had rented a bicycle from the municipal system in Lodz at least once. To ensure the sample met the target group specifications, a screening question was used at the beginning of the survey. Four interviewers were engaged and provided with thorough instructions to ensure accurate data collection. The survey was conducted among passers-by near bike stations. Control variables such as respondents' age, gender, education, and monthly household income were included in the study. Table 2 presents the characteristics of the sample based on these attributes.

Table 2. Characteristics of the research sample

	N	%
Age		
Up to 18 years old	13	4.39
19–26 years old	146	49.33
27–35 years old	68	22.97
36–45 years old	55	18.58
46 and more	14	4.73
Gender		
Woman	154	52.03
Man	142	47.97
Education		
Basic and primary	14	4.73
Secondary technical	42	14.19
General secondary education	70	23.65
Incomplete higher education	61	20.61
Higher	102	34.46
No data	7	2.36
Monthly household income		
Up to PLN 2,000	60	20.27
PLN 2,000–5,000	112	37.83
PLN 5,000–10,000	74	25.00
Over PLN 10,000	20	6.76
No data	30	10.14
Total	296	

Source: own work.

3.2. Measurement and data analysis method

Respondents indicated changes in their travel behaviour resulting from the availability of public bicycles in Lodz using 11 proposed alternatives:

– they abandoned traveling by private car in favour of public bicycles permanently, frequently, or occasionally,

– they abandoned traveling by public transport in favour of public bicycles permanently, frequently, or occasionally,

– they abandoned walking or pedestrian movements in favour of public bicycles permanently, frequently, or occasionally,

– they continued using their usual mode of transportation and considered public bicycles as an additional means of transport,

– they did not change their behaviour.

The financial incentive for using the bike-sharing service was assessed by inquiring whether cost savings motivated their use of the city bikes. The perceived affordability of the bike-sharing service was evaluated by asking respondents to rate their satisfaction with the price of renting a city bike using a 5-point Likert scale (1 = strongly unsatisfactory, 5 = strongly satisfactory).

Statistical analyses involved the Fisher test, the chi-square test of independence, and the Mann-Whitney test to examine the relationships between variables. The significance of the tests was assessed at 10%, 5%, and 1% significance levels. Effect sizes were determined using V-Cramer coefficients and correlation coefficients. All calculations were performed using Stata 17 software.

4. RESULTS

4.1. Modal substitution as a result of bike-sharing system availability

The influence of the public bike system's availability on altering respondents' travel behaviour is presented in Table 3. The respondents had the option to choose multiple answers (mutually exclusive options were eliminated by the authors). Among those who regularly use public mass transport, approximately 25% reported occasionally substituting public transport with bicycles. Slightly fewer respondents mentioned frequent substitution of public transport with bicycles. Significantly fewer respondents indicated a permanent shift compared to the „frequently" and „occasionally" categories. Similar patterns emerged among pedestrians, where a significantly smaller proportion permanently switched from walking to using a city bike compared to those who did it frequently or occasionally. These results highlight public bicycles as the primary alternative to both public transport and pedestrian mobility. However, the ongoing trend of replacing these modes of transportation with public bicycles may not be sustainable. In contrast, public bicycles are considerably less competitive with private cars, but when a change occurs, it tends to be frequent or occasional. Such changes also persist longer compared to pedestrians and public transport users.

Table 3. Modal substitution of respondents

Type of change in travel behaviour	Persistence of change	N	%
Abandoned traveling by private car in favour of public bicycles	Permanently	27	9.12
	Frequently	47	15.88
	Occasionally	38	12.84
Abandoned traveling by public transport in favour of public bicycles	Permanently	15	5.07
	Frequently	66	22.30
	Occasionally	73	24.66
Abandoned walking or pedestrian movements in favour of public bicycles	Permanently	12	4.05
	Frequently	51	17.23
	Occasionally	50	16.89
Perception of the influence of the availability of the bicycle system on the change in travel behaviour	I continue to use the same means of transport; a public bike serves as an additional option.	94	31.76
	The availability of the bicycle system has not led to a lasting alteration in transportation methods.	63	21.28

Source: own work.

One-third of respondents stated that public bikes served as an additional mode of transport, and they continued to use other existing mobility options with the same frequency. Approximately 20% of respondents believed that access to the bicycle system did not lead to a permanent change in their travel behaviour.

4.2. The impact of financial determinants on the travel behaviour change due to bike-sharing system availability

The relationship between respondents' declared changes in travel behaviour and financial predictors (including user income, the motive of saving transport expenses when renting a bicycle, and satisfaction with the price of renting a bicycle) was analysed. Income levels did not exhibit a statistically significant relationship with any variation of travel behaviour change. Out of 296 respondents, 84 (28.4%) indicated cost savings in transport expenses as a motivating factor for choosing a public bicycle, with half of them reporting an average monthly household income below PLN 5,000. Using the chi-square test of independence, the association between the financial motive for choosing a city bike and changes in travel behaviour in response to the availability of bike rental services in the city was assessed. The results of the analyses are presented in Table 4.

Table 4. Analysis of the frequency of answers for using a city bike, depending on whether respondents indicated "cost saving" as the most important reason for using a bike

Answer		Using a city bike because of cost savings				p	V
		No		Yes			
		N	%	N	%		
"I have permanently transitioned from using a car to a city bike."	No	195	91.98	74	88.10	0.295	0.061
	Yes	17	8.02	10	11.90		
"I frequently opt for a city bike over using a car."	No	177	83.49	72	85.71	0.637	0.027
	Yes	35	16.51	12	14.29		
"I occasionally choose a city bike over a car."	No	183	86.32	75	89.29	0.492	0.040
	Yes	29	13.68	9	10.71		
"I have permanently transitioned from using a public transport to a city bike."	No	203	95.75	78	92.86	0.306	0.060
	Yes	9	4.25	6	7.14		
"I frequently opt for a city bike over using a public transport."	No	171	80.66	59	70.24	0.052*	0.113
	Yes	41	19.34	25	29.76		
"I occasionally choose a city bike over a public transport."	No	164	77.36	59	70.24	0.200	0.075
	Yes	48	22.64	25	29.76		
"I have permanently transitioned from walking to a city bike."	No	204	96.23	80	95.24	0.698	0.023
	Yes	8	3.77	4	4.76		
"I frequently opt for a city bike over walking."	No	181	85.38	64	76.19	0.059*	0.110
	Yes	31	14.62	20	23.81		
"I occasionally choose a city bike over walking."	No	184	86.79	62	73.81	0.007***	0.156
	Yes	28	13.21	22	26.19		
"I continue to use the same means of transport, with the bicycle as an additional option."	No	140	66.04	62	73.81	0.195	0.075
	Yes	72	33.96	22	26.19		
"There has been no permanent change in my means of transportation."	No	161	75.94	72	85.71	0.064*	0.108
	Yes	51	24.06	12	14.29		

Explanations: p – empirical significance level of the chi-square test of independence (*p < 0.1, **p < 0.05, ***p < 0.01); V – V-Cramer coefficient (effect size).

Source: own work.

Cost savings for using city bicycles exhibited a highly statistically significant relationship (at the 1% significance level) with occasionally substituting walking with city bicycles, although the strength of this relationship was weak. At the 10% significance level, statistical significance was also observed among respondents who frequently substituted public transport with city bikes, occasionally

substituted walking with city bikes, or experienced no permanent change in their travel behaviour. In all cases, the strength of the relationship ranged from weak to very weak.

Respondents' satisfaction with the price of renting public bikes is summarized in Table 5. Satisfactory and very satisfactory ratings were prevalent, accounting for over 70% of respondents in total, indicating high financial accessibility of the service. This high satisfaction likely stems from the first 20 minutes of bicycle usage being free of charge and the dense network of stations, particularly in the city centre (on average 5.35 stations per 10 sq. km of the city area), making it possible to reach them within this time limit. Similar to other Polish and European cities, the price list rewards frequent and short-term bicycle users with no incurred costs and imposes fees that increase substantially with each subsequent hour of rental for longer routes (Fishman *et al.*, 2013; Kwiatkowski, 2018).

Table 5. Satisfaction ratings with the price of renting a shared bike

	1	**2**	**3**	**4**	**5**	**Difficult to say**	**Average**	**Median**
N	3	27	36	110	109	11	4.04	4
%	1.01	9.1	12.2	37.2	36.8	3.7	-	-

Source: own work.

Subsequently, using the Mann-Whitney test, respondents' average satisfaction ratings with the price of renting bicycles were compared based on their declared changes in travel behaviour. The results are presented in Table 6.

Table 6. Results of comparing user satisfaction with the price of using the city bike system depending on the declared change in travel behaviour related to the introduction of the city bike

Answer		**Price**		**Z**	**p**	**|r|**
		M	**SD**			
"I have permanently transitioned from using a car to a city bike."	No	3.83	1.26	-2.483	0.013**	0.144
	Yes	4.41	0.85			
"I frequently opt for a city bike over using a car."	No	3.84	1.23	-1.864	0.062*	0.108
	Yes	4.11	1.26			
"I occasionally choose a city bike over a car."	No	3.92	1.21	0.990	0.032**	0.058
	Yes	3.66	1.44			
"I have permanently transitioned from using a public transport to a city bike."	No	3.87	1.25	-0.528	0.597	0.031
	Yes	4.13	0.92			
"I frequently opt for a city bike over using a public transport."	No	3.83	1.24	-1.892	0.059*	0.110
	Yes	4.09	1.21			

Answer		Price		Z	p	|r|
		M	SD			
"I occasionally choose a city bike over a public transport."	No	3.96	1.18	1.524	0.127	0.089
	Yes	3.67	1.38			
"I have permanently transitioned from walking to a city bike."	No	3.91	1.20	0.804	0.422	0.047
	Yes	3.33	1.87			
"I frequently opt for a city bike over walking."	No	3.84	1.25	-1.395	0.163	0.081
	Yes	4.08	1.18			
"I occasionally choose a city bike over walking."	No	3.84	1.24	-1.647	0.099*	0.096
	Yes	4.10	1.99			
"I continue to use the same means of transport, with the bicycle as an additional option. "	No	3.89	1.28	0.693	0.488	0.040
	Yes	3.87	1.16			
"There has been no permanent change in my means of transportation."	No	3.91	1.26	1.276	0.202	0.074
	Yes	3.79	1.14			

Explanations: M – average; SD – standard deviation; Z – standardized Z-score for Mann-Whitney test statistics; p – empirical significance level of the Mann-Whitney test (*p < 0.1, **p < 0.05, ***p < 0.01); |r| – correlation coefficient (effect size).

Source: own work.

Statistically significant differences in the assessment of satisfaction with the price of using a city bike were revealed among people who switched to a city bike from a car permanently (at the 5% significance level), frequently (at the 10% significance level), or occasionally (at the 5% significance level). Among residents who frequently give up travelling by public transport in favour of a city bike, and among people who occasionally give up walking in favour of a city bike this relationship was significant at the 10% significance level. The switch from using a car to a city bike permanently yielded the most substantial effect size. However, in all cases, the magnitude of the observed effects was low.

Statistically significant differences in satisfaction ratings for using a city bike were observed among individuals who permanently switched from using a car to a city bike (at the 5% significance level), those who frequently made this change (at the 10% significance level), or those who occasionally did (at the 5% significance level). Among residents who frequently substituted public transport with city bikes and those who occasionally replaced walking with city bikes, this relationship was significant at the 10% significance level. The most substantial effect size was observed for the permanent switch from using a car to a city bike. However, in all cases, the observed effects were of low magnitude.

5. DISCUSSION

Our analysis reveals that bike-sharing serves as an additional mobility option for respondents without significantly altering their travel behaviour. Despite the increasing number of users in the Lodz bike-sharing system until 2019 and the noticeable share of trips made using rented bikes in the modal split (Borowska-Stefańska *et al.*, 2020), car travel remains the dominant mode of urban transportation in the city (Wiśniewski *et al.*, 2023). Other analyses also emphasize the significant role of private cars and the limited use of bicycles in the mobility of residents of Polish cities (Bartosiewicz and Pielesiak, 2019). Furthermore, studies on bike-sharing system performance in Poland indicate relatively low utilization, with the average TDB (the number of trips per day per bike) in 2018 being 1.93, lower than observed in larger global cities or Chinese cities, ranging from 0.12 to 4.89 (Bieliński *et al.*, 2019).

Nevertheless, our findings do indicate some impact of the bike-sharing system, which varies depending on the previous modes of travel. The most substantial behavioural change observed was the shift from public transport to public bicycles. To a lesser extent, public bicycles became competitive with walking, and to the smallest extent, they replaced individual car travel. These findings are consistent with results from studies conducted in various countries, confirming the competitiveness of public bicycles with public transport (Jäppinen *et al.*, 2013; López-Casasnovas, 2009; Jin, 2019; Wolny-Kucińska, 2020). Similar observations apply to e-bikes (Bielinski *et al.*, 2021). In Lodz, the well-developed public transport network, especially in the city centre, is countered by high traffic congestion, resulting in extended travel times, delays, and a decrease in the attractiveness of this mode of transportation (Borowska-Stefańska *et al.*, 2023; Wiśniewski *et al.*, 2023). Consequently, public transport users in Lodz may seek alternative means of transportation.

Considering the positive impact of cycling on health, changes from public transport to cycling should be viewed favourably. Conversely, switching from walking to cycling should be regarded as neutral. It's important to acknowledge the hierarchy of green transport, where walking trips are the most environmentally beneficial, healthy, and cost-effective (provided suitable pedestrian infrastructure exists). In contrast, cycling systems require financial investments for setup and operation, and they generate CO2 emissions throughout their life cycle due to system maintenance, vehicle relocation, and operation (Chen *et al.*, 2023). Thus, cycling may not be an attractive option for travellers on short pedestrian journeys, which is a common scenario in Lodz (Borowska-Stefańska *et al.*, 2020).

The most desirable shift, from private car travel to cycling, is optimal for balancing transport systems, reducing greenhouse gas emissions (Cao and Shen, 2019; Chen *et al.*, 2022b), and promoting public health. However, this transition is inadequately achieved in the studied city, consistent with findings from other studies (e.g., Midgley, 2011; Johansson *et al.*, 2019; Fishamnn *et al.*, 2014) re-

garding low car-to-bicycle mode substitution. This is attributed to individuals' heavy reliance on cars. Barbour *et al.* (2019) drew more extensive conclusions about the behaviour of registered users of bike-sharing systems, suggesting that people's dependence on cars leads them to rent bicycles less frequently and substitute bicycle travel with car travel when access to a bicycle system is unavailable. Furthermore, studies on the impact of bicycle systems on reducing car ownership suggest a small but immediate effect (Basu and Ferreira, 2021).

In the case of Lodz, despite the presence of a bike-sharing system with an efficiently distributed station network and a substantial number of bikes (Borowska-Stefańska *et al.*, 2020), it does not constitute an attractive alternative to car travel, especially considering the prevalent traffic congestion. The high dependence of Polish society on cars, the nature of car travel primarily for commuting to workplaces, and significant travel distances due to urban sprawl in urban regions motivate car usage (Bartosiewicz and Pielesiak, 2019). In 2019, the Lodz bike-sharing system also had a concentration of bike stations in the city centre, affecting its accessibility in the outskirts. Basu and Ferreira (2021) estimated a 3.3% reduction in kilometres travelled by car with the introduction of a new cycling station, which increased to 10% when integrated with public transport and when bike stations were located within one kilometre of each other.

Our results reveal a relationship between financial factors related to bike-sharing (cost-saving motives and satisfaction with rental prices) and certain changes in travel behaviour. Respondents who occasionally and frequently substituted walking or public transport with cycling were more likely to emphasize the importance of cost savings. In both cases, this behaviour change can be attributed to the cost-free nature of cycling for the first 20 minutes. Additionally, our research suggests that low bike rental costs have the potential to reduce car travel. Among respondents highly satisfied with the rental price, there was a higher incidence of permanently, frequently, or occasionally giving up car travel. However, these relationships are of weak magnitude. These findings align with other research indicating the significance of bike travel costs in influencing car-to-bike mode substitution (Narayanan *et al.*, 2023). In other studies, the importance of bicycle rental costs for intending to use the service was more pronounced among students compared to office workers (Duan *et al.*, 2023).

It's important to recognize that this study has certain limitations, primarily related to the non-representative nature of the research sample. Since the sample is not representative, we cannot extrapolate the research findings to encompass the entire population of Lodz's citizens or all users of Lodz's bike system. Such an attempt could potentially lead to biased conclusions, particularly when considering specific groups of residents who are not adequately represented in the research sample. Furthermore, the sample size is limited, which posed a challenge when attempting to introduce more advanced statistical techniques, such as multivariate regression analysis. Therefore, future developments of this study should prioritize

achieving sample representativeness in terms of the general sociodemographic structure and spatial distribution of respondents, as well as expanding the sample size for more robust analysis.

6. CONCLUSIONS

Our study primarily focused on examining modal substitution options involving shared bikes. These analyses contribute significantly to addressing a knowledge gap concerning the adoption of shared bicycles in Polish cities. The research conducted among shared bicycle users in Lodz revealed that the most substantial impact observed was the substitution of public transport trips with bicycle trips, while the influence on replacing car trips was minimal. Such patterns and the limited degree of modal substitution do not align with expectations and do not support the goals of transitioning to sustainable urban mobility. The bike-sharing system does not appear to be an effective tool for facilitating this transition by substituting private and multimodal trips with shared bikes and public transport.

In our study, we examined the significance of financial factors in the shift from other modes of transportation to bike rentals. What sets our approach apart from other approaches is the consideration of two predictors of this substitution: the financial incentive for using the bike-sharing service and the perceived affordability of the bike-sharing service. We have indeed identified a statistically significant relationship between satisfaction with pricing and the decision to give up car travel in favour of cycling, as well as the cost-saving motive and the substitution of walking and public transport travel with biking. However, these relationships are relatively weak, underscoring the importance of other contributing factors.

These findings have implications for policymakers. To enhance the impact of cycling in reducing car journeys, it is imperative to promote cycling systems and introduce more flexible and financially attractive conditions for bike rentals from the user's perspective. The promotion of cycling systems should emphasize the financial benefits associated with replacing car trips with bike-sharing. Additionally, encouraging multimodal journeys that combine first/last mile bike-sharing with public transport is essential. An illustrative example of innovative bike rental schemes is the one planned for implementation in Krakow, Poland, in 2023, offering the option to rent a city bike exclusively for one month.

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