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Cycling, Fuel Discount and the 9 € Ticket: Commuters Taking a Brake?

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Thünen-Series of Applied Economic Theory
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Working Paper No. 168

**Cycling, Fuel Discount and the 9 € Ticket:
Commuters Taking a Brake?**

by

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Cycling, Fuel Discount and the 9 € Ticket: Commuters Taking a Brake?

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Abstract

Does the promotion of public transport crowd out other modes of climate friendly mobility? During the summer of 2022, Germany introduced two policy measures to countervail the rising cost of living and energy. This paper demonstrates that these measures did not only affect individuals relying on motorized mobility but cyclists as well. Employing publicly available data from urban bike counters and data from city administrations, I find that the number of trips commuted by bicycle significantly decreased on average by 20 rides per hour and station. Moreover, I find lasting impacts after the withdrawal that indicate that the pre-intervention trend reverted.

Keywords: Mobility, bike counter, policy intervention, interrupted time-series

1 Introduction

Germany has witnessed a sharp increase in energy and consumer prices during the summer of 2022 and responded with a novel and unprecedented reaction: aimed to moderate the soaring cost of living and the skyrocketing energy and fuel prices following the invasion on Ukraine, the German government intervened with two policy measures – the 9 € ticket and the so called *Tankrabatt*. While the 9 € ticket implemented highly affordable public transport across Germany, the reduction in energy tax on fuels significantly depressed prices down below the 2 € mark. Both policy measures came into effect in the beginning of June and expired in the end of August. Survey data confirms great success of reduced travel fare but also indicates a shift from other modes of transport (VDV 2022b). Despite the *Tankrabatt*, fuel prices in Germany still exceeded their pre-existing levels.

I utilize this natural experiment enacted by the government and aim to answer the question of how the 9 € ticket and the fuel discount changed individual mobility behavior. To do so I concentrate on urban bike mobility and analyze the cycling mobility in selected German cities (> 100,000 residents) on the basis of data gathered from automated bike counters. I contribute to the questions what the measures achieved and what lessons can be learned for other policies that are currently under development or

in place such as the *Deutschlandticket* in Germany, the 49 € successor of the 9 € ticket, or the *Klimaticket* in Austria.

The remainder of the article is structured as follows: In the next section a classification into the existing body of literature as well as a synopsis of mobility behavior in Germany is provided. I then outline the empirical strategy and the data, followed by the estimation results. The paper concludes with an extrapolation of the findings and a brief outlook.

2 Background

2.1 Mode Choice

When commuting, running our daily errands or participating in leisure activities we take into account the costs, duration, comfort and convenience of the available modes of transport. However, the rational choice and the chosen mode do not necessarily align when circumstances change due to our already developed habits and information imperfections. Rather than making the active – and partially tiresome – effort of deciding on a transportation mode, we simply revert to habit or let inertia take the wheel. Goodwin (1977) described this as follows: "The traveller does not carefully and deliberately calculate each morning anew whether to go to work by car or by bus" and added that "[s]uch deliberation is likely to occur only occasionally, probably in response to some large change in the situation". We do not engage in rational optimization every day, but we change our repetitive choices or dissolve our inertia only when prompted by larger shocks. These disruptions can consist of positive supply shocks such as the availability of new travel modes and extension of services or negative shocks like service breakdowns strikes, e. g. the London tube strike (Larcom, Rauch, and Willems 2017), and technical outages.

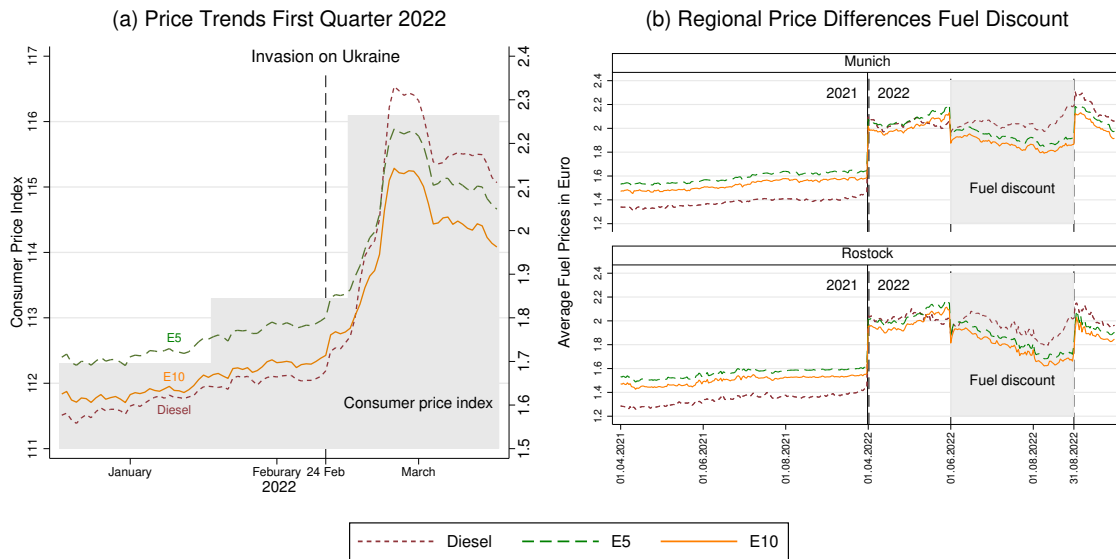
Leaps and disruptions of the status quo hold the potential to have longer and long-lasting impacts. In this sense, the 9 € ticket is viewed by us as an extended trial period allowing customers to collect experiences and form new habits that determine mode choice albeit daily rational assessments might come to other conclusions.

2.2 Mobility in the Face of War and Inflation

While Europe had entered the fifth Covid-19 wave with wary hopes of a transition to an endemic, Russia invaded Ukraine, starting an ongoing war in the aftermath. Energy products in particular had already become more expensive on average in 2021, but Western sanctions and supply cuts caused energy prices and food prices to even further spiral. This contributed to the largest price increase that reunified Germany has experienced so far.

To counter the sharp rise in living costs, Germany promulgated a set of policies aimed to counterbalance the repercussions of the war on its citizens. The paper in particular considers two policies that were directed towards mobility - the so called 9 € ticket and the tax reduction on fuels. The 9 € ticket was introduced by the German government as a sharply discounted fare valid for all public buses, trams, metros and

Figure 1: War and Tankrabbat Impacts on German Energy Prices



Note: Own illustrations, with data on regional fuel prices from Tankerkönig and the national consumer price index from Statistisches Bundesamt.

regional trains nationwide. It was offered for the symbolic prize of 9 € per month¹ and was available in June, July, and August 2022. The ticket enjoyed great popularity and was sold more than 50 million times. The second policy, the fuel discount, was introduced at the same time and for the same duration as the ticket. It reduced the prices of gasoline by 29.55 cent per liter and of diesel by 14.04 cent per liter (Presse- und Informationsamt der Bundesregierung 2022). Both policies attenuated the financial strain put on households but the 9 € ticket holds a greater significance beyond its initial purpose. The ticket itself represents a novelty in the German mobility landscape. Not only did the ticket harmonize segmented and complicated fare zones and varying pricing schemes, it also lured reluctant commuters and travelers away from individual transportation - an important step towards the fulfilment of the government’s Climate Action Programme.

The ticket was rightfully hailed as a chance to leap towards more sustainable mobility, but despite high media coverage and great public interest there have been few studies. This is likely due to the short period between the government resolution and its quick entry into force. However, there are three notable exceptions:

Technical University of Munich. Researchers at the TUM set up a research framework combining a three-wave survey and an app-based travel diary to investigate how the use of different forms of transport and the willingness to pay across different groups have changed with the 9 € ticket. Their study design is comprehensive and auspicious, however, focuses on the metropolitan region of Munich. Their gathered data contains information of 637 voluntary participants which both completed all surveys and used the app. They show that the share of public

¹As a comparison: a monthly pass for one adult for the city area of Hamburg without subscriptions or online discounts totalled at 111.20 € in 2020. In Munich it was about half of the price at 55.20 € (Heinrich-Böll-Stiftung 2020).

transport significantly increased during the 9 € ticket period, however work and education related trips were not affected by this behavioral change (Adenaw et al. 2022). Moreover, only two percent of the respondents stated that they had increased their car use due to the fuel discount, which was introduced at the same time (Loder, Cantner, Adenaw, Siewert, et al. 2022). After the withdrawal of the ticket they find a substantial shift in the modal share towards public transport from the car both in terms of travel distance (around 5 percent) and in trip frequency (around 7 percent) (Loder, Cantner, Adenaw, Nachtigall, et al. 2023).

Statistisches Bundesamt. Another analysis using mobile phone data was conducted by the Federal Statistics Office employing data from the mobile operator Telefonica. It showed that rail use increased by 44 percent for distances over 30 km and by 57 percent for distances between 100 and 300 km. The largest increase was recorded at weekends with a doubling of usage. At the same time, it became clear that the changes in road traffic were marginal (Statistisches Bundesamt 2022a). One limitation of this research is that only trips of more than 30 km could be analyzed. The traffic within cities remained unrecorded.

German Institute for Economic Research (DIW). The most recent contribution is research conducted by the DIW, which analyzes the usage of 9 € ticket on the basis of nationwide and representative data derived from tracking data and surveys. Data was obtained from the market research provider GIM Gesellschaft für innovative Marktforschung and findings were published in a weekly report (Gaus, Murray, and Link 2023) as well as a working paper (Guajardo Ortega and Link 2023). In the weekly report the authors conclude that the ticket had only little impact on typical mobility patterns, it was predominantly used for leisure activities, with the initial euphoria fleeting from month to month. The authors of the working paper analyze GPS tracking data of 860 individuals (sample size in the main model estimates: 352 individuals) from May to August 2022 in respect to inertia. Their findings corroborate the initial results, that car users are more reluctant to change behavior while cyclists and public transport users are more flexible.

In addition to these quantitative studies there is a plethora of qualitative research, most of which examined the appeal and usage of the 9 € ticket across different socio-economic groups. However, only a few studies were conducted nationwide. Among these is an online study conducted on behalf of the VDV, the association of Germany's transport companies. In the online survey 10 percent of participants reported that between June and August they had replaced at least one daily car trip. In addition, a total of 17 percent of 9 € ticket users had switched from other means of transport, such as car or bicycle, to public transport in August (VDV 2022b). However, they also find that after the ticket the use of cars in the mobility mix reverted back to the pre-ticket level while bike use declined (VDV 2022a). Another survey study by RWI also addresses the impact of the 9 € ticket on mobility. They surveyed 5,056 persons over two waves of data collection. Their results indicate, on the one hand, that season ticket holders and ticket purchasers travelled fewer kilometres by car than those without a ticket. It also showed that customers who had purchased the new 9 € ticket used the car less than season ticket holders did. On the other hand, it shows that the new customers used

the ticket mostly for leisure activities (RWI – Leibniz-Institut für Wirtschaftsforschung 2022), a finding reinforced by other studies as well (Allister Loder et al. 2023; Gaus, Murray, and Link 2023). A panel study by the DLR, the German Aerospace Center, initially set up to analyze the impact of the pandemic on mobility, shows that car use was initially reduced due to the increase in fuel prices. It also shows that the use of different modes of transport became significantly more frequent (DLR Verkehr 2022a).²

2.3 Mobility and Cycling Trends

The disruptive consequences of the corona pandemic affected almost every aspect of society in 2020, including mobility behavior. Triggered by government-imposed restrictions, altered mobility needs as well as conscious changes of behavior to avoid infection with SARS-CoV-2, caused a major drop in mobility estimated at 51 percent compared to the previous year (Statistisches Bundesamt 2023b). However, not only did traffic volumes change, general mobility patterns and attitudes changed as well. Anke et al. (2021) and Eisenmann et al. (2021) observe a shift away from communal to individual modes of transport. They show that public transport receded while individual modes of transport, especially the private car, became even more important in the wake of the pandemic. Eisenmann et al. (2021) attempt to partially explain this observation by a shift in attitudes towards different modes of transport. They find that the car gained importance regardless of whether the respondents owned one, while public transport suffered greatly in the perception of transport users. Their findings on the perception of the bicycle are less straightforward: On the one hand, the share of adults stating a bicycle in their mode choice dropped from 32 percent to 24 percent from before the pandemic to the lockdown and about 10 percent of respondents felt more inconvenient and much more convenient riding a bicycle compared to before the pandemic. On the other hand, about 4 percent of respondents stated that they started riding bikes. This ambivalence is also found by Möllers, Specht, and Wessel (2022). They observe that the impact of the consequences of the pandemic on cycling varies substantially across cities. The modal share of cycling decreases in cities that already have a relatively high share of cyclists, a high share of university students, and fewer public transport options. However, in cities with with a relatively low modal share, a lower share of students, and a generally better developed public transport system it drops. The question whether these shifts in mode choice persisted beyond the lockdowns and into the regained (almost) normal state has been tackled by Monterde-i-Bort et al. (2022). Based on self-assessments conducted in 10 countries (not including Germany) in spring and fall of 2020, they find that respondents estimated their mobility by car and walking as almost back to the time before the pandemic and cycling remained unaffected overall, while the use of public transport decreased and did not recover after the easing. Tough

²So far this section has focused on the introduction of the ticket and its impact on mobility behavior. I recognize that an evaluation of the two policy measures answering the question whether the introduction of the ticket and the discount on fuel were a "success" is multifaceted and requires an interdisciplinary approach. Other aspects such as social inclusion, sustainability or traffic fatalities/safety are integral for a more comprehensive evaluation of the policy. For instance, preliminary studies analyzing the impact of the 9 € ticket in terms of social inclusion and mobility justice arrive at the same result: the introduction of the ticket appears to have been a great success, enabling financially vulnerable to participate socially (Aberle et al. 2022; Hille and Gather 2022). Though I do not want to diverge further, those aspects are a crucial element for a comprehensive assessment.

this partially may be applicable to Germany as well, overall mobility still remained 20 percent beyond the baseline of 2019 (Statistisches Bundesamt 2023b) and other indicators such as the proportion of the labor force working in home offices increased from 21 percent in 2020 to 25 percent in 2021 and quasi stagnated in 2022 with 24 percent (Statistisches Bundesamt 2023a).

Apart from the irregularities in mobility that accompanied the corona pandemic and lockdowns in 2020, an overview of general mobility and underlying trends is provided in the *Mobility in Germany* report series. In 2002, 2008 and 2017, the Federal Ministry of Transport and Digital Infrastructure (BMDV) commissioned the mobility studies. For the past years they underline the importance of the bicycle in peoples' day-to-day mobility and show that mobility has overall developed in a consistent direction: both, the volume of trips as well as the kilometers travelled by bike, have increased significantly over the years (Nobis, Kuhnimhof, et al. 2019). Moreover, most cyclists are multi-modal and alternate between different means of transportation during the course of a week with great seasonal variance and even combine modes. Other more invariant factors such as topography and quality of the infrastructure are less influential. However, the most prominent external factor on the choice to take the bike or other modes of transportation is – not surprisingly – the weather (Nobis 2019). The responses to seasonal and climatic factors are, however, likely to differ across regions or more specifically *mobility cultures* (Böcker, Dijst, and Prillwitz 2013; Böcker, Priya Uteng, et al. 2019). Seasonal preferences in cycling appear to be more pronounced in Germany than in other countries like the Netherlands (Hudde 2023), with additional heterogeneity between the cities. Studies by Goldman et al.(2021) and Möllers et al.(2022) emphasize this cultural aspect linking the demographic and occupational composition, type of trip (utilitarian, recreational, mixed), and the *bicycle-friendliness* of a city to the respective response to the daily weather conditions. I integrate this aspect by observing each city and counting station individually in the analysis.

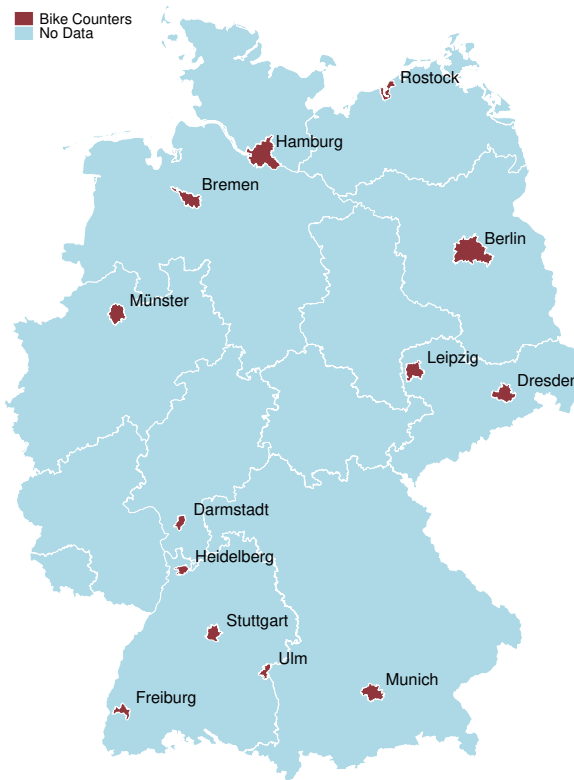
3 Data and Descriptive Statistics

3.1 Data Sources

For the analysis, I employ regional data from electronic bicycle counters as dependent variable. The counters track the number of cyclists passing each electronic device and are aggregated on an hourly basis. The data used is either publicly available on open data platforms or provided upon request from city administrations: For a documentation kindly refer to the section Data Sources in the Appendix (page 26), where all sources are listed and in-depth information is provided. The direction of travel is not considered in the analysis as this information is not consistently available. The focus lies on large cities according to the German categorization *Großstadt* which serve central functions within their area. All selected cities have well-developed public transportation networks with regular services and short intervals (Agora Verkehrswende 2023). The bike counters installed within the city area are more numerous and less focused on touristic activity than in rural areas.

The selection of cities includes Bremen, Darmstadt, Dresden, Freiburg im Breisgau, Heidelberg, Leipzig, Münster, Stuttgart, Rostock, Ulm and the metropolitan cities

Figure 2: Location of Selected Cities in Germany.



Berlin, Hamburg and Munich (see Figure 2). With this sample the paper covers about 16 percent of German cities in the category *Großstadt* (base year 2021) and a vast geographical variety. Counting stations where more than 10 percent of observations are missing are excluded, an approach taken in line with other research on bicycle mobility (Nosal and Miranda-Moreno 2014; Monfort, Cicchino, and Patton 2021).³

For the first part of the analysis, I focus on the months January-December 2021 and January-August in 2022 and for the second part I extend the period and include the remaining months of 2022, with the observations of 2021 serving as a control. For both approaches the analysis is limited to these two years and does not consider 2020 and earlier years since the corona pandemic led to a structural change in mobility behavior in Germany. This can be deduced from the strongly increased sales of bicycles (Zweirad-Industrie-Verband e.V. 2021) and the results of various surveys (DLR Verkehr 2022b), which confirm a deviation from the regular mobility patterns. At the same time, the

³Moreover, I control for outliers in the data using both graphical inspection and statistical methods. Using z-scores for season, year, hour, and weekday for each respective season, I exclude values that fall outside of three standard deviations from the mean provided that the values are not in the lower single digits. This is predominantly the case for values during the night time. Due to the low volumes of counted bike rides, deviations are already marked as outliers using the z-scores although the data only indicates a small increase in absolute bike rides. Applying this approach, about 0.14 percent of data points were additionally marked as missing. Whether these are based on malfunction or are event-driven was retrospectively not trackable, besides attempts to link outliers to inner-city events. These limitations lead to the exclusion of 20 counting stations in the daily data set and in the hourly sample. An overview of the counting stations, both those utilized and those excluded, is provided in Appendix, Table A.2.

year 2020 is heavily distorted by the temporary lockdown, many workers being placed on furlough, the rise of working from home⁴ and the regional school closures. Further, it is important to note that Berlin represents a special case, due to the fact that the local transport authority has continued the ticket for the Berlin area until the end of the year 2022. Though the ticket was not applicable nationwide, I argue for the analysis of the immediate ticket effect this distinction is negligible, especially because the focus of this paper is on short distance mobility.

To take into account the different regional conditions I employ station data by the German Weather Service (DWD) for the weather controls and use regional fuel prices. For each municipality, weather data from the nearest station was used. Remaining gaps were filled by information taken from the second or third closest station. In order to depict the most relevant weather influences, we use information on temperature, precipitation, wind strength and sunshine duration. We circumvent the self-imposed limitation for daily aggregates by additionally using daily data from the German Weather Service (DWD). For information on average fuel prices within a municipality, we use data from the website Tankkönig, a consumer information service registered with the federal cartel office.

3.2 Descriptive and Visual Analysis

I employ data of 92 counting stations from 13 cities in the analysis that are all characterized as *Großstadt*. However, apart from this commonality, the cities differ significantly from each other in terms of size, infrastructure, and demography. While the metropolitan cities Berlin, Hamburg, Munich and Stuttgart, have rapid transit systems in place, the other cities in the sample do not, and the city of Münster has solely buses operating in its public transport system. Furthermore, from a more qualitative perspective, the cities of Münster and Freiburg, which are characterized by a high student presence, received top marks in the ADCF’s Bike-Friendly Cities Rating⁵, distinctly ahead of the other cities in the sample (see Table 1). This indicates that cyclists in these cities are satisfied with their situation above average, contrasting the relative dissatisfaction of cyclists in the cities Stuttgart and Berlin.

Table A.2 in the Appendix provides the comprehensive descriptive statistics of the respective stations used in and excluded from the analysis. With some counters located at main thoroughfares and others in more recreational areas, the total rides differ significantly within cities. Particularly worthy of mention here, however, are the consistently high values in Münster, considering the size of the city, reaffirming the city’s reputation

⁴Though I recognize the potential explanatory power of home office adaptation on changes in mobility behavior, there is to my knowledge no option to control for it due to the lack of data. Recent contributions do not include detailed data from 2022 just yet (Aksoy et al. 2022; Statistisches Bundesamt 2023a) or employ shorter time spans (ifo 2023; Dolls and Lay 2023). I also step back from setting up a working hypothesis as adaption has fluctuated significantly across months, plus the legal obligation to offer home office by the employer expired at the end of March 2022, constituting a general framework change.

⁵The ADCF Bike-Friendly Cities Rating is a non-representative survey conducted every two years to assess cyclists’ perceptions of cycling in their home city or town. The overall rating is used as a proxy for perceived infrastructure quality and compute a city-specific ranking for the selected municipalities. More information on assessment criteria, survey participants, and methodology is available at <https://fahrradklima-test.adfc.de/english>.

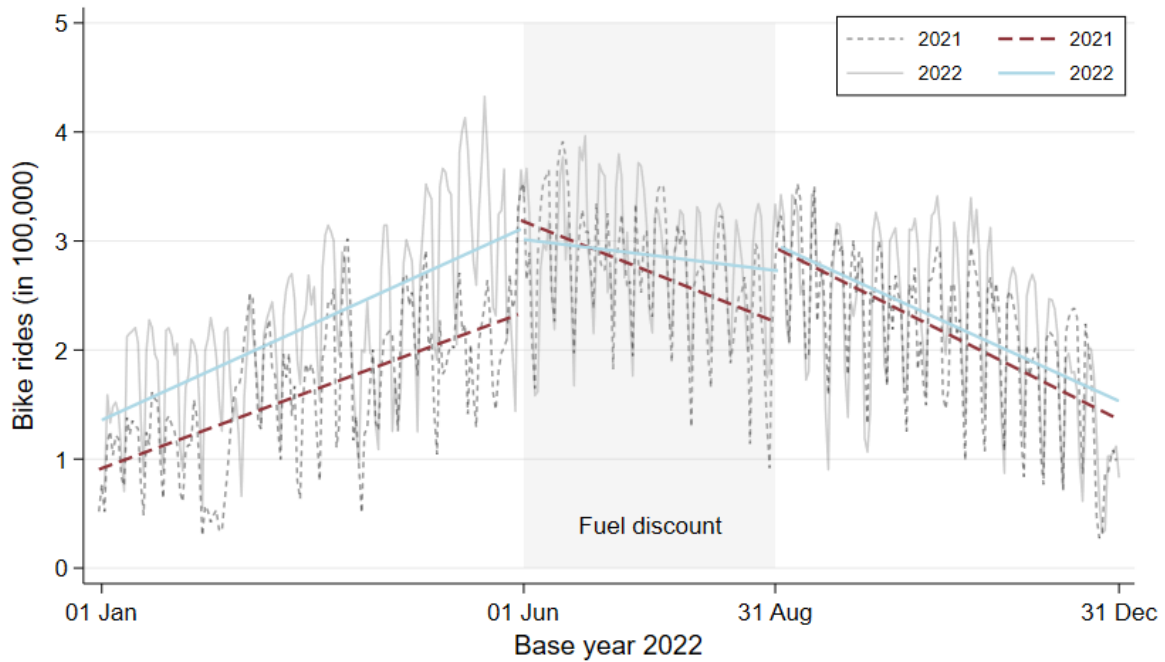
Table 1: City Characteristics

City	Population	Student share ^a	Public Transport			Cycling ranking ^b	
			Subway	S-Train	Tram	Rank	Rating
Berlin	3,677,472	5.1%	Yes	Yes	Yes	12	4.13
Bremen	569,352	6.1%	No	Yes	Yes	3	3.57
Darmstadt	159,631	27.8%	No	Yes	Yes	4	3.58
Dresden	555,351	6.8%	No	Yes	Yes	11	4.05
Freiburg	231,848	14.0%	No	Yes	Yes	2	3.11
Hamburg	1,853,935	5.2%	Yes	Yes	Yes	10	3.98
Heidelberg	159,245	22.3%	No	Yes	Yes	5	3.64
Leipzig	587,857	6.7%	No	Yes	Yes	6	3.84
München	1,487,708	7.7%	Yes	Yes	Yes	7	3.89
Münster	317,713	19.6%	No	No	No	1	3.04
Rostock	208,886	6.8%	No	Yes	Yes	8	3.95
Stuttgart	626,275	6.8%	Yes	Yes	Yes	13	4.20
Ulm	126,949	10.9%	No	No	Yes	9	3.96

^a Share of students as the ratio of enrolled students at the municipality's higher education institutions during the winter term 2021/22 (Statistisches Bundesamt 2022b) to the population.

^b Rankings based on the ratings of the ADFC Bicycle Climate Index 2022 (ADFC 2023). The rating in this paper differs from the ADFC's original rating as I do not distinguish cities by size beyond the 100,000 inhabitants mark. Instead the ranking is based on the overall grading system.

Figure 3: Overview Annual Cycling Trends



Note: The graphic depicts the aggregated raw data without counters located in Berlin and with no imputation for missings or other corrections. Solid lines are applicable for base year 2022. Values and predicted linear relationship displayed in dashed lines refer to the comparison dates in the previous year: 02 Jan 2021, 02 Jun 2021, 01 Sept 2021, and 01 Jan 2022 respectively.

as a bicycle city. Figure 3 depicts the accumulated daily counts, without Berlin due to the local continuation of the ticket, for bike rides in 2021 and 2022 with the data points of 2021 artificially assigned to matching dates in 2022, so in the graph each day of the week is stacked above the same day of the week in the previous year and the first Saturday of 2022 corresponds to 1 January 2022, the first Saturday in 2022. From this initial visual inspection, I assess that both years experienced similar bike trends with overall matching weekday and seasonal patterns, and the year 2022 surpassing 2021 in terms of overall volume in line with the general cycling trends. Moreover, calculating and displaying the segmented linear relationship for the time periods before, during, and after the 9 € ticket, the disruption during the summer months in 2022 and the return to the previous behavioral pattern can easily be identified, however, to a reduced extent. This *prima facie* evidence informs the choice of analytical approach, choosing an interrupted time-series design.

Figure 1 on page 3 displays the daily average values for the respective fuel types diesel, E5 (Super) and E10 exemplarily for the two municipalities Rostock and Munich. While in 2021 the prices for all fuel types differed only slightly across the municipalities, the variance became larger in 2022. Between April and the end of May, prices varied strongly and developed upwards. During June-August, when the *Tankrabatt* was applied, the prices in the municipalities diverge strongly. In Rostock, the prices for E5 and E10 fell after a short price increase from just over 1.9 € to well below 1.8 €. In

Munich, on the other hand, prices increase after the first few days to a level of just over 1.9 €. Afterwards, however, the average never fell below 1.8 € mark. This level effect continues after the end of the measure and I suspect that this is likely to have affected the mobility behavior of the respective inhabitants.

Last but not least, I also look at the change in weather over the 2-year observation period. The year 2022 experienced significantly warmer, sunnier and more arid weather than 2021 across all cities in the sample (see Table A.3). These more favorable weather conditions presumably contributed to the increase of bike rides in 2022 with only the increase in measured wind speeds opposing.

4 Empirical Strategy

4.1 Hypothesis

The working hypothesis is that the decrease of disposable household income led people to switch to a more inexpensive mode of mobility. Due to the sparse information on users of public transport in scope and direction, I expect public transport and bike use to have risen but can only contribute indications to the latter. This initial conjecture is supported by the findings of the VDV (2022b). Further, due to the multi modality of cyclists, I assume that (occasional) cyclists have changed their means of transport with stronger responses to adverse weather conditions.

4.2 Empirical Approach

I employ two different approaches for the analysis to capture both the effect during the ticket and the effect after the ticket on hourly and daily levels. Table A.4 provides an overview of all variable specifications. For the first model hourly data is used and the dependent variable *Cyclist* describes the number of bike rides per hour recorded by a counting station. It allows for zeros in the observations and hence is a count variable by structure. The most commonly used method for count data is the Poisson regression. However in the data the conditional variance exceeds the conditional mean, violating one of the core assumptions. I therefore apply in the first part of the analysis a Negative Binomial Regression Model, which deals with this problem by incorporating an additional term to account for the excess variance. Due to the panel structure of the data, I in addition employ a panel regression with fixed effects as control, which in a third model is combined with the Poisson approach, running a conditional fixed-effects Poisson model instead of a conditional fixed-effects Negative Binomial model to account for all predictors following the contributions of Hilbe (2012).

I use *Ticket* as a dummy variable that serves as an indicator for the period of the 9 € ticket, which is used to test the hypothesis. To account for seasonal and weekly dynamics I use a time-stratified model with indicator variables for *Season* as well as *Hour* and introduce controls for regionally varying school holiday periods and public holidays as well as business days. The variables *Fuel*, *Work* and *Revenue* are all included in the set of control variables. *Weather* combines a number of climatic variables: *Sunshine*, *Rain*, *Temperature* and *Wind*. The variable *Fuel* includes one of the prices of the three types of fuel (Diesel, E5 and E10) or their unweighted mean. I further include

the monthly revenue of the German bike sector in the empirical model. This proxy serves the purpose of including the general bicycle boom. Reports from the bicycle industry association underpin that demand remained robust despite supply bottlenecks and prolonged waiting times associated with the pandemic and the flustered international trade situation (Kolberg 2023). In addition, *Revenue* serves a second purpose: I employ the variable as a seasonal control as the revenue matches the seasonal cycling patterns.

For the second part of the analysis, I move away from hourly data and employ daily aggregates in a panel interrupted time series analysis (PITSA) approach (Linden 2015; Linden 2022) testing if any effects persisted beyond the validity of the 9 € ticket. The pre-intervention trend projected into the treatment period serves as the counterfactual. This quasi-experimental design is commonly used to evaluate public health and regulatory interventions but has also been applied in mobility and more specifically cycling research (Fuller et al. 2012; Xiao et al. 2022). The ticket is in the analysis introduced as a treatment which is withdrawn after three months, improving validity as suggested by Shadish (2001). In the removed-treatment design seasonality and weekly dynamics were modelled using Fourier terms with two sine and cosine pairs.

5 Results

5.1 Immediate Effects

In the first analysis, I concentrate on the immediate effect of the ticket on hourly bicycle volumes. The results are displayed in Table 2. The coefficients of the dummy variable *Ticket* are negative in all models, indicating a decrease in bicycle rides during the 9 € ticket period. For a more intuitive interpretation, I have calculated the marginal effects with the mean values. This shows that the hourly number of cyclists has decreased by 20.011 in the negative binomial, by 23.327 in the panel regression and by 18.445 in the panel-poisson regression. Looking at the incidence-rate ratios, this corresponds to a reduction in traffic volumes by 14.4 percent during the ticket in the first NB model. This result is indicative of a strong influence on cycling behavior. The coefficients of the different estimation approaches are overall very close with the effects of the negative binomial and the fixed-effect Poisson regression only differing slightly, reinforcing the validity of the estimation results.

In an additional specification I test whether the type of fuel has an impact on the analysis. The results are displayed in Table 3. I observe that the coefficients hardly differ with respect to the different fuel types. However, the coefficient for diesel fuel is smaller than that for E5 and E10. Nevertheless, this suggests that fuel prices have similar effects regardless which fuel type is used as independent variable, so it can be assumed that the change in behavior is uniform among fuel types. In all cases, an increase in fuel prices is expected to lead to an aligned increase in cycling.

Table 4 shows the marginal effects of the cities separately. Berlin, Bremen, Dresden, Freiburg, Heidelberg, München, and Rostock have similarly large effects as I estimated in the overall model. Stuttgart in contrast falls short of this with a marginal reduction of 2.971 rides, so the effect of the 9 € ticket appears weaker there. Furthermore, the estimated effects are significantly stronger in Hamburg and Münster. Reasons for these

Table 2: Results Hourly Effect Ticket

	(1) NB	(2) Panel	(3) Panel-Poisson
Ticket	-0.155*** (0.003)	-23.327*** (2.404)	-0.154*** (0.010)
<i>Fuel price</i> : Mean	0.486*** (0.003)	43.798*** (6.041)	0.381*** (0.030)
Marginal Effect Ticket	-20.011***	-23.327***	-18.445***
<i>Controls:</i>			
Station	Yes	Yes	Yes
Hour	Yes	Yes	Yes
Season	Yes	Yes	Yes
Weather	Yes	Yes	Yes
Workday	Yes	Yes	Yes
Holiday	Yes	Yes	Yes
Revenue	Yes	Yes	Yes
Stations	92	92	92
Observations	1,333,487	1,333,487	1,333,487

Note: Significance levels at *** $p < .001$, ** $p < .01$, * $p < .05$

large differences could be a better topography or different priorities in infrastructure policy or a different culture of bike usage. Darmstadt and Ulm show moderate increases in contrast to the other cities, these results are, however, based on a single station respectively and might therefore have only limited explanatory power for their city overall. Therefore the three cities with only one counting station are excluded. The results of the reduced sample are shown in Table A.5, column (2). The results with the reduced sample only differ slightly with stronger coefficients for both *Fuel* and *Ticket* but overall align with the results of the full sample. The rather large impact heterogeneity on cycling levels is congruent with the results of other studies. Möllers et al.(2022) for instance find similar strongly varying effects and magnitudes in their study of the influence of the corona pandemic on active mobility in Germany across cities.

Furthermore, the analysis shows that the marginal effects are more pronounced during commuting times with spikes around 7 am as well as between 4 and 6 pm when there is more traffic volume in general. The results are graphically displayed in Figure 4. The same pattern applies for Saturdays, Sundays and official regional and state wide holidays though with more moderate effects.

As one of the control checks, I test whether corona infections did play a role in the observed changes but do not find statistically relevant results employing the incidence rates at the municipal level as control.⁶

⁶In 2022 there were no mobility restrictions imposed to combat the spread of SARS-CoV-2, so any avoidance behavior would have been voluntary and motivated by the perception of risk rather than the realized threat. I suspect that although the incidence rate was the main indicator for the spread of SARS-CoV-2 in Germany, that its signaling effect flattened over time with the introduction of vaccines, home testing and a progressing normalization. In addition, the validity of the reported

Table 3: Impact by Fuel Type

	NB			Panel-Poisson		
	(1)	(2)	(3)	(4)	(5)	(6)
Ticket	-0.203*** (0.003)	-0.117*** (0.003)	-0.117*** (0.003)	-0.191*** (0.012)	-0.125*** (0.009)	-0.124*** (0.009)
<i>Fuel prices:</i>						
Diesel	0.389*** (0.003)			0.303*** (0.032)		
E5		0.543*** (0.003)			0.425*** (0.032)	
E10			0.544*** (0.003)			0.426*** (0.032)
<i>Controls:</i>						
Station	Yes	Yes	Yes	Yes	Yes	Yes
Hour	Yes	Yes	Yes	Yes	Yes	Yes
Weather	Yes	Yes	Yes	Yes	Yes	Yes
Season	Yes	Yes	Yes	Yes	Yes	Yes
Workday	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
Revenue	Yes	Yes	Yes	Yes	Yes	Yes
Stations	92	92	92	92	92	92
Observations	1,333,487	1,333,487	1,333,487	1,333,487	1,333,487	1,333,487

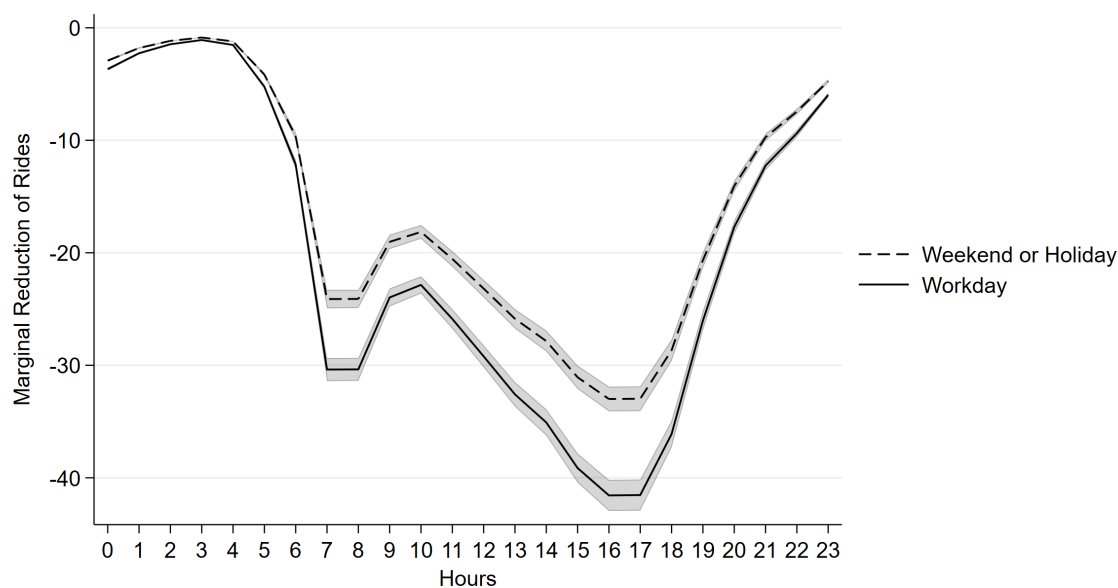
Note: Significance levels at *** p<.001, ** p<.01, * p<.05

Table 4: Average Marginal Effects of Ticket within each City

City	Marginal Effect Ticket	Stations	N
Berlin	-24.567***	16	232,917
Bremen	-20.226***	8	116,423
Darmstadt	4.697***	1	14,481
Dresden	-16.598***	8	116,476
Freiburg	-22.526***	4	58,196
Hamburg	-48.729***	1	14,555
Heidelberg	-15.843***	10	145,193
Leipzig	-28.568***	5	71,917
München	-20.518***	4	58,323
Münster	-49.647***	9	144,202
Rostock	-20.903***	9	128,036
Stuttgart	-2.971***	15	218,185
Ulm	2.406*	1	14,583

Note: Significance levels at *** $p < .001$, ** $p < .01$, * $p < .05$

Figure 4: Average Marginal Effects of Ticket with 95 Percent Confidence Intervals



5.2 Continued Effects

In addition to the analysis of behavioral changes during the 3-month ticket period, I also aim to take a look into persisting impacts. I use a panel interrupted time-series design to quantify changes in daily cycling trips following the inception of the ticket, and any additional change after the abrogation. By implementing this design, I can disjoint the impact of the ticket into trend and level changes. For the calculation the Stata package `xtitsa` by Linden (2021) is used. Table 5 shows the results for the total and log daily bike rides. First, I find a general positive trend towards cycling between 2021 and the inception of the ticket while controlling for weather, fuel prices, school and public holidays, and time-effects in the panel analysis. This trend is then interrupted by the launch of the ticket, which leads to both a statistically significant level decline and a reversal of the underlying trend by -341.404 points and -6.392 points respectively. This aligns with the popularity of the ticket and is in range with the initial analysis. After the withdrawal of the ticket there is a statistically significant jump in the time-series by 520.279 points, followed by a statistically significant increase in the daily trend by 4.064 points compared to the ticket period. Comparing the pre-ticket and post-ticket time periods, the results suggest that after the ticket expired daily bicycle volumes decreased by a rate of 1.130 points more or less reverting the initial trend.

I test for autocorrelation by using the Stata command `acetest` by Baum und Schaffer (2013) but find no evidence of autocorrelation after the adjustments for seasonality and weekly patterns. In contrast to the immediate effects, *Revenue* is not included in the model as revenue is highly correlated with the seasonal trend.

6 Environmental Implications - A Rough Estimate

All in all, I come to the conclusion that the 9 € ticket has at least partially counteracted the objectives of the climate change act by diverting people from a more climate-friendly mode of transport to (a slightly) less climate-friendly ones. To enrich the first finding, I aim to roughly assess the impact of the findings in the next step in terms of external costs during the ticket. First, I assume that overall mobility did not decrease in the period under review. From this, I build upon the first precondition and assume that the decline in bike rides associated with the 9 € ticket led to an increase of passengers in either public transport or motorized individual transport. Given the environmental costs for mobility in Germany by vehicle (see Figure A.1) provided by the German Federal Environmental Agency (Umweltbundesamt 2020), a switch from bike to urban public transport entails additional environmental costs of 1.67 €-ct/km using the tram and 2.39 €-ct/km using the urban bus. These values at least double when people switch from bikes to cars, causing additional environmental costs of 5.30 €-ct/km. Next, I

corona cases for the incidence of infection has decreased significantly in 2022 when testing obligations ceased, a cost contribution for administered tests was introduced and PCR tests became less easily accessible. Though I assume that a potential infection was still on people's minds, there is to my knowledge no suitable data to control for it. The Federal Institute for Risk Assessment did survey the perceived risk in a bi-weekly study, however, the survey question did change in February 2022 shifting from physical (Bundesinstitut für Risikobewertung 2022), like the use of door handles, to situational risks (Bundesinstitut für Risikobewertung 2023), like the use of public transport. To my knowledge there is no representative survey that contains an indicator for perceived risk for the study period.

Table 5: Results Interrupted Time-series Analysis

	Daily Bike Rides	
	Total	Log
<i>Baseline:</i>		
Level	1,972.202***	7.254***
Trend	1.198***	0.001***
<i>During Ticket:</i>		
Δ Level	-341.407***	-0.145***
Δ Trend	-6.392***	-0.003***
<i>Post Ticket:</i>		
Δ Level	520.279***	0.206***
Δ Trend	4.064***	0.001*
<i>Controls:</i>		
Fuel prices	Yes	Yes
Station	Yes	Yes
Weather	Yes	Yes
Public and school holidays	Yes	Yes
Seasonal Dynamic	Yes	Yes
Weekly Dynamic	Yes	Yes
Stations	76	76
Observations	54,978	54,978

Note: Significance levels at *** $p < .001$, ** $p < .01$, * $p < .05$

combine these calculations with the findings and project the decline of bike rides on an average 5 kilometer distance and the duration of the 9 € ticket. To keep the calculation simple, I take the mean impact across the different fuel types (see Table 6) which results in an average decline of 20 bike rides per station and hour. Aggregated for the ticket period, the change in mobility mode from bike to public transport (car) on an average 5 kilometer distance accumulates to external effects of about 3,689 - 5,280 € (11,775 €) per counter station. Alternatively, when can also look at the overall reduction of cycled kilometers. For the latest Mobility in Germany study in 2017, the authors estimate that per day on average 24.8 Mio. kilometers are travelled and commuted by bike in larger cities (Nobis 2019). When I combine this value with the observed reduction in bike volume in the analysis, I roughly estimate additional environmental costs of 59.610 - 85,310 € when switching to public transport. Though this is rather a back-of-the-envelope calculation, it illustrates one of the side effects of the ticket.

7 Discussion

Commuting by bicycle offers a wide array of advantages in terms of individual and societal aspects: cycling is linked to physical and mental health benefits, environmental sustainability, allows for economic savings and urban planning improvements. As urbanization intensifies and environmental concerns grow, the advantages of cycling for commuting have garnered significant attention from researchers, policymakers, and the general public. The working paper taps into this interest and analyzes how highly affordable public transit alters existing cycling volumes and patterns.

I use automated count data on bicycle rides in 13 German cities. In the analysis I find a significant decrease of urban bike mobility as a response to the two policy measures in the summer of 2022. Moreover, the results indicate that inherent characteristics of the cities moderate the response to the policies and no north-south pattern or other regional patterns is identified. The results are statistically significant and indicate a decrease of 14.4 percent of bike rides on an hourly level with effects being more pronounced during the week and especially strong during typical commuting hours. The results are robust across specifications and the panel regression provides a robustness-check which corroborates the estimates from the negative binomial and panel Poisson model. The analysis further shows that the ticket triggered a prolonged effect after the abrogation while introducing a statistically significant negative trend towards cycling. However, the analysis of the continued effects should be taken with a grain of salt: I was only able to incorporate four months after the withdrawal which fell into fall and winter months. Though I control for seasonal effects, cycling is rather a habit than a day-to-day decision and I suspect that during fall and winter people are less likely to form or reactivate an outdoor habit. I do not have sufficient information to conclude that the ticket does adversely effect modal share of cyclists in the long run but have evidence that the temporary introduction of the ticket did put off people from cycling in the period under review.

As described in the introduction, large cities with a population above 100,000 were considered in the analysis. Therefore the findings are likely to be transferable to other cities in this category. However, it is not advisable to generalize beyond this, as medium-sized and small cities vary greatly in infrastructure and mobility patterns. Possible

Table 6: Calculation of Aggregated External Costs

Vehicle	Associated costs of change in transport mode during the period of the 9€ ticket:					
	(A)			(B)		
	Costs per km	Costs compared to bike	Duration	Marginal Effect	Costs per km	Costs per 5 km
Bike	0.36 €-ct	-			-	
Tram	2.03 €-ct	1.67 €-ct	x 24 hours	x 20.0	738 €	3,689 €
Urban bus	2.75 €-ct	2.39 €-ct	x 92 days		1,056 €	5,280 €
Car	5.66 €-ct	5.30 €-ct			2,355 €	11,775 €
					Incident Rate	Daily cyclist km in Mio.
					x 14.4	x 24.8
						Costs in Mio.
						59,610 €
						85,310 €
						189,181 €

Baseline values for 2017 were derived from the Mobility in Germany study with an average of 558 passenger kilometers in metropolitan areas and 434 km in millions per day in urban areas that fit the category *Großstadt* (Nobis and Kuhmhof 2018). The authors of the study find that 5 percent of these passenger kilometers were covered by bike (Nobis 2019), resulting in a rough estimate of 24.8 Mio. kilometers per day in metropolitan and urban areas rode by bike. The aggregated cycling volume does that not account for seasonal variation, therefore a downward bias is suspected.

extensions comprise the inclusion of additional cities and city categories in order to detect categorical size, compositional and regional trends across the cities. Moreover, due to the scope of the research question and the pandemic, I limited the period under review but foresee a potential extension of the time period, linking the research to the upcoming edition of the mobility survey in Germany (more information is provided here: <https://www.mobilitaet-in-deutschland.de/index.html>). An extension of the time period further allows to analyze whether the disruption of cycling habits remained and an evaluation of the 49 € ticket, which was introduced shortly after in May 2023 and might therefore trigger different responses albeit a significant price difference.

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A Appendix

Table A.1: Information on Data Sources, Data Structure, and Licensing

Berlin

- XLSX file *Jahresdatei geprüfter Rohdaten der Radzählstellen* was downloaded from the city administration's website for environment, mobility, consumer and climate protection.
- Data points that were marked with "Periods in which no or implausible count data occurred at counting points" were imported as missings and hence excluded.
- Licensing: DL-DE->BY-2.0

Bonn

- Annual CSV files with an hourly resolution were downloaded from the city's open data platform <https://opendata.bonn.de/>
- Licensing: <https://creativecommons.org/publicdomain/zero/1.0/>.

Bremen

- In the input mask all available stations were selected and downloaded as a CSV file for the period 01.01.2018 - 31.12.2022.
- The selected resolution was hourly.
- The information from each station on cycling trips in different directions was summed up.
- Licensing: CC BY-NC-ND

Darmstadt

- City administration, Mobilitätsamt Wissenschaftsstadt Darmstadt, provided access to the EcoCounter platform and data was downloaded as a single CVS file on an hourly basis.
 - Licensing: CC BY-NC-ND
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Dresden

- City administration provided raw data for each station via a cloud solution. An Excel file for each month and station was downloaded for the period 01.01.2018 - 31.12.2022.
- The bike counter station *Tharandter Straße* was excluded from the analysis due to technical problems causing irregularities. The information concerning the irregularities in the data was distributed to the data users on 14.03.2023 via mail by the city's office for mobility.
- Licensing: The Straßen- und Tiefbauamt of the State Capital Dresden agreed to the publication of the research results in writing on 03.02.2023.

Freiburg

- The data was downloaded from Mobi DataBW, a cross-modal open data platform for mobility data of the state of Baden-Württemberg, using the XLSX file *Historische Fahrradzählraten (Januar 2013 - heute)* as list for the respective links. For each month, a compressed CSV file was downloaded.
- Licensing: <https://www.govdata.de/dl-de/by-2-0>

Hamburg

- The CSV document "Datadownload" was downloaded under "Weitere Verweise".
- The data preparation was limited to the period 01.01.2018 - 31.12.2022.
- Licensing: <https://www.govdata.de/dl-de/by-2-0>

Heidelberg

- The Heidelberg Office for Mobility, part of the city administration, set up a guest account with the provider EcoCounter to access the raw data. The data was downloaded as CSV files with hourly resolution for each of the 14 counting station.
- Licensing: CCO 1.0

Leipzig

- The data was provided on two separate occasions via mail by the City of Leipzig, Traffic and Civil Engineering Office. On 21.11.2022 an XLSX file for the period 01.01.2018 - 31.09.2022 was sent, the second XLSX file was sent on 13.02.2023 for the the time period 01.01.2022 - 31.12.2022.
 - Licensing: DL-DE->BY-2.0
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Munich

- Data was downloaded from the city administrations open data website <https://opendata.muenchen.de/dataset>.
- Licensing: <https://www.govdata.de/dl-de/by-2-0>

Münster

- Data of the 10 counting stations in hourly resolution was downloaded from the website of the Office for Mobility and Civil Engineering, City of Münster. We downloaded a separate XLSX file for each station and each year.
- Licensing: <https://www.govdata.de/dl-de/by-2-0>

Reutlingen

- The data from Mobi DataBW, a cross-modal open data platform for mobility data of the state of Baden-Württemberg, contains information on eight counting stations located in Reutlingen. However, the data was not used in the main analysis because the data for the respective counting stations did not meet the quantitative requirement of a maximum of 10 percent missing data.
- The data sources were identified using the XLSX file *Historische Fahrradzählraten (Januar 2013 - heute)* for list of respective links. For each month, a compressed CSV file was downloaded.
- Licensing: <https://www.govdata.de/dl-de/by-2-0>

Rostock

- We downloaded the files *XLSX Daten der Radmonitore* and *CSV Daten der Radmonitore* to obtain a time series for the period 01.01.2018 - 31.12.2022.
 - To obtain additional information on the locations of the counting points, we used the CSV file *CSV Standorte der Radmonitore*.
 - The quarter-hourly data were aggregated to an hourly basis.
 - Licensing: <https://creativecommons.org/publicdomain/zero/1.0/>
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Stuttgart

- The data was downloaded from Mobi DataBW, a cross-modal open data platform for mobility data of the state of Baden-Württemberg, using the XLSX file *Historische Fahrradzählraten (Januar 2013 - heute)* as list for the respective links. For each month, a compressed CSV file was downloaded.
- Licensing: <https://www.govdata.de/dl-de/by-2-0>

Ulm

- The CSV file `49631b61-cda1-46af-b58c-f1e4965f0bd4` was downloaded via the city's open data website datenhub.ulm.de for the period 17.01.2020 - 31.12.2022.
 - Licensing: <https://creativecommons.org/publicdomain/zero/1.0/>
-

Table A.2: Station Summary Statistics, Hourly Level

Station sorted by city	Obs	Integrity	Total rides	Mean	SD	Min	Max
<i>Berlin</i>							
Alberichstraße	17,517	100.0%	373,886	21.344	23.241	0	553
Berliner Straße	17,516	100.0%	4,022,427	229.643	213.479	0	1,098
Breitenbachplatz	17,354	99.1%	1,677,086	96.640	101.774	0	658
Frankfurter Allee	17,412	99.4%	3,245,549	186.397	160.530	0	778
Invalidenstraße	17,517	100.0%	3,290,348	187.837	161.733	0	877
Jannowitzbrücke	17,517	100.0%	5,319,449	303.674	277.232	0	1,558
Kaisersteg	17,517	100.0%	951,474	54.317	51.473	0	279
Klosterstraße	17,517	100.0%	1,077,210	61.495	54.610	0	285
Mariendorfer Damm	17,502	99.9%	962,725	55.007	48.338	0	314
Markstraße	17,509	99.9%	1,063,598	60.746	51.544	0	299
Maybachufer	17,517	100.0%	3,455,867	197.286	165.146	0	833
Monumentenstraße	17,379	99.2%	2,711,531	156.023	141.737	0	844
Paul-undPaula Uferweg	16,811	96.0%	1,891,171	112.496	113.456	0	952
Prinzregentenstraße	17,517	100.0%	1,100,052	62.799	64.010	0	434
Schwedter Steg	17,517	100.0%	1,793,318	102.376	99.236	0	489
Yorckstraße	17,517	100.0%	3,833,813	218.862	188.659	0	1,079
<i>Bremen</i>							
Graf-Moltke-Straße	17,518	100.0%	1,464,783	83.616	71.929	0	311
Hastedter Brückenstraße	17,158	97.9%	2,197,507	128.075	122.614	0	778
Langemarckstraße	17,518	100.0%	2,570,446	146.732	126.364	0	590
Osterdeich	17,518	100.0%	2,777,464	158.549	130.991	0	1,016
Radweg KleineWeser	16,918	96.6%	2,328,581	137.639	132.331	0	776
Schwachhauser Ring	17,167	98.0%	1,369,953	79.802	73.948	0	436
Wachmannstraße	17,518	100.0%	3,497,109	199.629	185.031	0	897
Wilhelm-Kaisen-Brücke	17,518	100.0%	6,883,771	392.954	330.031	0	1,492
<i>Darmstadt</i>							
Lincoln Siedlung	17,432	99.5%	641,658	36.809	37.398	0	392

Table A.2: Station Summary Statistics, Hourly Level

Station sorted by city	Obs	Integrity	Total rides	Mean	SD	Min	Max
<i>Dresden</i>							
Albertbrücke	17,520	100.0%	3,179,319	181.468	172.035	0	1,058
Elberadweg	17,520	100.0%	1,418,314	80.954	99.335	0	618
Elberadweg Nord	17,363	99.1%	1,227,050	70.670	85.920	0	712
Kreuzstraße	17,520	100.0%	1,005,118	57.370	57.984	0	735
Lennéstraße	17,520	100.0%	819,845	46.795	43.347	0	261
St. Petersburger Straße	17,520	100.0%	1,126,467	64.296	59.622	0	334
Waldschlößchenbrücke	17,520	100.0%	2,290,128	130.715	138.912	0	864
Winterbergstraße	17,112	97.7%	1,224,055	71.532	71.125	0	383
<i>Freiburg</i>							
FR1 Dreisam / Hindenburgstr.	17,496	99.9%	2,623,230	149.933	144.096	0	797
FR2 Güterbahn / Ferd.-Weiß-Str.	17,496	99.9%	2,111,537	120.687	114.348	0	616
FR3 Eschholzstr. / Egonstr.	17,496	99.9%	2,133,989	121.970	94.677	0	525
Wiwilibrücke	17,496	99.9%	6,746,350	385.594	325.922	0	1,533
<i>Hamburg</i>							
An der Gurlittinsel	17,495	99.9%	4,259,465	243.468	250.311	0	1,770
<i>Heidelberg</i>							
Bahnstadtpromenade	14,469	82.6%	1,731,197	119.649	113.626	0	582
Berliner Straße	17,518	100.0%	1,094,849	62.499	51.529	0	273
Eppelheimer Straße	17,518	100.0%	604,994	34.536	29.165	0	193
Ernst-Walz-Brücke	17,518	100.0%	5,224,502	298.236	268.414	0	1,377
Gaisbergstraße	17,518	100.0%	3,172,688	181.110	162.923	0	732
Hardtstraße	17,011	97.1%	1,163,041	68.370	65.145	0	386
Kurfürstenanlage	17,518	100.0%	963,961	55.027	57.585	0	1,643
Liebermannstraße	17,518	100.0%	2,981,788	170.213	151.412	0	679
Mannheimer Straße	16,774	95.7%	1,492,149	88.956	81.461	0	471
Plöck	9,939	56.7%	1,490,785	149.993	138.458	0	768
Rohrbacher Straße	17,518	100.0%	2,162,066	123.420	103.902	0	472

Table A.2: Station Summary Statistics, Hourly Level

Station sorted by city	Obs	Integrity	Total rides	Mean	SD	Min	Max
Schlierbacher Landstraße	11,863	67.7%	391,402	32.994	35.308	0	239
Theodor-Heuss-Brücke	17,518	100.0%	5,604,419	319.923	275.296	0	1,270
Ziegelhäuser Landstraße	11,919	68.0%	409,266	34.337	34.411	0	190
<i>Leipzig</i>							
Eisenbahnstraße	334	1.9%	81,423	243.781	157.159	13	684
Gerberstraße	17,518	100.0%	1,778,264	101.511	95.455	0	538
Gustav-Freytag-Straße	322	1.8%	11,770	36.553	38.967	0	226
Jahnallee	7,703	44.0%	1,422,932	184.724	150.479	0	1,224
Karl-Liebknecht-Straße	17,518	100.0%	3,737,263	213.338	175.554	0	1,363
Lene-Voigt-Park	17,518	100.0%	1,417,595	80.922	77.036	0	399
Manetstraße	16,557	94.5%	2,374,210	143.396	156.839	0	1,162
Merseburgstraße	477	2.7%	31,396	65.820	54.362	0	244
Semmelweisstraße	17,287	98.7%	2,124,195	122.878	107.072	0	540
<i>Munich</i>							
Arnulf	14,931	85.2%	545,916	36.563	46.909	0	338
Erhardt	17,520	100.0%	3,447,128	196.754	199.910	0	1,247
Hirsch	17,520	100.0%	1,063,845	60.722	72.428	0	471
Kreuther	17,520	100.0%	497,965	28.423	32.553	0	209
Margareten	17,520	100.0%	2,451,738	139.939	133.399	0	723
Olympia	15,648	89.3%	1,189,405	76.010	88.571	0	833
<i>Münster</i>							
Gartenstraße	17,517	100.0%	1,870,627	106.789	95.213	0	472
Hafenstraße	17,518	100.0%	4,601,763	262.688	194.798	0	1,041
Hammer-Straße	17,518	100.0%	4,800,490	274.032	236.714	0	1,556
Hüfferstraße	17,517	100.0%	3,496,564	199.610	191.474	0	896
Kanalpromenade	17,502	99.9%	644,629	36.832	45.104	0	386
Neutor	16,262	92.8%	6,026,325	370.577	326.699	0	1,802
Promenade	17,517	100.0%	9,618,028	549.068	460.685	0	2,287

Table A.2: Station Summary Statistics, Hourly Level

Station sorted by city	Obs	Integrity	Total rides	Mean	SD	Min	Max
Warendorfer Straße	17,518	100.0%	4,276,276	244.108	222.046	0	1,034
Weseler Straße	17,517	100.0%	1,978,830	112.966	96.343	0	498
Wolbecker Straße	17,430	99.5%	5,987,654	343.526	284.597	0	1,396
<i>Reutlingen</i>							
Bellinostraße	14,381	82.1%	463,000	32.195	40.373	0	282
Charlottenstraße	14,357	81.9%	275,190	19.168	20.753	0	355
Hindenburgstraße	14,381	82.1%	393,293	27.348	28.314	0	158
Konrad-Adenauer-Straße	14,357	81.9%	275,597	19.196	19.451	0	123
Metzgerstraße	14,381	82.1%	306,694	21.326	22.483	0	188
Moltkestraße	14,381	82.1%	125,518	8.728	13.964	0	141
Tübinger Tor	14,381	82.1%	941,101	65.441	64.775	0	774
Unter den Linden	14,357	81.9%	534,837	37.253	38.333	0	1,426
<i>Rostock</i>							
Am Strande/Holzhalbinsel	17,494	99.9%	3,339,635	190.902	191.449	0	1,102
Graal-Müritz	15,646	89.3%	296,426	18.946	43.761	0	1,036
Hamburger Straße/Braesigplatz	16,606	94.8%	907,139	54.627	56.085	0	334
Hamburger Straße/Liningweg	17,494	99.9%	648,176	37.051	39.713	0	228
Hinrichshagen	15,958	91.1%	317,218	19.878	37.080	0	312
Hundertmännerstraße	15,502	88.5%	1,373,485	88.601	83.299	0	538
Lange Straße Süd	17,494	99.9%	962,509	55.019	57.217	0	748
Markgrafenheide	15,982	91.2%	442,774	27.705	57.842	0	570
Mühlendamm/Flussbad	16,102	91.9%	2,020,466	125.479	136.027	0	818
Uni-Campus	17,470	99.7%	527,183	30.176	34.245	0	308
Warnemünde Wetterwarte	17,470	99.7%	2,502,943	143.271	221.224	0	1,358
<i>Stuttgart</i>							
Am Kräherwald	17,496	99.9%	286,853	16.395	19.661	0	201
Böblinger Straße	17,496	99.9%	798,310	45.628	51.062	0	304
Inselstraße	17,496	99.9%	644,592	36.842	41.324	0	696

Table A.2: Station Summary Statistics, Hourly Level

Station sorted by city	Obs	Integrity	Total rides	Mean	SD	Min	Max
Kirchheimer Straße	17,496	99.9%	453,568	25.924	29.740	0	294
Kremmlerstraße	17,496	99.9%	478,550	27.352	33.089	0	258
König-Karls-Brücke	17,496	99.9%	2,262,571	129.319	138.360	0	988
Lautenschlager Straße	17,496	99.9%	825,459	47.180	44.532	0	498
Neckartalstraße	17,496	99.9%	408,314	23.338	32.125	0	961
Samaraweg	17,496	99.9%	958,547	54.787	60.626	0	385
Solitudenstraße	17,496	99.9%	311,759	17.819	18.869	0	128
Suttgarter Straße	17,496	99.9%	302,902	17.313	17.816	0	130
Taubenheimstraße	17,496	99.9%	197,807	11.306	11.366	0	101
Tübinger Straße	17,496	99.9%	1,721,717	98.406	99.595	0	602
Waiblinger Straße	17,496	99.9%	229,509	13.118	12.329	0	121
Waldburgstraße	17,160	97.9%	301,504	17.570	23.243	0	197
<i>Ulm</i>							
Blautalradweg	16,991	97.0%	731,882	43.075	49.246	0	323

Table A.3: Daily Weather Characteristics, Annual Comparison

	Mean Temperature in °C				Precipitation in mm				Wind Speed in m/s				Sunshine in Hours			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
<i>Berlin</i>																
2021	10.49	7.94	-9.00	28.70	1.46	3.82	0.00	41.70	10.08	3.37	3.80	23.60	4.36	4.25	0.00	15.23
2022	11.58	7.63	-6.80	30.00	1.07	2.50	0.00	20.40	10.27	4.04	3.20	27.90	5.52	4.43	0.00	15.43
<i>Bremen</i>																
2021	9.89	6.90	-8.60	26.60	1.70	3.19	0.00	20.00	10.73	4.07	3.10	27.30	4.30	4.13	0.00	15.68
2022	10.99	6.63	-6.60	28.10	1.51	3.06	0.00	21.30	11.41	4.70	2.60	32.60	5.61	4.53	0.00	16.13
<i>Darmstadt</i>																
2021	9.96	7.01	-8.50	26.60	1.76	3.52	0.00	23.90	10.02	3.57	3.00	29.30	5.04	4.56	0.00	15.67
2022	11.59	7.39	-8.90	27.50	1.49	3.56	0.00	29.70	10.66	3.72	3.50	33.90	6.14	4.90	0.00	15.50
<i>Dresden</i>																
2021	10.17	7.75	-11.70	28.10	1.96	4.58	0.00	50.20	10.50	3.90	3.60	33.10	4.27	4.16	0.00	14.38
2022	11.49	7.54	-6.70	29.20	1.27	3.37	0.00	31.50	11.13	4.14	4.60	26.10	5.64	4.66	0.00	15.77
<i>Freiburg</i>																
2021	10.87	7.07	-6.30	26.20	2.43	4.73	0.00	36.90	8.97	3.82	2.50	21.00	4.90	4.45	0.00	14.07
2022	12.86	7.69	-5.80	28.30	2.01	4.92	0.00	36.40	9.36	4.10	2.60	26.40	6.08	4.71	0.00	14.68
<i>Hamburg</i>																
2021	9.78	7.05	-7.80	27.10	1.99	3.68	0.00	22.70	10.80	3.77	2.60	24.90	4.09	4.15	0.00	15.23
2022	10.73	6.51	-5.30	27.10	1.98	3.91	0.00	23.20	11.41	4.26	3.10	28.50	5.40	4.48	0.00	15.57
<i>Heidelberg</i>																
2021	10.91	7.03	-7.40	27.80	1.70	3.63	0.00	31.20	8.84	3.45	2.90	23.50	5.02	4.64	0.00	15.50
2022	12.82	7.59	-7.90	29.50	1.66	4.59	0.00	44.80	8.71	3.27	3.30	26.00	6.05	4.81	0.00	15.45
<i>Leipzig</i>																
2021	10.00	7.63	-12.10	27.20	2.09	5.50	0.00	67.60	8.27	3.05	3.10	22.90	4.80	4.32	0.00	15.55
2022	11.25	7.45	-7.90	28.70	1.34	2.98	0.00	21.50	8.83	3.64	3.00	22.60	5.98	4.65	0.00	15.53
<i>Munich</i>																
2021	9.73	7.37	-7.90	25.80	2.93	6.15	0.00	46.40	9.32	3.82	3.70	24.10	5.45	4.68	0.00	15.62

Table A.3: Daily Weather Characteristics, Annual Comparison

	Mean Temperature in °C				Precipitation in mm				Wind Speed in m/s				Sunshine in Hours			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
2022	11.37	7.62	-7.20	28.20	2.27	4.91	0.00	43.10	9.83	4.26	3.30	26.10	6.24	4.82	0.00	15.72
<i>Münster</i>																
2021	10.26	6.87	-10.00	27.80	1.74	3.38	0.00	25.20	9.76	4.03	2.60	27.10	4.04	4.06	0.00	15.38
2022	11.56	6.75	-5.40	28.10	1.52	3.21	0.00	22.40	10.34	4.58	2.90	34.00	5.42	4.61	0.00	15.48
<i>Rostock</i>																
2021	10.17	6.98	-4.80	28.60	1.99	4.77	0.00	57.60	11.60	4.02	4.50	27.60	4.81	4.60	0.00	16.32
2022	10.72	6.56	-5.60	28.80	1.37	3.70	0.00	33.20	11.97	4.61	3.80	30.70	5.76	4.73	0.00	16.10
<i>Stuttgart</i>																
2021	10.43	7.17	-7.60	27.00	1.81	4.53	0.00	59.20	9.25	3.72	3.50	25.10	5.09	4.53	0.00	15.30
2022	12.26	7.62	-6.50	29.00	1.62	3.96	0.00	36.00	9.56	3.80	2.90	27.50	6.22	4.74	0.00	15.33
<i>Ulm</i>																
2021	7.93	7.14	-10.60	23.70	2.14	5.30	0.00	56.40	8.70	3.22	3.20	22.20	5.01	4.52	0.00	15.67
2022	9.54	7.37	-8.80	24.40	1.90	4.88	0.00	55.10	9.14	3.26	3.20	22.00	6.06	4.91	0.00	15.23

Table A.4: Utilized Variables.

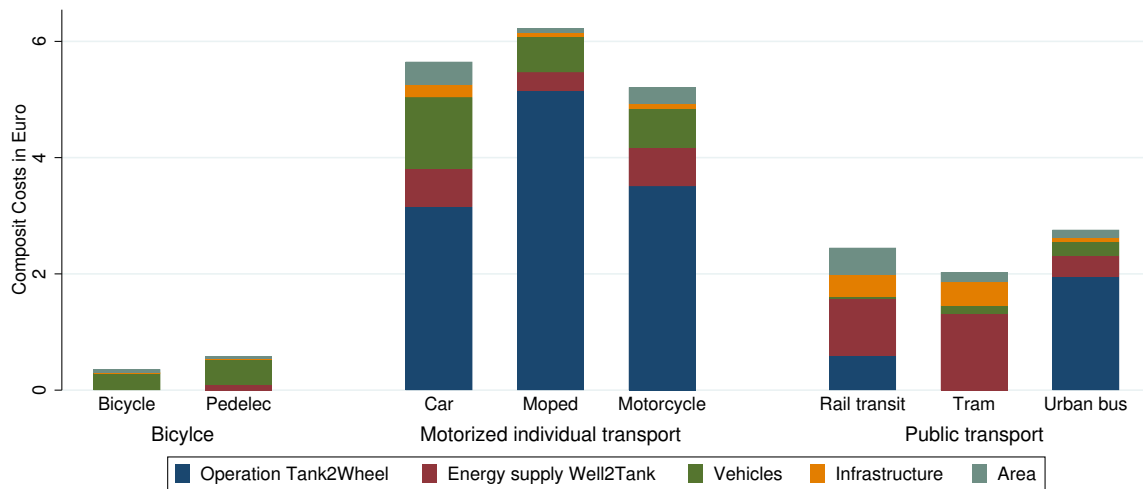
Variable	Characteristics
Mean	Daily average fuel price of unweighted mean of Diesel, E5, E10 in Euro
Diesel	Daily average fuel price of Diesel in Euro
E5	Daily average fuel price of E5 in Euro
E10	Daily average fuel price of E10 in Euro
Workday	Dummy variable, 1 indicating a day that is not Saturday nor Sunday and not a Public Holiday
Holiday	Dummy variable, 1 indicating school holidays
<i>Hourly</i>	
Rides	Hourly number of bike rides measured at a counter station
Ticket	Dummy variable, 1 indicating days with 9 € ticket
Temperature	Hourly air temperature at 2m above ground in °C
Rain	Hourly precipitation amount in mm
Wind	Hourly wind velocity ca. 10m above ground in m/s
Sunshine	Hourly sun shine duration in minutes
Revenue	Percentage change in revenue of the bicycle retail trade in comparison to 2015
Season	Seasonal time periods for winter, spring, summer, autumn
<i>Daily</i>	
Rides	Aggregated hourly number of bike rides measured at a counter station
Temperature	Daily air temperature at 2m above ground in °C
Rain	Daily precipitation amount in mm
Wind	Daily maximum wind speed at ca. 10 m above ground in m/s

Table A.5: NB Results Hourly Effect Ticket Across Samples

	(1) Full sample	(2) N Stations > 1	(3) Without Berlin
Ticket	-0.155*** (0.003)	-0.160*** (0.003)	-0.151*** (0.003)
<i>Fuel price:</i> Mean	0.486*** (0.003)	0.495*** (0.003)	0.530*** (0.004)
Marginal Effect Ticket	-20.011***	-20.636***	-19.421***
<i>Controls:</i>			
Station	Yes	Yes	Yes
Hour	Yes	Yes	Yes
Season	Yes	Yes	Yes
Weather	Yes	Yes	Yes
Workday	Yes	Yes	Yes
Holiday	Yes	Yes	Yes
Revenue	Yes	Yes	Yes
Stations	92	89	76
Observations	1,333,487	1,289,868	1,100,570

Note: Significance levels at *** $p < .001$, ** $p < .01$, * $p < .05$

Figure A.1: External Costs by Vehicle.



Data Source: Umweltbundesamt (2020), p. 236