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The impact of service expansion on modal shift from private car to public transport. A quantitative analysis in the Bonn/Rhein-Sieg area, Germany

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Vehicle emissions have been identified as a cause of air pollution and one of the major reasons why air quality in many large German cities such as Berlin, Bonn, Hamburg, Cologne or Munich does not meet EU-wide limits. As a result, in the recent past, judicial driving bans on diesel vehicles have been imposed in many places since those vehicles emit critical pollutant groups. For the increasing urban population, the challenge is whether and how a change of the modal split in favor of the more environmentally and climate-friendly public transport can be achieved.

This paper presents the case of the Federal City of Bonn, one of five model cities sponsored by the German federal government that are testing measures to reduce traffic-related pollutant emissions by expanding the range of public transport services on offer. We present the results of a quantitative survey ($N = 14{,}296$) performed in the Bonn/Rhein-Sieg area and the neighboring municipalities as well as the ensuing logistic regressions confirming that a change in individual mobility behavior in favor of public transport is possible through expanding services. Our results show that individual traffic could be reduced, especially on the city's main traffic axes. To sustainably improve air quality, such services must be made permanently available.

1. Introduction

Human-induced climate change and developing sustainable environmental strategies are fundamental challenges of the 21st century, with the transport sector playing a central role. In Germany, exceedances of EU-wide pollutant limits are leading to court-imposed driving bans in affected cities. As a result, the Federal City of Bonn participated as one of five model cities in the Lead City project funded by the German government, which investigated whether and how a behavioral change in travel patterns could be achieved by expanding public transport services.

In contrast to service expansions in other cities, where the effects of investments in infrastructure were analyzed, this project implemented measures based on existing infrastructure. The expansion of services included increased frequency in bus and train schedules and improved public transport connections through additional bus stops, especially in rural areas. With a population of 338,396 (as of January 1, 2023), (Statistics: Bonn in figs. 2020) Bonn is considered one of the economically strongest cities in the state of North Rhine-Westphalia and offers jobs to 188,930 employees over an area of more than 141 km^2 (as of June 30, 2022) (Statistics: Bonn in figs. 2020). The surrounding municipality of the Rhein-Sieg district with its more than 600,000 inhabitants represents an important business location. Local transport primarily serves the entire Bonn urban area but also parts of the Rhein-Sieg area and the surrounding area of the city of Cologne.

In our study, we used Kaufmann, Bergman and Joyce (2004) theoretical model to examine the conceptual and theoretical relationships between spatial and social mobility. This construct, referred to as "motility", describes the potential and actual ability of people, goods, or information to be both geographically and socially mobile. To represent the complexity of travel behavior, we structured the survey along three main characteristics as proposed by Kaufmann et al., 2004 – access, skills, and appropriation. To operationalize the variables, we referred to the study from Flamm and Kaufmann (2006). We derived the choice of variables relevant for our study from prior studies and will describe them in more detail in Chapter 2.2.

A total of 14,296 people from the Bonn/Rhein-Sieg area and neighboring municipalities participated in the online survey on service expansion. Using logistic regression, we identified significant predictors of car trip savings.

In this paper, we present our findings on what influence the expansion of the transport offer could have on people's mobility behavior in

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the short term and whether the measure could lead to a shift in commuter traffic from individual traffic to local public transport.

2. Theoretical background

2.1. Related activities

Individual vehicle centered mobility is highly attractive for users, despite the well-known negative consequences such as traffic congestion; excessive consumption of energy and resources; negative environmental impacts such as noise, vibration, and the emissions of various pollutants; and their contribution to global warming (González, Marrero, Rodríguez-López & Marrero, 2019). Many pilot projects promote a modal shift in mobility by increasing the attractiveness of public transport, most often by a price reduction or free public transport.

For several years, a lively debate has been taking place in Europe about abolishing public transport fares (Urbanek, 2019). Critics claim that, from the point of view of benefits, efficiency, and economic growth (Cervero, 1990; Storchmann, 2003), zero fares could financially harm public transport networks and lead to useless mobility (Baum, 1973; Duhamel, 2004). In addition, scholars and practitioners who see mobility problems through the issue of sustainable development (Kębłowski & Bassens, 2018) point to the weakness of public transport in inducing modal shift from private vehicles to public transport (Cats, Susilo & Reimal, 2017; Fearnley, 2013). Proponents of free public transport see great potential to support the traffic turnaround through more climate-friendly traffic as well as to ensure mobility for the socially disadvantaged (Briche et al., 2017; Brown, Hess & Shoup, 2003; Giovanangelli & Sagot-Duvauroux, 2012; Kipfer, 2012; Larrabure, 2016; Maricato, 2013; Santana & Silva, 2013; Schein, 2011; Volinski, 2012). In our study, we take these controversial views as an opportunity to discuss the effects of expanding the public transportation offer for the Bonn/Rhein-Sieg area.

In the past, numerous models have attempted to cause a modal shift by increasing the attractiveness of public transport (Kębłowski, Van Criekingen & Bassens, 2019). The central measure of most relevant projects is a price reduction or free use of public transport, but the design of the models and their results and consequences vary (Grzelec & Jagiello, 2020). Since our study was conducted in Germany, we see field trials in the European area as offering the greatest comparability with regard to transport systems, distances, and useful lessons from the volume of traffic. For this reason, we focused on and considered only scientifically studied European field trials.

In Germany, for instance, two small eastern towns (Templin, 16,000 inhabitants, and Lübben, 15,000 inhabitants) have experimented with offering local public transport free of charge to customers. Initially, the measure resulted in a huge increase in passengers, which could only be managed by increasing the number of journeys, and as a result the volume of Individual vehicle traffic and the air pollution were reduced (Fearnley, 2013). The costs arising during the pilot schemes were completely covered by the towns. However today, tickets are no longer free, and the number of journeys has been reduced. Nevertheless, the services are inexpensive compared to the price level in similar towns, and the number of trips has remained above the original level.

In Belgium, free public transport was introduced in the city of Hasselt with 70,000 inhabitants in 1997. The city is the destination of many commuters and had a well-developed public transport network even before the introduction of the free fare. At the same time as introducing free public transport, multi-lane roads were dismantled. Due to massive cost increases, the sale of tickets had to be reintroduced in 2013 (Fearnley, 2013). Here, too, the usage after the end of the measure has remained above the original level. The potential of free public transport for a modal shift of commuters was also investigated for the capital Brussels (De Witte et al., 2006). Brussels has a highly developed and well-used bus and train network that is comparatively inexpensive, but not free of charge (Proost, 2008). The free public transport led to a modal shift from car to public transport, but it also showed that price is not the only decisive factor (De Witte, Macharis & Mairesse, 2008).

In Estonian, Tallinn with 425,000 inhabitants was the largest city that introduced free public transport for locals in 2013 (Cats et al., 2017; Tuisk & Prause, 2018). The project was motivated by the social ambition of making public transport affordable for every inhabitant, regardless of income level (Hess, 2017). The use of public transport increased from 55% to 63%, remaining below expected changes (Prause & Tuisk, 2020).

The Austrian capital Vienna with about 1900,000 inhabitants offers a 365 € annual ticket for the use of public transport. The measure introduced in 2012 has resulted in 760,000 Viennese using such a ticket and the share of car trips being reduced by one third between 1993 and 2014 from 40% to 27% (R. Buehler, Pucher & Altshuler, 2017). In addition to the expanded infrastructure, future growth plans and the heavily subsidized ticket, Vienna is ensuring that other measures such as an increase in parking prices will lead to a modal shift to public transport. The entire package of measures is an incentive policy decision to strengthen the economy, but the services run at a deficit and are subsidized by the City of Vienna and the federal government (R. Buehler, Pucher & Altshuler, 2017).

Luxembourg has the highest number of cars per capita in the country in Europe and 120,000 incoming commuters per day from the surrounding countries of Germany, France, and Belgium (Shimauchi, 2020). As a measure to relieve road congestion, in summer 2020, Luxembourg was the first country in the world to offer its public transport free of charge to everyone. It has one of the highest traffic densities and one of the financially strongest economic sectors in Europe (Carr & Hesse, 2019). The measure was not an economic decision but an ecological and social one. The aim is not only to reduce congestion and air pollution but also to make collective mobility accessible to people with lower incomes (Carr & Hesse, 2020). Due to the COVID19 pandemic, it is difficult to assess commuter adoption, but recently released figures show a positive trend. According to the report, an average of 31,000 passengers per day were using the trams in February 2020. In February 2021, a peak of 42,000 passengers was reached, although the situation has not yet returned to normal due to home office use in various sectors.

All these projects mainly focus on price reduction to make public transport more attractive and to promote a modal shift (Hahn, Pakusch & Stevens, 2020). For some of these projects, the price reduction was accompanied by expanding the range of services on offer. Yet non-monetary incentives do not seem to be the focus of these projects.

In particular, these projects did not study whether an increase in the supply of public transport alone could also lead to a modal shift in favor of public transport. Yet, results from studies such as that by De Witte et al. (2008) demonstrate that a long travel time and poor public transport connections are obstacles for non-customers. It seems obvious that extending a public transport offer could make public transport more appealing and thus attract additional users. However, transport choices are complex and often influenced by long-term decisions such as buying a car (Müggenburg, 2017). Against the background of the financial challenges mobility providers face, this paper aims to address the gap between the benefits of non-monetary factors, such as a well-developed network of routes, access to public transport, higher frequencies and reliability, and the short-term benefits of switching to public transport.

It is evident that the focus of prior studies has been primarily on low-cost or free public transportation. In our study, we focused on the change in modal shift due to non-monetary factors such as the reduction of passenger waiting times on weekdays in the main bus and train lines, expansion of the timetable service on weekends, better interconnection between peripheral areas, and an optimized connection of these areas to the city center via new passenger routes. A study from Moriyama, Fujiwara & Zhang, 2005 examined non-monetary indicators for evaluating public transportation services in rural areas. The results indicate that non-monetary indicators of public transport services, such as quality of life, customer satisfaction, and equivalence of public transport

services can contribute to improved public transport services.

2.2. Access, skills, and appropriation as drivers for mobility

To also take non-monetary factors into account, we adopt Kaufmann et al. (2002, 2004) theoretical motility model as an analytical lens. Kaufmann et al. (2002, 2004) understand motility as the potential and actual ability of goods, information, or people to be both geographically and socially mobile. Mobility thus represents a possibility that is realized by a journey (Kellermann, 2016; Wilde, 2013). Motility can be viewed as a form of capital in itself that influences social integration (Kaufmann & Audikana, 2020). The primary goal of a journey is to get from point A to point B, if possible, in line with the individual's own behavioral framework and derived eudemonic well-being (Shliselberg, Givoni & Kaplan, 2020).

Following Kaufmann et al. (2004), an individual decision to undertake a particular trip is generally shaped by three factors: access, skills, and appropriation (see Fig. 1). The main advantage of this perspective is that it shows that not one but several factors are decisive for the decision to travel and the choice of transport mode (De Witte, Hollevoet, Dobruszkes, Hubert & Macharis, 2013). This conceptual approach is multifaceted and has been recognized in various studies (Cuignet et al., 2019; Haldimann, Heers & Rérat, 2022; Hamidi, 2020; Seinsche, Zijlstra & Giannouli, 2020).

On this theoretical basis, we derived the subcategories relevant for our study from previous studies. The **access** category includes the variable information on the supply, car availability in the household, and residential situation, which were also applied in the studies by De Witte et al. (2006, 2008, 2013) and Macharis et al. (2006). In addition, we added the variable size of the household since, for our research, household size is closely related to car availability in the household. Including this measure opens up further possibilities for analysis. In the **skills** category, we adopted educational level and age from the studies by De Witte et al. (2006, 2008, 2013) and Macharis et al. (2006). Analog to the studies Akyelken (2013) and Turdalieya and Edling (2018), we included the variable gender in our model. In the **appropriation** domain, we were able to consider the variables change assessment, experience with public transport, and evaluation Lead City Bonn. This content is largely in line with the studies by De Witte et al. (2006, 2008, 2013) and Macharis et al. (2006), who investigated experience with public transport and travel habits.

3. Data and methods

3.1. Procedure and participants

The study is based on a survey concerned with citizens' evaluations of the mobility measure of an expanded public transport system. The survey enables information to be derived on the overall impact of the measure. For this research, a written quantitative online survey on further development of public transport through a change in supply was evaluated for the urban area of Bonn and for parts of the Rhein-Sieg area.

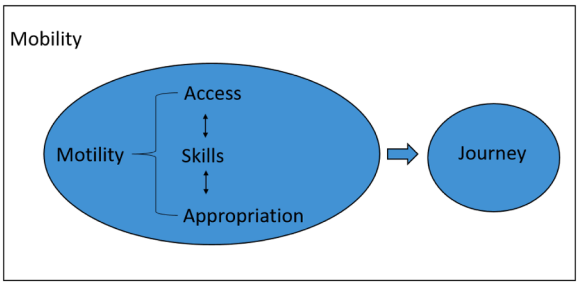

Fig. 1. Motility concept according to Kaufmann. De Witte et al. (2008).

A total of 264,740 households from the urban area of Bonn and relevant neighboring municipalities were contacted by mail and invited to participate in the survey online. 14,296 individuals, 5.4% of the invited households, took part in the survey conducted between August and September 2019. The data sets of this population of $N = 14{,}296$ surveys were statistically analyzed to draw conclusions about the effectiveness of the measures and the resulting mobility behavior of people from the region (Table 1).

Any differences between the sums of the numbers and the total population ($N = 14{,}296$) are attributable to "do not know" or invalid answers (370 for age, 226 for gender and 284 for place of residence. The percentages refer to the valid responses for each predictor and always add up to 100%.

3.2. Survey design

In the survey, the three main categories of access, skills, and appropriation were based on Kaufmann et al. (2004) theoretical principles and assigned further subordinate categories. Table 2 shows the relevant factors.

To answer our research question, identifying the variables for predicting car trip avoidance through regression analysis is critical. The predictor variables in the study are categorical. The results of our logistic regression are presented by forming reference categories and discussing their necessity and influence on our study.

3.3. Statistical data analysis

The survey complexity meant that a large number of data records were collected, which could then be categorized and processed according to the analysis table from Kaufmann. Before data analysis began, the survey data were screened for values that would inhibit an error-free analysis, and the data were adjusted accordingly. Then, to evaluate the data and obtain an overview, descriptive statistics methods were applied, such as the calculation of frequencies and mean values. The exploratory data analysis procedure was used to sift through data to identify unusual values, extreme values, gaps in the data, or other anomalies (Döring & Bortz, 2016). In addition to descriptive statistics, inductive statistics were also used to draw conclusions about the entire sample (Eid, Golwitzer & Schmitt, 2017). Furthermore, correlations were calculated to determine the relationships between the relevant variables. To statistically answer the research question, logistic regressions were prepared and performed in SPSS 27 data analysis software. We examined the relationship between several predictors of the three categories access, skills, and appropriation plus mobility practices as independent variables and the nominally scaled criterion "avoidance of car trips" as the dependent binary variable.

The evaluation of the omnibus test of the model coefficients gives the result of the likelihood ratio test as a Chi-square value and the associated

Table 1
Demographics of survey participants.

Characteristic:	Number:	Percent:
Survey participants by age:		
up to 18 years:	347	2.5%
19–25 years:	1,068	7.7%
26–45 years:	4,711	33.8%
46–60 years:	4,456	32.0%
61 and older:	3,344	24.0%
Gender:		
Women:	6,760	48.0%
Men:	7,310	52.0%
Place of residence:		
Bonn:	9,339	66.7%
Adjacent municipalities:	4,673	33.3%

Table 2
Assignment of the independent variables to the three motility categories.

Access:	Skills:	Appropriation:
Information on the supply	Educational level	Assessment of change
Size of the household	Age	Experience with public transportation
Car availability in the household	Gender	Evaluation Lead City Bonn
Residential situation		

significance level (p-value). The result of the model summary gives the values of −2log likelihood and the coefficient of determination according to Cox & Shell and the modified pseudo-R^2 according to Nagelkerkes as a measure of quality. This value shows how well the variance of the dependent variable "car avoidance" can be explained by the independent variables of the four categories (Backhaus, Erichson, Plinke & Weiber, 2018). To be able to classify the significance of the coefficient of determination, we calculated the effect size in line with Cohen (1988) according to the equation: $f^{\lambda} = R^2/1 - R^2$.

The output table contains the information on the model, independent variables, estimated regression coefficient, expected standard error and Wald test, odds ratios (OR), and 95% confidence interval (CI). The results of the analysis are listed in Table 3 and the interpretation of the significant p value are discussed in the text.

In addition to the three models access, skills, and appropriation according to Kaufmann, we also formed the logistic regression analysis with a fourth block for the mobility practices. The results show an overall model in which the four blocks were integrated using the variable inclusion method in SPSS. The table "cumulative model as a large model" at the bottom of Table 3 contains the value of the chi-square, the significance of the model, and the coefficient of determination for each of the four blocks.

4. Results and discussions

4.1. Effect of measures

The aim of the effectiveness review was to determine whether respondents who had indicated that they used bus and train "rather more often" had in fact reduced their number of car journeys and whether this reduction could partially take pressure off the problem regions, which at the time were at risk of enforced driving bans. This reduction was true for 2,948 participants (Fig. 2).

If the "don't know" and "not less" answers are ignored, just under two out of three respondents stated that they had reduced the amount of car travel due to increased use of public transport. This ratio corresponds to 1944 people, almost 14% of the total sample. A more detailed analysis of that subset shows that 854 of the 1944 interviewees (6%) stated that the omitted journeys concerned the traffic load axes mentioned. It

Table 3
Results of logistic regression analysis.

Modell	*Variable*	*b*	*S.E.*	*Wald*	*p*	*OR*	*CI 0.025*	*CI 0.975*
Access	Information on the supply	−0.026	.087	0.090		0.974	0.822	1.155
(ref category: H_1 Person)	Household_2 Persons	−0.083	.210	0.157		0.920	0.610	1.388
	Household_3 Persons	.283	.272	1.079		1.327	0.778	2.262
	Household_4 Persons	−0.090	.315	0.081		0.914	0.493	1.696
(ref category: none)	Car Availability_occasional	.021	.270	0.006		1.021	0.602	1.733
	Car Availability_almost_always	.940	.243	15.000	***	2.559	1.591	4.118
(ref category: urban)	Residence_Bonn	−0.583	.248	5.518	*	0.558	0.343	0.908
Skills	Education_main_school	.458	1.110	0.170		1.581	0.179	13.932
(ref category: none)	Education_secondary_school	.481	.934	0.266		1.618	0.260	10.086
	Education_high_school	−0.019	.878	0.000		0.981	0.176	5.480
	Education_university	−0.065	.876	0.005		0.937	0.168	5.214
	Education_other	−0.555	1.073	0.268		0.574	0.070	4.700
	Age	.018	.006	9.741	**	1.018	1.007	1.029
(ref category: male)	Gender	−0.062	.172	0.130		0.940	0.671	1.317
Appropriation	Change_assessment _rather_no	.804	.258	9.694	**	2.234	1.347	3.705
(ref category: no change)	Change_assessment _rather_yes	1.836	.291	39.908	***	6.271	3.548	11.086
	Change_assessment _yes	2.287	.345	43.923	***	9.845	5.006	19.362
	Experience with public transportation	.220	.072	9.418	**	1.246	1.083	1.434
	Evaluation Lead City Bonn	.055	.070	0.633		1.057	0.922	1.212
Mobility Practices	Car_less_1_month	−0.592	.317	3.484		0.553	0.297	1.030
	Car_1_to_3_month	.299	.264	1.284		1.349	0.804	2.263
(ref category: never)	Car_1_to_3_week	.434	.249	3.033		1.544	0.947	2.516
	Car_daily	.773	.310	6.208	*	2.167	1.179	3.982
	PT_less_1_month	.126	.785	0.026		1.134	0.244	5.282
(ref category: never)	PT_1_to_3_month	1.304	.759	2.947		3.683	0.831	16.317
	PT_1_to_3_week	1.160	.748	2.408		3.191	0.737	13.814
	PT_daily	1.226	.749	2.679		3.408	0.785	14.800
	car_passenger_less_1_month	.237	.229	1.067		1.267	0.809	1.986
(ref category: never)	car_passenger_1_to_3_month	.353	.226	2.434		1.423	0.914	2.216
	car_passenger_1_to_3_week	.560	.280	4.016	*	1.751	1.012	3.029
	car_passenger_daily	.443	.540	0.672		1.558	0.540	4.492
	Bicycle_less_1_month	.424	.373	1.294		1.528	0.736	3.172
(ref category: never)	Bicycle_1_to_3_month	−0.011	.294	0.001		0.990	0.556	1.761
	Bicycle_1_to_3_week	−0.080	.265	0.091		0.923	0.549	1.552
	Bicycle_daily	−0.116	.257	0.205		0.890	0.538	1.473

*$p<.05$, **$p<.01$, ***$p<.001$.

Cumulative values as a large model

Model 1: X^2 (6) = 44.219, $p<.001$, R^2=0.058
Model 2: X^2 (8) = 31.070, $p<.001$, R^2=0.097
Model 3: X^2 (5) = 110.189, $p<.001$, R^2=0.229
Model 4: X^2 (16) =38.717, $p<.001$, R^2=0.273

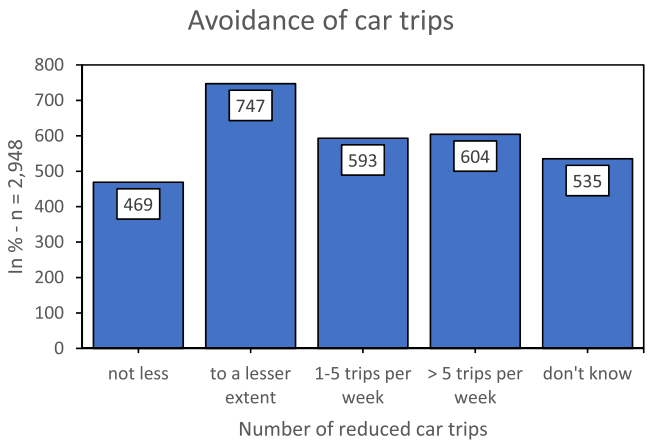

Fig. 2. Extent to which car trips could be saved.

should also be emphasized that 604 respondents stated that they had renounced the car more than five times per week. However, these respondents were already using public transport before the measures, had no car in their household, and used a job ticket (reduced fare tickets for employees) comparatively often.

On the basis of the research question, it can be specifically stated that a modal shift had taken place as a result of the expansion of services. Accordingly, car journeys could be avoided and traffic pressure on the Bonn city center and on the two main traffic axes could be relieved. This central gain in knowledge about the shift in traffic caused by the expansion of services is generally consistent with the study's findings about the final evaluation of the measures as well as with the findings of other studies (Carroll, Caulfield & Ahern, 2019; Giuffrida, Le Pira, Inturri & Ignaccolo, 2021).

A total of 6890 study participants (62.5%) rated the expansion of the offer on a 5-Likert scale as "relatively good (4)" or "very good (5)". In contrast, 870 respondents rated it as "relatively bad (2)" and 260 participants as "very bad (1)". Paired with the neutral (3) answers, the positive evaluations were thus opposed by 33.8% of the respondents. These contrasting results produce an average value of 3.52, which can be classified as neutral.

Overall, there was a positive basic tenor. The respondents felt that public transport was more attractive due to the expansion of the range of services. However, the investigation of the sample indicates that, in addition to the positively perceived expansion of the services, the price of tickets in Bonn and the Rhein-Sieg area, in particular, was rated as too high. For a permanent shift in traffic, the prices of the transport offer would thus have to be lowered.

The systematic approach of Kaufmann's motility concept and the reference categories formed for our study allow the results of the statistical data analysis to be assigned to the main characteristics of access, skills, and appropriation in the form of a logistic regression. This structuring gives more detailed information and helps interpreting the results. The explanations for the observed differences in the individual mobility behavior are derived from the data sets and consequently conclusions are drawn for the future mobility behavior through the further developed transport offer.

4.2. Results of logistic regression analysis

It can be seen that, with each inclusion of an additional model and extension by independent variables, the variance also increases. In the same course, the significant variables have been significantly reduced. We also tested for multicollinearity and excluded redundant variables (Backhaus et al., 2018). Thus, the entire model could prove a strong correlation between the dependent variable "car avoidance" and the independent variables with the high variance of 27.3%. The high R^2 is a sign that possible spurious significances were eliminated. The R^2 for the overall model was 0.273, which is indicative for a high goodness of fit according to Cohen (1988). The resulting effect size of 0.376 shows that our regression analysis has a strong effect.

The results of the logistic regression are interpreted and discussed in the respective reference categories of the individual variables of our theoretical model according to Kaufmann.

4.3. Access

In our study, accessibility refers to the framework conditions that make the use of mobility possible for individuals. Access to comprehensive information on the new public transport offer was provided by an extensive marketing campaign aimed at making people from Bonn and the region aware of the advantages of public transport. Furthermore, whether those people use the transport offer depends on factors such as the accessibility of the transport networks. Further access factors are the size of households, the availability of cars, and the residential situation.

4.3.1. Information on the supply

The result of the logistic regression for the independent variable information on the supply in the access model initially showed a significant influence on the dependent variable (Table 3). However, this correlation was no longer true after a blockwise integration of the categories skills, appropriation, and use of means of transport, so that a positive evaluation of the information on the supply does not indicate an avoidance of car trips.

Even if the result of the logistic regression does not show any significance for the avoidance of car trips, the expansion of the offer was accompanied by a far-reaching information campaign. The measures were intensively advertised in the media in Bonn and the neighboring municipalities and presented to people through various communication channels. Just under 79% of those surveyed stated that they had received information about the expansion of services. 46.5% of them were satisfied or very satisfied with the information policy. The results of a media response analysis provide information on the reach and presence of the information campaign. For example, 66.7% of participants stated that they had learned about the campaign by mail.

Participants who rated the offer as "fairly attractive" were more likely than average to perceive the information as positive. The evaluation of the campaign and the main goals of the project was very good.

4.3.2. Size of the household

Similarly, the size of the households has no significant influence on the avoidance of car trips.

According to the Federal Statistical Office, the city of Bonn and the Rhein-Sieg area predominantly consist of single-person households and couples. These living conditions are also reflected in our sample. This target group constitutes almost 56% of the respondents.

Population mapping of Bonn shows that families live predominantly in the outlying areas or in the surrounding countryside. This distribution is certainly due to the reduced financial means of family and higher expenses of the city but also to the way of life. The distribution also shows that larger households often have more than one car. The number of cars is part of the total household assets and is higher due to adult children living with their parents. In return, such a situation creates more drivers and often mobility through individual vehicle and less public transport. An increase in household income has a positive impact on mobility (Dargay, 2007).

4.3.3. Availability of cars in the household

Respondents who seldom have access to a car have no significant influence on the avoidance of car trips. Accordingly, the trips of these individuals cannot easily be compensated by using public transport due to factors such as place of residence, connection to public transport, or

time of the trip. A strong significant correlation results from the statistical calculations in the case of high car availability. The OR value of 2.559 shows that there is a 155.9% chance of reducing car trips.

Initially, it cannot be assumed that the temporary expansion of supply has changed the availability of cars. Purchasing an automobile represents a long-term decision in favor of the individual vehicle and the number of cars in households can only be reduced through a permanently attractive public transport offer. Our study shows that, when car availability is higher, more car trips are also made, but the OR of saving car trips also increases.

Of the participants in the online survey, 93.6% had a driving license, and 70.2% of them could use their own car or car-sharing vehicles at any time. Occasional use of a car and no use at all was the case for the remaining participants. In our sample, the majority (79.6%) of households had access to at least one car. Just under 30% had access to two or more cars. A higher number of cars increases the probability that the car is preferred to public transport (Dargay, 2007).

4.3.4. Residential situation

The result of the logistic regression for the independent variable place of residence is significant and shows a negative correlation between Bonn as place of residence and the avoidance of car trips (OR = 0.558). Accordingly, there was a 44.2% reduction in the chance of avoiding car trips for subjects who live in Bonn.

The statistical result suggests that people living in Bonn often travel short distances and make use of alternative mobility options. According to the study, people from the surrounding communities in particular have saved on car trips. The majority of the survey participants (66.7%) lived in Bonn. The remaining almost 33% were distributed among the neighboring municipalities. Although rents and property prices are high in those municipalities, they are still significantly lower than those in the city of Bonn. The origin of the interviewees thus greatly influenced their attitudes and the possibilities of using the transport modes. Accessibility of public transportation plays a critical role in the sustainability of transportation systems in metropolitan areas (Saghapour, Moridpour & Thompson, 2016).

The respondents from the city of Bonn can be classified into the four districts of the Bonn urban area. According to this classification, 47.5% of respondents had their residence in Bonn City, the largest district, 21.4% in Beuel, 18.7% in Bad Godesberg, and 8.6% in Hardtberg. The rent index and the purchase prices lead to strong differences in the population. Particularly in the socially weak districts of the city, few cars were available and the inhabitants had to use public transport.

4.4. Skills

The skills of each individual are shaped by the mobility they experience, coupled with their knowledge of the subject and their attitude towards the available transport modes. The choice of transport mode has to correspond to the lifestyle and life cycle of the individual. In the household survey, analogous to the study by De Witte et al. (2008) in Brussels, the respondents' skills were assessed on the basis of their educational level, but also on factors such as age and gender.

4.4.1. Education level

Table 3 shows that, in the skills model domain, the statistical analysis identifies no significant relationship between education and the avoidance of car trips. Nevertheless, the independent variable represents an important factor for the coefficient of determination and is essential for the significance of our entire model.

In addition to professional status, the level of education is also partly responsible for lifestyle and the choice of mobility. The study by De Witte et al. (2008) shows that commuters in Brussels with a low level of education are more likely to use the train than those with a high level of education. This finding is consistent with the findings of other studies, which conclude that people with higher education tend to work in responsible positions in their careers and are tightly timed. For these people, the time factor is often in the foreground, and the car as a flexible form of mobility is detached from other monetary and non-monetary factors (De Witte et al., 2008; Pickery, 2005).

Our survey shows that the city of Bonn and the region have a high proportion of well-trained specialists. In our sample, just under 58% have a university degree, followed by 23.6% with a high school diploma. Less than 19% of respondents did not yet have a degree, a secondary-school leaving certificate or a secondary-modern school leaving certificate.

The findings from Brussels and other studies do not match the results of our survey. Accordingly, it has been confirmed that education level in Bonn and the neighboring municipalities is not a decisive factor for avoiding car trips.

4.4.2. Age

Furthermore, the analyses regarding age confirm a significant correlation between age and avoidance of car trips. That is, the older our respondents, the higher the probability of avoiding car trips. The OR of 1.018 represents a small 1.8% chance of avoiding car trips.

For the purposes of this study, ages are broken down into five subcategories, which are significant in the results but contain only a small possibility of change. Only 10% of the respondents were under 25 years old (2.5% aged under 18, 7.7% aged 19–25).

Especially for this young generation, the share of public transport users is steadily increasing due to climate-friendly beliefs. Grimsrud et al. (2013) also found in their study that young people in Montreal go through lower life cycle stages and that the overall demand in this age group increases with regard to the use of public transport.

Respondents aged between 26 and 45 years represent the largest target group with 33.8%. Often a central residential area is preferred due to the living situation. With the founding of a family and start having children, the topics of buying a house and living in the outskirts of the city often arise and attitudes change. Mobility behavior shifts, and accordingly, further journeys are often made from a place of residence with poor infrastructure. This target group has the will to use public transport, but living conditions with children do not always allow it as desired. In the U.S., Klein et al. (2017) also found in their study that young adults own fewer cars than previous generations.

A total of 32% of the interviewees were in the age group 46–60 years. In this age group, adult children were also living in the household and therefore more cars were needed and available. Especially in the peripheral areas, public transport was used less frequently, as the distances to work were too great.

Respondents aged 60 years and older account for 24% of the total number of respondents. This target group presented a contrasting picture. Since many children had started their own families and no longer lived with their parents, these respondents had sometimes sold their only partially used houses and preferred to live in the city centers. According to Dargay (2007), an increasing car ownership and use can be observed among the older generation. These findings are in line with the research results of Currie and Delbosc (2011).

4.4.3. Gender

The gender of the subjects is not responsible for the saving of car trips and is not significant in the result.

The current gender distribution of the German population shows, according to the Federal Statistical Office, a slight surplus of women nationwide, which can be explained by the greater life expectancy of women. Bonn has 335,975 inhabitants, of which 162,519 are male and 173,449 female. Our sample thus includes 52% male and 48% female participants, and there is thus a slight surplus of men in our sample in comparison to the national average. Our results show that the topic of mobility and optimizing trips has a great impact on both genders.

4.5. Appropriation

Appropriation refers to the behavior that people derive for themselves from the mobility options. In our study, there was a high degree of information through advertising campaigns about expanding the range of services. In addition to informal access to information, individuals can integrate using the public transport network or the availability of cars in the household into their everyday lives. Together with their own abilities, access determines travel behavior and how the mobility offers are used.

4.5.1. Change assessment

Our statistical analysis in the Appropriation model shows that the subjects change assessment has a significant influence on the avoidance of car trips. The odds ratios for a positive assessment are particularly interesting. A generally positive change assessment shows an OR of 6.271, which in the result shows a more than fivefold increase in the chance of reducing car trips. The OR of 9.845 in the case of a positive assessment means that the possibility of avoiding car trips increases by 884.5%. Even in the subjects who, have a negative change assessment there is a chance of avoiding car trips. The OR in this case is 2.234.

The travel habits refer to regular and recurring travel behavior. Accordingly, the route to work is not reconsidered every day but is made on a permanent basis after weighing up the advantages and disadvantages (De Witte et al., 2008). A change in this habit is possible at any time, but for it to happen there must be strong positive or negative effects for the individual. Following on from the expansion of supply, a shift in traffic could be observed. Since the measures related to this study were temporary, it remains to be seen whether any effect will continue after the end of the measures. Rewards can be an effective tool for changing habits (Ben-Elia & Ettema, 2011).

However, sustainable effects in the sense of the campaign, i.e. a permanent change in the traffic habits of the respondents, were questioned by our respondents. Even if the respondents see a very high probability that, with a permanent offer, there is also a willingness to change on the part of the citizens. 5376 participants did not see a lasting change in transport habits towards public transport after the end of the project. After excluding the 663 respondents who answered with “don’t know/undecided”, 38% of respondents were of this opinion, mainly due to a reduction of the offer and to unreliability arising from delays and cancellations.

4.5.2. Experience with public transport

The expansion of services provided new experiences in using public transportation. The regression analysis shows that the independent variable experience with public transport has a significant influence on the avoidance of car trips. Accordingly, greater use of public transport also leads to less congestion on the roads.

Referring to opinions about experiences with the local public transport in Bonn and Rhein-Sieg area, a differentiated picture arose in our study. Many people (33.9%) experience an attractive (4) or very attractive (5), satisfying public transport system. Others (26.7%), on the other hand, see public transport as rather unattractive (2) or unattractive (1). In our evaluation, this difference again means that opinions vary greatly in terms of attractiveness. The average value of 3.11 is in the neutral range.

4.5.3. Evaluation Lead City Bonn

The result of the statistical analysis initially indicated a significant value between the evaluation of the Lead City measure and the avoidance of car trips, but this result could not be confirmed by the calculation of the whole model and the inclusion of all independent variables. The comparison of public transport in the past and today, however, shows a significant result and an OR of 1.246, i.e., an increase of the possibility by 24.6%, related to the avoidance of car trips.

A total of 4234 people indicated that they would permanently to switch to bus and train in the future. These were particularly survey participants who were already using public transport before the measure. The almost 30% of respondents with increased sustainability awareness shows, in particular, one thing: The project was particularly successful in the target group of up to 25-year-olds. Younger respondents in particular stated that they would continue to use public transport.

4.6. Mobility practices

In addition to Kaufmann’s model, we included the fourth area of mobility practices in the overall model and looked at the influence between transport use and the avoidance of car journeys. In our analysis, in addition to the two main modes of transportation, car and public transport, we asked the subjects about their use of bicycles and trips as a passenger in a car.

The model area of mobility practices shows that infrequent car use also has no influence on the avoidance of car trips. This circumstance is understandable since these people most likely have a low availability or cannot use public transport as an alternative. There is a significant correlation between daily car use and an OR of 2.167 for the dependent variable. Accordingly, people with a high car use have a 116.7% chance of avoiding car trips and using the service extension. Another significant correlation could be found between the car passengers who drive only 1–3 times a week. These respondents have an OR of 1.751, i.e., a 75.1% chance of avoiding car trips and have an increased willingness to change to public transport.

For the independent variables, it initially looked as if infrequent use of public transport and daily use of bicycles would be a significant influence, but this is not the case. Our overall model shows no influence between the modes of public transport and bicycles on the avoidance of car trips.

5. Limitations and implications for future research

When considering the overall results, it should be noted that we were able to reach a total of 14,296 households in this study. Nevertheless, 338,396 people live in Bonn (as of 01.01.2023) so our results cannot be directly applied to the population, in general. It should also be noted that the survey was conducted in Bonn and that the German transportation system and consumption patterns differ from those in other countries (Pakusch, Stevens, Boden & Bossauer, 2018).

The present study shows case-specific results related to the particularities of Bonn and the transport conditions found there. Bonn, as a former federal capital, shows a very well-developed route network and many public transportation offerings. Even after the relocation of many institutions to Berlin, some authorities as well as two DAX companies have kept their headquarters in Bonn. According to a recent study from Allianz pro Schiene (06/2023), Bonn has the best accessibility to public transportation in all of Germany. According to this study, the population in the inner city as well as in the rural regions, has optimal access to public transport services. In addition to high-quality geographic conditions, the strong ecological political will contributes to the modal shift.

The Lead City Project was a temporary project that reaffirmed the fundamental focus and shift from cars to emissions-friendly public transportation. Transit companies are struggling with challenges such as a lack of infrastructure, a lack of buses and trains, higher fuel prices, and staffing shortages. Even if subsidies are available for the project period, these other factors must be overcome to facilitate a successful long-term transition. In particular, rising operating costs and staffing shortages due to demographic change must be addressed.

Beyond the additional supply, other monetary considerations must also be examined. Furthermore, questions such as how can technical solutions reduce operating costs and flatten out the personnel shortage be addressed. A modal shift is politically desired, but the appropriate conditions and attractiveness must be created.

6. Conclusion

In the past, there have been projects similar to the Lead City project in Bonn, whose impact we studied and presented in this paper. Those projects mainly focused on lowering the costs for public transportation rather than on expanding the range of services. The measures aimed to achieve a modal shift in favor of public transport. The emphasis was often on socioeconomic factors, and the cases showed that the financial deficit resulting from cost measures could not be permanently refinanced. In our study, we focused on the expansion of supply as a non-monetary factor.

The measures in Bonn were aimed at increasing the population's awareness of climate protection and the search for effective alternatives to individual transportation. Due to the different issues involved, the measures from the other European case studies cannot be compared directly with our research. It can be observed, however, that an expansion of supply can also favor a shift in transport towards public transport. The Bonn case thus shows that not only price but also non-monetary factors influence a modal shift. To bring about a larger and lasting modal shift, many respondents stated that the offer must be combined with an economically attractive price. The income and willingness to pay for mobility must be considered in more detail for future decisions.

While the car was positively assessed for users in 2007 and there was a tendency to prefer the car over public transport regardless of income (Dargay, 2007; Flamm, 2004), it is clear that a shift towards public transport is definitely taking place in Bonn. Due to the climate change, there are social efforts to reduce CO2 emissions. Our study has shown that young people in particular rely on public transport and support a traffic turnaround. The main result of our research is that a modal shift has taken place as a result of the expansion of services. Of the 15% of respondents who had increasingly switched to public transport since the timetable change, 80% were able to reduce car travel in a targeted manner.

Our study has shown that, along the main traffic routes, car journeys have been reduced. The average CO2 emissions of newly registered passenger cars in Germany fell continuously between 1998 and 2022 (Statista; 2023). The low value of 147 g CO2 per kilometer is due to the increased number of new registrations with alternative driving systems. Even if the trend is downward, CO2 emissions consumed in public transport are 57 g CO2 per passenger kilometer (Bundesministerium für Wirtschaft und Klimaschutz 2022).

As can be seen in the current statistics on CO2 emissions of different modes of transport, the CO2 consumption per kilometer driven by car is higher than per kilometer from public transport. Based upon this fact, it can be assumed that a modal shift from car to public transport has also led to a reduction in CO2 emissions.

The reduced traffic supply thus might have improved the climate for the period of the measures. It is to be feared, however, that this is a short-term effect that will be reversed after the end of the project. To achieve a permanent modal shift and climate improvements, it would be important to keep the standard of public transport attractive in the long term. These ambitions are certainly there, but it is doubtful who will provide the financing for this permanent offer.

Public transport was perceived as more attractive due to the expansion of the range of services. According to the respondents, the results would be even more positive if the measures were extended beyond the city limits of Bonn and to other target groups. There was a strong correlation between the subjective perception of the attractiveness of public transport and the respondents' response behaviors. Regardless of the current use, respondents who described the local public transport offer as attractive were positive about the Lead City Bonn project and about the general development in recent years.

Basically, it has to be considered that the evaluation of the measures does not correspond to the actual effect of the measures. Thus, there are respondents who evaluate the measures and the development of the public transport as positive but do not use public transport. Furthermore, the measures are temporary and therefore results are only relevant for the time of the study. For the short period of time, the modal shift can certainly be considered a success, as habits change only slowly. The majority of those surveyed assume that the attractiveness of public transport will decline sharply after the subsidy is discontinued and that many people cannot or will not want to use public transport under the old conditions.

Kaufmann's systematic approach helps explain all the important factors and show their influence on our results. However, according to many of the respondents, the transport services that help to shift traffic are too weak as a sole measure. It is essential to attractively price the offer. In further research, the pricing should be examined more closely and the users of any climate-based tickets should be questioned.

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Declaration of Competing Interest

There are no competing interests.

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