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Ride-Hailing Services in Germany: Potential Impacts on Public Transport, Motorized Traffic, and Social Welfare

By David Ennen and Thorsten Heilker*

In the policy debate on ride-hailing services such as Uber, the impacts on traffic, emissions, and public transport are hotly discussed. The regulatory framework in Germany has so far prevented a widespread entry of ride-hailing providers. In this paper, we use a mode choice model and trip data to determine the likely impacts of ride-hailing services for a representative region in Germany. We find that the significantly lower fares compared to taxis lead to strong substitution of public transport, cycling, and walking. As a consequence, motorized traffic increases, despite the pooling of individual rides by ride-hailing providers. However, the total impact on mode choice and traffic remains modest, and a widespread displacement of public transport is not to be expected. The final welfare analysis shows that the emergence of ride-hailing services is beneficial for society as a whole. In particular, the benefits from lower fares exceed the external costs arising from additional motorized traffic.

Keywords: Ride-hailing, Transportation Network Company, TNC, Taxi, Regulation, Germany
JEL: L92, L98

I. Introduction

App-based ride-hailing services like Uber are established and widely used in countries such as the U.S. (Cramer and Krueger, 2016). In Germany, however, they play only a minor role. This is mainly due to the regulation of passenger transport in Germany. Local authorities set fares for taxi services and restrict market entry in many regions by issuing a limited number of taxi licenses. (Cetin and Deakin, 2017). Therefore, ride-hailing providers, also known as Transportation Network Companies (TNC), use private hire licenses instead of taxi licenses to offer their services. Private hire operators are not subject to price regulation, though other more restrictive rules apply compared to the taxi industry. In particular, drivers need to return to the company office after each ride in order to accept the next ride request. Uber initially did not obey this rule which was one of the reasons why their UberPop business model was finally banned after several court rulings since 2014 (DeMasi, 2016).

However, the German government plans to reform the existing passenger transportation law in order to provide a less restrictive and legally secure operating basis for the new digital mobility services. The reform plans are linked to hopes of lower prices and improved individual mobility in rural areas. However, there are also fears that traditional public transport systems could be displaced and that motorized traffic could increase substantially, thereby exacerbating congestion.

Surveys of ride-hailing users in the U.S. indicate that if these services were not

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available, a large proportion of users would have walked, cycled or taken public transport (Rayle et al., 2016; Clewlow and Mishra, 2017; Circella et al., 2018; Gehrke et al., 2018). The results of these surveys suggest that the emergence of ride-hailing services has led to an increase in motorized traffic in the U.S. (Schaller, 2018). Nevertheless, ride-hailing has in principle the potential to reduce traffic. The precondition is that a large share of individual ride requests can be pooled so that passengers mostly share a ride with other passengers. Simulation studies, such as those of the International Transport Forum (ITF) for Lisbon and Helsinki, demonstrate that ride pooling with shared taxis and larger taxi busses could potentially reduce traffic and emissions (Viegas et al., 2016; Furtado et al., 2017). However, these simulation studies typically assume that users of private motorized transport switch either completely or largely to shared mobility options without modeling their individual behavior.

The aim of this paper is to assess the impacts of ride-hailing services for a representative region in Germany. For our analysis, we develop a transport demand model to estimate the impacts of a change in mobility options on urban transport mode choice. In contrast to previous studies such as the simulation studies of the ITF, our model assumes that individuals choose the transport mode that gives them the highest utility. For the model estimation, we use data on reported trips from a mobility survey, and data on transport mode alternatives that were available for individual trips.

Using the mode choice model, we determine the impacts of ride-hailing services by simulating a decline in fares for taxi services. The simulation also takes into account a (slight) increase in travel time due to ride-pooling. The extent of the underlying fare decline is based on a cost analysis of ride-hailing services, which considers the better ride-matching technology and higher capacity utilization compared to the traditional taxi industry. Building on the cost analysis, we determine ride-hailing fares for one scenario with perfect competition between providers, and for one scenario with market power.

The results suggest a significant increase in the use of taxi-like services. We find that the additional trips largely replace those originally made by foot, bicycle or public transport, while the number of replaced car and motorcycle trips is comparatively small. As a result, ride-hailing leads to an increase in motorized traffic despite the pooling of individual rides. Nonetheless, the final welfare analysis shows that the ride-hailing services are beneficial for society as a whole, in particular because the benefits from lower fares exceed the external costs of additional motorized traffic.

The rest of this paper is organized as follows: Section II presents the methodology including the mode choice model and the calculation of ride-hailing fares and travel times. Section III describes the data sources and model variables. Section IV discusses the results of the model estimation and ride-hailing simulation. Section V concludes.

II. Methodology

A. Mode Choice Model

We model the transport mode decision of travelers with a discrete choice model. In the model, travelers choose one of the following transport mode alternatives for a trip: (1) car/motorcycle, (2) taxi, (3) public transport, (4) cycling, or

(5) walking. The utility that a traveler i (or a traveler group) obtains from using transport mode j for trip t is assumed to be given by

$$u_{ijt} = \boldsymbol{x}_{ijt}\boldsymbol{\beta} + \omega_{ijt}, \tag{1}$$

where $\boldsymbol{x}_{ijt}$ is a vector of observed mode, trip, and traveler characteristics, $\boldsymbol{\beta}$ is a vector of marginal effects of these observed characteristics on mode utility, and ω_{ijt} is unobserved utility specific to traveler i. The observable part of utility can therefore be defined as $\delta_{ijt} = \boldsymbol{x}_{ijt}\boldsymbol{\beta}$.

To account for correlation between the unobserved utility of alternatives with similar characteristics, we apply the nested-logit approach and group similar alternatives into nests. Following the exposition in Cardell (1997), the unobserved utility can then be written as

$$\omega_{ijt} = \nu_{itg}(\sigma) + (1-\sigma)\epsilon_{ijt}, \tag{2}$$

where $\nu_{itg}(\sigma)$ captures unobserved utility that is the same for all alternatives in nest g and depends on the parameter σ. The parameter σ measures the correlation between the unobserved utility of alternatives in a nest, with zero indicating no correlation and one, perfect correlation. The remaining unobserved utility ϵ_{ijt} is assumed to be identically and independently distributed.

Correlation of unobserved utility is likely between the motorized transport alternatives. People who particularly dislike physical activity or being exposed to the weather obtain higher utility from all motorized transport options. Therefore, we group all these options into one nest resulting in the two-level nested-logit structure depicted in Figure 1.

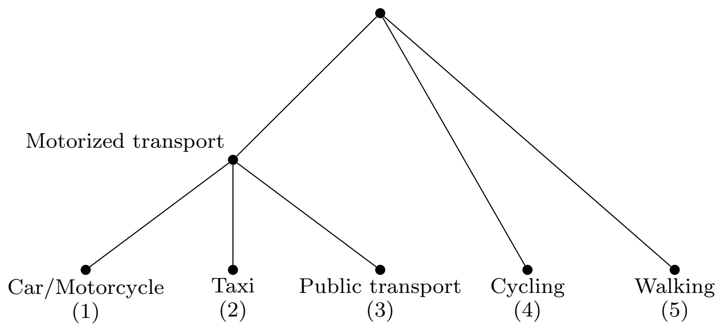

Figure 1. Nested-Logit Tree Structure

Assuming that travelers choose the transport mode that gives them the highest utility, and that ω_{ijt} follows a certain form of generalized extreme value (GEV) distribution, the standard nested-logit formula can be derived (McFadden, 1978). Thus, the predicted probability of a traveler i choosing mode j for trip t is given by

$$P_{ijt} = \frac{e^{\delta_{ijt}/(1-\sigma)}}{D_{gt}} \cdot \frac{D_{gt}^{1-\sigma}}{\left(\sum_{gt} D_{gt}^{1-\sigma}\right)}, \quad \text{where} \quad D_{gt} = \sum_{j \in g} e^{\delta_{ijt}/(1-\sigma)}. \tag{3}$$

Estimating the model using trip data and the maximum-likelihood method yields estimates of the demand parameters. The calibrated model can then be used to simulate a change of mobility options. As shown later in Section III.C, ride-hailing fares are expected to be significantly lower than regulated taxi fares. Consequently, we assume that ride-hailing services completely displace traditional taxi services in the long term. In our model, we consider this transition as a change in the taxi alternative, which is characterized by a substantial fare decline and a slight increase in travel time due to ride pooling.

The fare and travel time change affects the observed utility δ_{ijt} of the taxi alternative. Impacts on mode choice are determined by recalculating the choice probabilities for each mode and trip. Summing the probabilities for each mode then yields the expected number of trips from which we derive changes in the modal split and in traffic volumes.

B. *Ride-Hailing Fares and Travel Times*

We determine ride-hailing fares by initially calculating the costs of a typical ride. Then, using the calculated costs, we determine fares based on two different competition scenarios. In the first low-fare scenario, there is perfect competition between ride-hailing providers, which leads to low marginal cost fares. In the second high-fare scenario, providers have market power, which leads to high fares. As a benchmark for ride-hailing fares, we also determine cost-covering taxi fares.

The fare analysis distinguishes between pooled trips, for which different riders share a ride, and solo trips, with a single rider or rider group. In the following mathematical description, $j = \{\text{taxi}, \text{tnc}\}$ denotes the transport service, $o = \{\text{solo}, \text{pooled}\}$ the transport option, and $s = \{\text{low}, \text{high}\}$ the fare scenario. The operating costs for a trip with transport service j and transport option o are given by

$$c_{j,o} = d_{j,o} \cdot c_j^d + t_{j,o} \cdot c_j^t, \tag{4}$$

where $d_{j,o}$ is the trip distance in kilometers, c_j^d is the cost per vehicle kilometer, $t_{j,o}$ is the trip time in minutes, and c_j^t is the labor cost per minute. Trip distance and time also include driving distance and time to reach the passenger pickup location, as well as waiting time for the next ride request. For an operator offering only solo trips, the average trip distance and time can be calculated using the relationships

$$d_{j,solo} = \frac{d^*_{j,solo}}{\theta^d_j} \quad \text{and} \quad t_{j,solo} = \frac{t^*_{j,solo}}{\theta^t_j}, \tag{5}$$

where $d^*_{j,solo}$ is the occupied trip distance, θ^d_j is the occupancy rate based on vehicle kilometers, $t^*_{j,solo}$ is the occupied trip time, and θ^t_j is the occupancy rate based on operating time.

If a ride-hailing provider that offers only solo trips introduces ride pooling, detours become necessary for pooled trips in order to pick up and drop off all riders. Therefore, the average trip distance and time of a pooled trip can be described by

$$d_{tnc,pooled} = d_{tnc,solo} + d^+ \quad \text{and} \quad t_{tnc,pooled} = t_{tnc,solo} + t^+, \tag{6}$$

where d^+ is the additional driving distance in kilometers and t^+ is the additional trip time in minutes.

The cost per ride-hailing or taxi trip allow us to determine the cost per passenger ride. For the solo ride, the cost per ride equals the trip cost:

$$k_{j,solo} = c_{j,solo} \tag{7}$$

For the pooled ride, we have to consider that not all pooled ride requests can be pooled, so that passengers sometimes travel alone. The cost per pooled ride for a ride-hailing provider is thus given by

$$k_{tnc,pooled} = \pi \cdot \frac{c_{tnc,pooled}}{n} + (1-\pi) \cdot c_{tnc,solo}, \tag{8}$$

where π is the match rate, which is the probability that multiple ride requests can be pooled, and n is the numbers of riders sharing a ride.

Using the cost per ride, we then can calculate the fare per ride. The fare level depends on the revenue share of the dispatcher ($\lambda_{j,s}$) and on the applicable sales tax rate (τ_j):

$$f_{j,o,s} = \frac{k_{j,o}}{(1-\lambda_{j,s})} \cdot (1+\tau_j) \tag{9}$$

In the next step, we have to take into account that only some of the ride-hailing users choose the pooled ride option, while the rest prefers a solo ride. The average fare that a ride-hailing user pays is therefore given by

$$\bar{f}_{tnc,s} = (1-\rho) \cdot f_{tnc,solo,s} + \rho \cdot f_{tnc,pooled,s}, \tag{10}$$

where ρ denotes the share of pooled ride requests. For taxis, where ride pooling is not an option, the average fare paid is simply:

$$\bar{f}_{taxi} = f_{taxi,solo} \tag{11}$$

The ratio $\bar{f}_{tnc,s}/\bar{f}_{taxi}$ represents the relative fare difference between ride-hailing and taxi. To account for the fare change in our mode choice model, we multiply this ratio by the official taxi fare for a specific trip t ($Price_{taxi,t}$) to obtain the expected ride-hailing fare:

$$Price_{tnc,t,s} = Price_{taxi,t} \cdot \frac{\bar{f}_{tnc,s}}{\bar{f}_{taxi}} \tag{12}$$

The average travel time for ride-hailing services increases compared to taxis because of ride-pooling. The average travel time for a trip t is described by

$$TravelTime_{tnc,t} = TravelTime_{taxi,t} + \rho \cdot \pi \cdot t^+_{ride}, \tag{13}$$

where t^+_{ride} is the additional travel time for a ride in minutes.

III. Data

A. Main Data Sources

The data source for trips made is the survey *Mobilitt in Deutschland* (MiD) 2008. The MiD dataset contains information on trip characteristics such as the chosen transport mode or trip purpose, and on traveler characteristics such as age or occupation. For two regions in Germany, the destination coordinates of the trips were also recorded, but this additional data is only provided with the agreement of the local authorities. We have been able to obtain the geocoded dataset for the Bonn/Rhine-Sieg region, which is located in the west of Germany and consists of the city of Bonn and the surrounding Rhine-Sieg district. In total, the dataset contains information on about 32,000 trips made by a total of 10,000 people.

The city of Bonn, with its population of about 330,000, is officially defined as a core city, and the Rhine-Sieg district with a population of 600,000 as an urban district. Figure 2 illustrates the modal split for the Bonn/Rhein-Sieg (BRS) region. As can be seen, the modal split in the BRS region is similar to the average modal split in urban regions in Germany, which consist of core cities and urban districts.

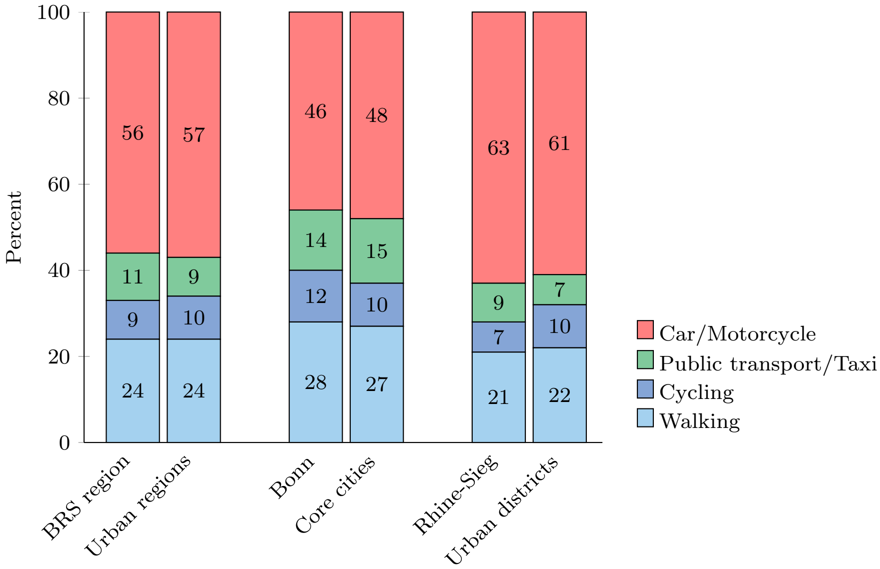

Figure 2. Modal split

With the destination coordinates from the dataset, we can determine the origin coordinates for most geocoded trips by using the chronological order of the trips and the information on which trips started at home. Together, the origin and destination coordinates enable us to determine important mode characteristics such as travel times and distances. For this reason, we limit our analysis to the Bonn/Rhine-Sieg region for which geoinformation has been recorded. Mode characteristics such as travel times and distances are obtained by querying route-planning services for each trip and transport mode alternative. For a query, we use the origin and destination coordinates of the respective trip, the arrival time, and the day of the week from the MiD dataset. Unfortunately, the route planners only allow queries for trips in the future. Therefore, we retrieve data for a representative week in 2018 without public and school holidays (19–25 November). Infrastructure improvements between 2008 and 2018 could in principal have shortened travel times, however, over that period, the spatial extent of the railway network and the federal road network remained virtually the same. Notable infrastructure improvements were limited mainly to the densification of the railway network, which involved the addition of six stations, raising the total to 131. Thus, we conclude that the retrieved travel times should approximate the actual travel times sufficiently accurately.

The route planner that we use for car, taxi, cycling, and walking is Google Maps. For public transport, we use the journey planner of the Rhine-Sieg Transport Authority (VRS). The VRS journey planner normally returns five possible journeys with different arrival times. To obtain a single value for characteristics such as travel time, we calculate average values based on the characteristics of the returned journeys.

B. Model Variables

Table 1 provides an overview of the model variables and the data sources. The variables can be categorized as mode, trip and traveler characteristics. Below we explain the principle behind each variable and describe its construction.

Table 1—Model Variables and Data Sources

Modes: Car/Motorcycle (1), Taxi (2), Public transport (3), Cycling (4), Walking (5)

Variable (Modes)	Data sources (Modes)
Mode characteristics	
Price, in Euro (1-3)	Car manufacturer prices (1), ADAC car cost calculator (1), Destatis price indexes (1), EU fuel prices (1), Official taxi fares (2), VRS journey planner (3)
Population density, in persons per sq. km. (1)	Census 2011
Travel time driver, in minutes (1)	GMaps route planner
Travel time passenger, in minutes (1-3)	GMaps route planner (1, 2), VRS journey planner (3)
Travel time cycling, in minutes (4)	GMaps route planner
Travel time walking, in minutes (5)	GMaps route planner
Number of transfers (3)	VRS journey planner
Headway, in minutes (3)	VRS journey planner
Mode constants (1)+(2)+(3)+(4)	–
Trip characteristics	
Shopping (1, 2)	MiD 2008 mobility survey
Leisure trip on weekend night (1)	MiD 2008 mobility survey
Rain/Snow (4)	MiD 2008 mobility survey
Winter (4)	MiD 2008 mobility survey
Traveler characteristics	
(Leisure avail.) x (Travel time) (1-5)	MiD 2008 mobility survey (1-5), GMaps route planner (1,2,4,5), VRS journey planner (3)
Car unavail. (1)	MiD 2008 mobility survey
(Car unavail.) x (Work/School trip) (1)	MiD 2008 mobility survey
Driver(s) older than 64 (1)	MiD 2008 mobility survey
Walking impairment (1, 2)	MiD 2008 mobility survey
Gender constants (1)+(3)+(4)	MiD 2008 mobility survey

Mode Characteristics

Mode characteristics include price, travel time and other convenience attributes. The price of private motorized transport is approximated by the marginal costs of car usage, which include kilometer-related depreciation, fuel cost, and maintenance and repair costs. We calculate car costs based on three car segments (compact, midsize, executive) and three fuel types (gasoline, diesel, autogas). For each combination of car segment and fuel type, we choose a representative car model based on the best-selling models in Germany in 2008/09.[1] Following Intraplan Consult et al. (2015), we assume for privately used vehicles, an average useful life of 12 years and that half of the depreciation is attributable to mileage. Using car manufacturer prices in 2008/09 and an average annual mileage of 15,000 kilometers, we then calculate the depreciation per vehicle kilometer for each car model and year.

Maintenance and repair costs are obtained from the car cost calculator of the General German Automobile Club (ADAC) for the 2018 versions of the chosen 2008/09 car models. To deflate the costs to 2008/09 levels, we use the price index for maintenance and repair of vehicles from the German Federal Statistical Office (Destatis). Fuel costs are calculated using monthly fuel prices from the Oil Bulletin of the European Commission, and the average fuel consumption per car segment and fuel type as reported in the MiD data. Finally, we determine an average monthly price per car kilometer by weighting the model-specific costs by the proportion of models in the total vehicle fleet. The vehicle fleet composition is derived from the MiD data for the Bonn/Rhine-Sieg region. With the price per vehicle kilometer and the retrieved trip distance by car, we then compute the trip costs per person for the car alternative, assuming a maximum of five persons per car.

The taxi fare generally depends on the taxi tariff of the respective city or district, driving distance, and standstill time in traffic. To determine the taxi fare for each trip, we use the official taxi tariffs in 2008/09 for Bonn and the Rhine-Sieg district, the retrieved trip distance by car, and assume that one third of the retrieved travel time by car is standstill time. The proportionate fare per person is then the taxi price, here assuming a maximum of four persons per taxi.

The public transport price is the average price per person for the travelers. We assume that travelers with a season pass, as reported in the MiD data, do not need an extra ticket, while all others have to purchase a single ticket. The fare for a single ticket is determined using the VRS public transport tariffs in 2008/09, the tariff level obtained from the VRS journey planner, and the age of the person (child or adult).

Additional costs of a car ride are parking fees or search costs incurred to find a free parking space. Particularly in city centers, many parking spaces are subject to charges, and free parking spaces are usually hard to find. Therefore, we follow Train (1980) and include as a proxy for parking costs the average population density at the origin and destination of the trip for the car alternative. The population data used is grid cell data with a spatial resolution of one kilometer, and is taken from the Census 2011, which is provided by the German Federal and State Statistical Offices.

[1] The chosen representative car models for gasoline/autogas are: Volkswagen Polo IV/V 1.2 (compact), Volkswagen Golf V 1.4 (midsize), BMW 316i (executive); and for diesel: Volkswagen Polo IV/V 1.4 TDI (compact), Volkswagen Golf V 1.9 TDI (midsize), BMW 318d (executive).

Besides price, travel time is another important determinant of transport mode choice. The valuation of travel time savings typically differs between transport modes (Wardman et al., 2016). Therefore, we distinguish between four different types of travel time in our model: time as a driver of a motorized vehicle, time as a passenger in a motorized vehicle (including public busses and trains), cycling time, and walking time.

When using public transport, additional inconveniences arise from transfers between individual lines and a low service frequency, which results in longer waiting times. Thus, we include as additional variables for public transport, the number of transfers and the headway, which is defined as the average time interval between service. Data on both variables are retrieved from the VRS journey planner. Lastly, to account for unobserved mode characteristics such as the privacy offered by a car or the average waiting time for a taxi, we include mode dummy variables.

Trip Characteristics

Trip characteristics include the trip purpose and the circumstances of the trip, such as prevailing weather conditions. Shopping trips typically require additional storage for the purchased goods, which makes traveling by car more attractive. Therefore, we include a dummy variable for shopping trips for the car and taxi alternatives. Another trip purpose that may affect mode choice is visiting night clubs, bars or parties, where alcohol is involved. For these trips, the private car is a significantly less suitable transport mode. Thus, we construct a dummy variable indicating leisure trips between 10:00 pm and 6:00 am on Friday and Saturday nights, and include this variable for the car alternative.

Rain, snow, and cold temperatures influence the choice between weather-protected and weather-unprotected means of transport. Cycling is particularly affected by bad weather. To capture this effect, we include a dummy variable that indicates rain or snow on the day of the trip, as reported in the MiD data, and a dummy variable that indicates whether the trip occurred in the winter months between November and March.

Traveler Characteristics

Mode choice is also influenced by traveler characteristics such as individual opportunity costs of time, access to cars, and mobility impairments. Opportunity costs of time are higher for those working full-time than for those with more leisure time, such as pupils. To account for the fact that the opportunity costs of time depend on occupation, we include an interaction term consisting of the travel time variable and a variable that indicates the share of travelers with substantial leisure time. People who are assumed to have a lot of leisure time include children, students, retirees, and unemployed. In addition, we also assume that part-time workers, temporarily released workers, and housemen/housewomen belong to the group as those with a lot of leisure time if there are no young or school-aged children in the household.

A car is not always available if shared with others in the household. Therefore, as a measure of car availability we calculate for each household the number of cars per driver license holder. The measure is capped at a maximum of one, where one indicates that a car should always be available for a trip. The variable for car unavailability that we include in our model is then one minus the car availability measure. If people share a car in a household, conflicts between different trip plans are more likely the longer the car is needed. A car is needed for a particularly long period for trips to work or school. Thus, we include an interaction term consisting of the car unavailability variable and a dummy variable for work/school trips.

Mobility impairments render the usage of specific modes more desirable. Older people tend to have more problems with seeing and hearing, which makes the car a less attractive alternative. We capture this relationship by including a dummy variable, which is one if all potential car drivers of the group of travelers are older than 64 and zero otherwise. On the other hand, walking impairments make the car or taxi more attractive. Therefore, we include the share of travelers with walking impairments for the car and taxi alternative. Lastly, gender dummy variables are included for car, public transport, and cycling.

Availability of Transport Modes

Not all transport modes are available to all travelers and on all trips. We exclude the car/motorcycle alternative if both car and motorcycle are not options. In both cases, depending on the size of the traveler group, sufficient vehicles and driving license holders are required. For car, we again assume a maximum seating capacity of five, and for motorcycle, a maximum of two. Car is thus not an option if (i) not enough people have the required age for driving cars (18 years), (ii) not enough have car driving licenses, (iii) there are not enough cars in the household, or (iv) not enough people have access to the cars in the household.[2] Motorcycle is not an option if (i) not enough people have the required age for driving at least a small motorcycle (15 years), (ii) not enough have motorcycle driving licenses, or (iii) there are not enough motorcycles in the household. Furthermore, we exclude the cycling option if there are not enough bicycles in the household.

Data Restrictions

The trip data contains trips for which the transport mode is basically not a free choice. This applies to regular work trips, which include trips of taxi drivers, deliverers, or craftspersons, and are therefore excluded. In addition, we remove trips with no purpose of changing the location. These are roundtrips and those with a purely recreational purpose (going for a walk, for a run, or with the dog).

The trip data may also contain erroneous information from survey participants or data entry errors. Therefore, as a cross check, we compare the reported trip distance with that obtained from route planners and delete observations if the two distances deviate too much from each other. In particular, a trip is excluded if (i) one distance is more than twice as large as the other, (ii) the two distances deviate by more than 10 kilometers from each other in the case of a motorized trip, or (iii) the two distances deviate by more than two kilometers from each other in the case of a walking or cycling trip.

C. *Ride-Hailing Fares and Travel Times*

The data used to calculate ride-hailing fares and travel times are from different sources. Table 2 shows the source for each parameter and the resulting parameter values.

[2] We use both age and driving license ownership as exclusion criteria, as information on both is not available for all individuals.

Table 2—Parameters for Calculation of Fares and Travel Times

Parameter		Value	Sources and remarks
c^d_{tnc}	Cost per km, TNC (€)	0.379	Calculation and sources in Appendix
c^d_{taxi}	Cost per km, taxi (€)	0.385	Calculation and sources in Appendix
c^t_{tnc}	Cost per minute, TNC (€)	0.125	Linne+Krause (2008)
c^t_{taxi}	Cost per minute, taxi (€)	0.125	Linne+Krause (2008)
d^*_{solo}	Occupied distance, solo trip (km)	5	Statistical Office for HH-SH (2017)
d^+	Additional distance, pooled trip (km)	2	Assumed
t^*_{solo}	Occupied time, solo trip (min.)	15	Statistical Office for HH-SH (2017)
t^+	Additional time, pooled trip (min.)	6	Assumed
t^+_{ride}	Additional time per ride, pooled trip (min.)	3	Assumed
n	Number of riders, pooled trip	2	Huett (2015)
θ^d_{tnc}	Occupancy rate based on distance, TNC (%)	60	Cramer and Krueger (2016)
θ^d_{taxi}	Occupancy rate based on distance, taxi (%)	46	Statistical Office for HH-SH (2017)
θ^t_{tnc}	Occupancy rate based on time, TNC (%)	50	Cramer and Krueger (2016)
θ^t_{taxi}	Occupancy rate based on time, taxi (%)	28	Statistical Office for HH-SH (2017)
π	Match rate (%)	60	Hawkins (2018), Huett (2015)
$\lambda_{tnc,low}$	Revenue share dispatcher, TNC, low scenario (%)	3	BZP (2010)
$\lambda_{tnc,high}$	Revenue share dispatcher, TNC, high scenario (%)	25	Fee quoted by Uber
λ_{taxi}	Revenue share dispatcher, taxi (%)	3	BZP (2010)
τ_{tnc}	Sales tax rate, TNC (%)	7	Sales tax rate for taxi in Germany
τ_{taxi}	Sales tax rate, taxi (%)	7	Sales tax rate for taxi in Germany
ρ	Pooling share (%)	40	McGee (2017)

Vehicle costs per kilometer are computed based on the cost calculation of the German Taxi and Private Hire Car Association for a single-car taxi company (BZP, 2010). In contrast to taxi costs, ride-hailing costs do not include those for taxi meter, radio set, roof sign, and taxi meter calibration. For some cost components, we use different data sources or assumptions than BZP (2010). Details are provided in the Appendix.

Labor costs per hour are derived from the taxi report for the Rhine-Sieg district in 2008 (Linne+Krause, 2008). For the average single-car taxi company, Linne+Krause (2008) reports an annual profit of €22,780, annual personnel expenses of €13,774, and an annual operating time of 4,867 hours. Summing profit and personnel expenses and dividing by operating hours yields an average compensation of €7.51 per hour (€0.125 per minute) for the taxi-driving company owner and hired (part-time) employees.

The trip distances and times represent a typical taxi ride. The 2016 taxi report for the city of Hamburg states an average trip distance of 6.6 kilometers and an average trip time of 14.7 minutes (Statistical Office for Hamburg and Schleswig-Holstein, 2017). The numbers are based on taxi meter data from 70% of the taxis in Hamburg. For simplicity, we assume a trip distance of five kilometers and a trip time of 15 minutes. For the pooled ride-hailing trip, we assume two parties sharing a ride, a detour of two kilometers, a detour time of four minutes, and two additional minutes for the additional pickup and drop-off. The additional travel time per passenger is therefore three minutes. We do not consider the option of more than two parties sharing a ride, for two reasons: (i) The passenger capacity of standard cars is limited, since they cannot accommodate more than two parties of two riders each. (ii) Matching three or more parties with similar directions at a similar time is difficult. Even in cities such as San Francisco, where the proportion of shared rides is highest, Lyft reports that only 20% of its shared rides are triple matches (Huett, 2015).

The occupancy levels for taxi are from the 2016 taxi report for the city of Hamburg. The occupancy levels for ride-hailing are based on Uber data from Cramer and Krueger (2016). For large U.S. cities, Cramer and Krueger report occupancy times of between 46% and 54%, and occupancy kilometers of between 55% and 64%. Note that these figures refer to periods in which UberPool was either not yet available in the respective city or was launched only recently. The match rate that we assume is based on statements from Uber and Lyft. Uber states a match rate of 60% for UberPool and Lyft claims that it matches the far majority of shared-ride requests (Hawkins, 2018; Huett, 2015).

In the low-fare scenario, with perfect competition between ride-hailing providers, the revenue share for dispatching equals the marginal costs for this service. In the taxi cost calculation of BZP (2010), the fee for membership in the cooperative taxi dispatch agency corresponds to about 3% of annual revenue. Therefore, we assume for cost-based pricing, that both ride-hailing and taxi companies have to spend a share of 3% of their revenue on the dispatching service. For the high-fare scenario, where ride-hailing providers have market power, we assume a revenue share of 25% for the dispatching service, based on the commission quoted by Uber. Note that Uber grants its customers many discounts, so that the fare and commission fee are effectively lower.

The sales tax that taxi companies pay in Germany is 7%. In contrast, private hire operators a subject to the full sales tax of 19%. We assume that the regulatory change involves an equalization of tax rates, so that private hire operators also pay the reduced sales tax of 7%. The assumed pooling share of 40% is based on statements from Uber and Lyft. Lyft states 40% shared ride requests in cities where this service is available (McGee, 2017).

The resulting fares and costs for the typical taxi ride are shown in Table 3. The taxi fare of €12.0, which is necessary to cover costs, basically equals the fare according to the official taxi tariff of the Rhine-Sieg district of €11.6.[3] For ride-hailing, we obtain a fare decline of 42% compared to taxis in the low-fare scenario and a decline of 26% in the high-fare scenario.

IV. Results

A. Model Estimates

The estimated model parameters are shown in Table 4. All parameters have the expected signs and most parameters are significantly different from zero. Before discussing the results in detail, we assess the explanatory power of the model. With 76% accuracy, the model predicts the mode choice correctly for the majority of trips. Furthermore, the McFadden R^2 of 0.63 indicates good explanatory power. According to McFadden (1979), values of 0.4 already represent excellent fit.

The estimation results show, as expected, that the price for using a transport mode negatively affects the choice of that mode. In addition, the results provide evidence that people derive lower utility from a car trip, if it begins or ends in a densely populated area, presumably because of high parking (search) costs. The

[3] For calculating the official fare, we assume that one third of the travel time is waiting time in traffic.

TABLE 3—COSTS AND FARES FOR RIDE-HAILING AND TAXI RIDES

	Taxi (solo)	TNC (solo)		TNC (pooled)	
Cost per trip (€)	10.9	6.9		8.4	
Cost per ride (€)	10.9	6.9		5.3	
	Taxi (solo)	TNC (solo)		TNC (pooled)	
		low	high	low	high
Fare per ride (€)	12.0	7.6	9.9	5.8	7.5
	Taxi (solo)	TNC (solo + pooled)			
		low		high	
Average paid fare (€)	12.0	6.9		8.9	
Fare difference to taxi (%)	–	−42		−26	

TABLE 4—MODEL PARAMETER ESTIMATES

Modes: Car/Motorcycle (1), Taxi (2), Public transport (3), Cycling (4), Walking (5)

Variable (applies to modes in parentheses)	Coefficient	Standard error
Mode characteristics		
Price (1-3)	−0.392**	0.030
Population density (1)	−0.177**	0.013
Travel time driver (1)	−0.035**	0.006
Travel time passenger (1-3)	−0.020**	0.003
Travel time cycling (4)	−0.137**	0.006
Travel time walking (5)	−0.126**	0.003
Number of transfers (3)	−0.028	0.076
Headway (3)	−0.003*	0.002
Mode constants (baseline: walking)		
Car/Motorcycle (1)	−0.347**	0.075
Taxi (2)	−4.103**	0.223
Public transport (3)	−2.793**	0.102
Cycling (4)	−1.499**	0.079
Nested logit parameter (motorized) (1-3)	0.195**	0.032
Trip characteristics		
Shopping (1, 2)	0.304**	0.058
Leisure trip on weekend night (1)	−0.110	0.231
Rain/Snow (4)	−0.706**	0.120
Winter (4)	−0.803**	0.074
Traveler characteristics		
Car unavail. (1)	−1.090**	0.138
(Car unavail.) x (Work/School trip) (1)	−2.172**	0.243
(Leisure avail.) x (Travel time) (1-5)	0.017**	0.002
Driver(s) older than 64 (1)	−0.398**	0.072
Walking impairment (1, 2)	0.574**	0.148
Gender constants (female=0, male=1)		
Car/Motorcycle (1)	0.003	0.073
Public transport (3)	−0.305**	0.092
Cycling (4)	0.117	0.086

Notes: * Significant at the 5% level, ** Significant at the 1% level.

coefficients of the travel time variables indicate that the inconvenience of travel time differs significantly by transport mode. The negative impact on mode choice is higher for the physically active modes of cycling and walking, than for motorized transport. The impact also differs significantly between drivers and passengers of motorized vehicles. The larger coefficient in absolute terms for travel time as a driver may be explained by the fact that driving can be stressful, particularly in heavy traffic, and that the in-vehicle time cannot be used productively.

The price and travel time coefficients allow us to derive the average willingness to pay (WTP) for travel time savings. The WTP is calculated as $WTP = \beta_{\text{TravelTime}}/\beta_{\text{Price}}$. We obtain a WTP for a reduction in travel time as a driver of €5.32 per hour and and as a passenger of €3.11 per hour. This is largely in line with the methodology for evaluating transport infrastructure projects in Germany which specifies for the base year 2012, a time value of €4.81 per hour for private trips of 15 kilometers (Intraplan Consult et al., 2015).

Furthermore, the estimation results show that a high headway (low service frequency) represents an additional inconvenience of using public transport. This finding can be explained by longer waiting times at the initial stop or station. The impact of the number of transfers is, however, not found to be significant, although it is negative.

The trip variables indicate that taking a private car or taxi is associated with additional utility for shopping trips. On the other hand, people are not less likely to choose the car for leisure trips on weekend nights. Rainy and cold weather indeed reduce the probability of cycling, as the negative coefficients of the weather and winter variables indicate.

The traveler variables show that limited car availability in a household has a negative impact on car use. The effect is particularly strong for work or school trips, for which the car is typically not available to other household members for a longer period of time. As expected, the disutility of travel time is lower for people with more leisure time, such as children. Mobility impairments are also found to affect mode choice. All other things being equal, people older than 64 are less likely to take the car and those with walking problems are more likely to take the car or taxi. Gender appears to play a subordinate role in transport mode choice, with the gender constants for car/motorcycle and cycling being indifferent from zero. However, the significant gender constant for public transport suggests that women have a stronger preference for public transport than men.

B. Mode Choice and Motorized Traffic

The estimated mode choice model is used to predict the impact of a widespread entry of ride-hailing platforms. Based on the fare and travel time changes calculated in Section III.C, we simulate a price decline of taxi services and a (slight) increase in average travel times due to ride-pooling. Thereby, we effectively assume that the traditional taxi industry is completely displaced by less expensive ride-hailing services.

Table 5 shows the original modal split in the first column. About 60 percent of the trips are taken by car or motorcycle, 17 percent by foot, 13 percent by public transport, and 10 percent by bicycle. The modal share of taxis is relatively small, at only 0.26 percent of all trips in the Bonn/Rhine-Sieg region. Note that the modal split differs slightly from the official values, because of our different trip definition. In particular, the modal share of walking is lower as we exclude trips with no aim of changing the location, like recreational walks. The predicted impact of ride-hailing services on the modal split is displayed in the second and third columns of Table 5. The lower prices of ride-hailing services lead to a significant increase in the modal share of taxi-like services. The modal share rises from 0.26 to 0.64 percent in the low-fare scenario, and to 0.44 percent in the high-fare scenario. This translates to a relative growth of 147 percent and 70 percent. For comparison, in New York City, the number of taxi and ride-hailing trips grew by 101 percent in the eight years after the launch of Uber in March 2011 (New York City Taxi and Limousine Commission, 2019).

Table 5—Predicted Modal Shift

	Original modal share (%)	Change absolute (%)		Change relative (%)	
		low	high	low	high
Car/Motorcycle	59.71	−0.10	−0.05	−0.16	−0.08
Taxi/Ride-hailing	0.26	+0.38	+0.18	+146.86	+70.12
Public transport	12.87	−0.15	−0.07	−1.16	−0.53
Cycling	9.69	−0.06	−0.03	−0.67	−0.31
Walking	17.47	−0.07	−0.04	−0.39	−0.22

The growth of the modal share of taxi-like services results in a corresponding reduction in the modal shares of other transport modes. However, with a predicted modal share of ride-hailing of less than one percent, the impact on established transport modes remains modest. The largest change can be observed in public transport with a decline in passenger numbers of between 0.53 and 1.16 percent. But given the small magnitude of passenger decline, a widespread displacement of traditional public transport appears unlikely.

To analyze the mode substitution in more detail, Table 6 displays the number of substituted trips relative to the number of all additional trips with taxi-like services. As can be seen from the first two columns, the results differ only slightly between the two fare scenarios. Most additional rides replace public transport trips with a share of around 38 percent. Trips previously made by bicycle or by foot, each account for about 18 percent of the additional rides. By contrast, only about 25 percent of the additional rides replace motorized transport with private vehicles.

Table 6—Predicted Mode Substitution

<table>
<tr><th rowspan="3"></th><th colspan="6">Substituted trips (%)</th></tr>
<tr><th colspan="2">Predicted</th><th colspan="4">Reported in U.S. surveys</th></tr>
<tr><th>low</th><th>high</th><th>Clewlow and Mishra (2017)</th><th>Gehrke et al. (2018)</th><th>Circella et al. (2018)</th><th>Henao (2017)</th></tr>
<tr><td>Car/Motorcycle</td><td>26</td><td>25</td><td>50</td><td>25</td><td>14</td><td>49</td></tr>
<tr><td>Public transport</td><td>39</td><td>37</td><td>19</td><td>58</td><td>66</td><td>33</td></tr>
<tr><td>Cycling</td><td>17</td><td>17</td><td>9</td><td rowspan="2">17</td><td>4</td><td rowspan="2">18</td></tr>
<tr><td>Walking</td><td>18</td><td>21</td><td>22</td><td>16</td></tr>
<tr><td>Region</td><td colspan="2">Bonn/ Rhine-Sieg</td><td>7 U.S. metro areas</td><td>Boston</td><td>San Francisco</td><td>Denver</td></tr>
</table>

For comparison, Table 6 also shows the mode substitution that can be derived from surveys of ride-hailing users in the U.S. In these surveys, people were asked which transport mode they would have used if ride-hailing services were not available. A comparison with our results reveals that the substitution of public transport appears to be stronger in San Francisco and in Boston than in the Bonn/Rhine-Sieg region. This finding can be explained by the high use of public transport in these two large U.S. cities. In the Bonn/Rhine-Sieg region, which encompasses the less densely populated Rhine-Sieg district, car use is much more prevalent. By contrast, in U.S. regions with lower public transport usage, the substitution of private car and motorcycle use is significantly more pronounced than in the Bonn/Rhine-Sieg region. This seems to apply to the city of Denver and entire U.S. metropolitan areas, which cover a far larger area surrounding a core city.

Whether ride-hailing services increase or decrease motorized traffic depends on two opposing effects. One the one hand, the substitution of public transport, cycling, and walking with ride-hailing, strictly increases motorized traffic (assuming that public transport service is not reduced). On the other hand, ride-hailing also replaces taxi and private car trips, which may decrease motorized traffic, if a better ride-matching technology and ride-pooling increase vehicle utilization sufficiently. Table 7 shows the predicted change in motorized vehicle kilometers in relation to the total motorized vehicle kilometers that ride-hailing replaces. The substitution of car/motorcycle trips is found to increase motorized traffic. The switch to ride-hailing services makes pick-up trips necessary, which causes additional vehicle kilometers. The pooling of individual rides apparently cannot compensate for this effect. In contrast, the replacement of taxi trips with ride-hailing reduces motorized traffic. The better ride-matching technology of ride-hailing providers and the use of ride pooling reduce unoccupied vehicle kilometers and increase vehicle utilization. However, the traffic growth from replacing walking, cycling, and public transport trips exceeds the traffic reduction from replacing taxi trips. Therefore, in total, ride-hailing is found to increase motorized traffic. Each vehicle kilometer replaced by ride-hailing results, on average, in 1.23 to 1.79 additional vehicle kilometers.

Table 7—Predicted Change in Motorized Vehicle Kilometers

	Vehicle kilometers as percentage of total replaced vkm					
	Replaced		Added by ride-hailing		Net change	
Original mode	low	high	low	high	low	high
Car/Motorcycle	14	6	22	10	+8	+4
Taxi	86	94	60	65	−26	−29
Other modes	0	0	97	48	+97	+48
All modes	100	100	179	123	+79	+23

C. Benefits and Costs

The increase in motorized vehicle kilometers causes additional external costs such as congestion or environmental costs. But at the same time, the decline in fares raises consumer surplus. The welfare analysis in this section assesses the benefits and costs of ride-hailing services and determines whether a welfare gain arises for society as a whole.

In order to calculate the additional external costs, we use the marginal external costs per vehicle kilometer shown in Table 8. These values for 2008 are from Delft et al. (2011) for urban daytime conditions and high climate costs (146 €/tonne CO_2). The marginal external costs without congestion amount to € 0.13 per car kilometer, and consist of accident, climate, air pollution, noise, and up and downstream costs. The external congestion costs amount to €0.33 per car kilometer at maximum and are assumed to occur only in peak periods. Based on the trip time distribution in the MID dataset, we define the peak period weekdays from 7.00 to 9.30 a.m. and from 3.30 to 7.00 p.m.

Table 8—Parameters for Calculation of External Costs

Parameter	Value	Source
External costs in off-peak (€/vkm)	0.13	CE Delft et. al (2011)
External costs in peak (€/vkm)	0.46	CE Delft et. al (2011)
Peak period	Weekdays, 7.00−9.30 a.m., 3.30−7.00 p.m.	Trip time distribution in MiD 2008 mobility survey

To determine the gain in consumer surplus of new users of taxi-like services, we apply the so-called 'rule of a half'. This rule assumes that the demand function is approximately linear between the old and the new equilibrium. Under this assumption, the average surplus gain accruing to a new consumer after a price reduction is exactly half the price reduction. By contrast, the surplus gain of an existing consumer equals the full price reduction.

Figure 3 illustrates the welfare effects for each transport mode and for both fare scenarios. The welfare effects, both positive and negative, tend to be larger in the low-fare scenario, because lower fares lead to more mode substitution and a higher consumer surplus gain. The substitution of car/motorcycle rides in itself reduces external costs (ΔC_{Ext}), which has a positive effect on welfare. In addition, the decline in private car and motorcycle use leads to a reduction in energy and sales tax (ΔT), which in itself must be regarded as a negative welfare effect. The same applies to the loss in ticket revenue (ΔR) and the corresponding sales tax revenue in public transport. The largest welfare effects can be observed in ride-hailing use. The additional external costs that arise from an increase in vehicle kilometers can be more than offset by several welfare gains. On the one hand, there are additional tax revenues in the form of fuel and sales tax. On the other hand, there are gains in consumer surplus from lower prices, which include gains for people who have used taxis before (ΔCS_O) and for people switching from other transport modes (ΔCS_N). In the high-fare scenario, where ride-hailing providers have market power, there is an additional welfare effect. The market power of ride-hailing providers allows charging fares above marginal costs, resulting in profits (Π) which have to be considered a welfare gain.

Overall, in both scenarios the total welfare effect is positive, as the private benefits significantly exceed the social costs. The welfare gain for each ride-hailing trip and person is, on average, €0.81 in the low-fare scenario and €1.30 in the high-fare scenario. That the welfare gain is larger with market power in the high-fare scenario than with perfect competition in the low-fare scenario can be explained by the external costs of motorized transport, which are not fully internalized by fuel and sales taxes. Therefore, with marginal private costs below marginal social costs, the higher fare in the market-power scenario results in a traffic volume closer to the social optimum. It should be noted, however, that the introduction of an efficient road charge, differentiated by time of day and driving distance, could achieve the social optimum under perfect competition in the ride-hailing market.

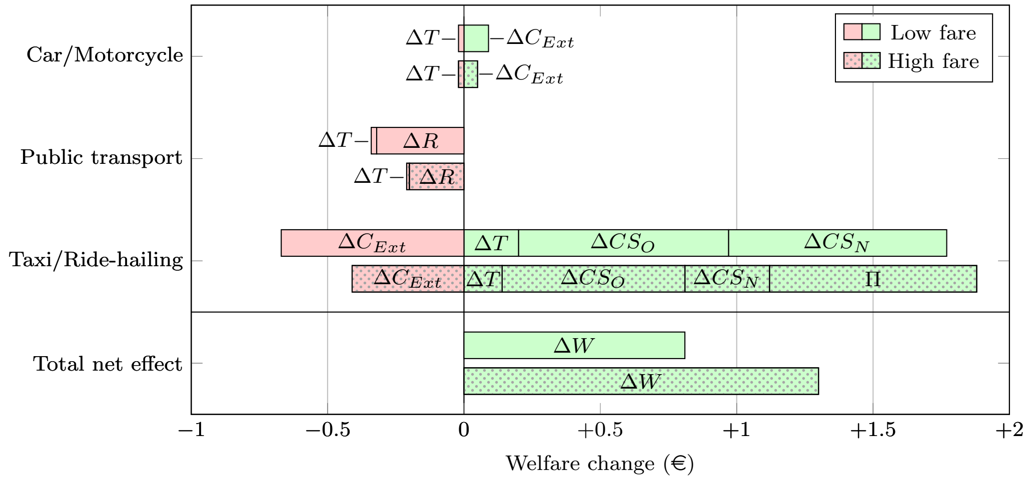

Figure 3. Welfare Change per Ride-Hailing Trip and Person

V. Conclusions

In the policy debate on ride-hailing services, opponents argue that ride-hailing leads to increased traffic and emissions, and displaces traditional public transport. In contrast, proponents claim that ride-hailing avoids traffic and emissions by pooling individual rides and by more effectively matching drivers and riders in comparison to taxi companies. This paper uses a mode choice model to assess the expected impacts of ride-hailing services for Germany, where the restrictive regulatory framework has so far prevented a widespread entry of these services.

In our analysis for the Bonn/Rhine-Sieg region, we find that the lower fares compared to taxis result in strong substitution of trips previously done by foot, bicycle or public transport. In contrast, the number of replaced car and motorcycle trips is comparatively small. However, the determined ride-hailing fares are still significantly higher than private car costs and public transport fares. Therefore, the total impact of ride-hailing on mode choice is modest and a widespread displacement of public transport is not to be expected.

The results also show that the substitution of non-motorized transport modes leads to an increase in motorized traffic volumes. The pooling of rides and the higher vehicle utilization than taxis cannot compensate for this effect. Consequently, ride-hailing services do not provide a solution to urban congestion problems.

The final cost-benefit analysis reveals that a widespread market entry of ride-hailing services in Germany is associated with a societal welfare gain. The gain in consumer surplus due to lower fares exceeds the additional external costs of transport such as congestion, air pollution, noise, and climate change. Therefore, the planned reform of the German passenger transport law (PBefG) is desirable from a societal perspective. We note, however, that the external costs of ride-hailing services could in principal be internalized, for example by a mileage-based toll, and therefore do not constitute a general argument against these services.

A limit of our modeling approach is that we take the decisions for car and public transport pass ownership as given. This approach can be justified by the fact that these decisions depend heavily on regular trips, for example to work or school, and that covering these trips exclusively with ride-hailing services would be a relatively expensive and unattractive alternative. Nevertheless, future analyses of the impacts or ride-hailing services could incorporate decisions for car and public transport pass ownership.

Appendix

Ride-Hailing and Taxi Vehicle Operating Costs

Ride-hailing and taxi vehicle operating costs are calculated based on the cost calculation of the German Taxi and Private Hire Car Association for a single-car taxi company (BZP, 2010). In comparison to taxi costs, ride-hailing costs do not include those for taxi meter, radio set, roof sign, and taxi meter calibration. For some costs, we use different data sources or assumptions than BZP (2010). Fuel prices are obtained from the Oil Bulletin of the European Commission. Maintenance and repair costs are determined using the car cost calculator of the General German Automobile Club (ADAC). We use the price index for maintenance and repair of vehicles from the German Federal Statistical Office (Destatis) to deflate the costs to 2008 levels. For liability and comprehensive car insurance, we assume that the average driver enjoys a 50% no-claims discount in contrast to BZP (2010), who assume no discount. The average garage rent in the Bonn/Rhine-Sieg region is obtained from the Bonn Rent Index 2011.

Table 9 summarizes the calculation and data sources of the individual cost components and shows the resulting costs per vehicle kilometer.

Table 9—: Ride-Hailing and Taxi Costs per Vehicle Kilometer

Costs	TNC	Taxi	Source and remarks
Depreciation			
Car purchase price (€)	28,283	29,411	BZP (2010), Mercedes-Benz E 200 CDI, TNC vehicle w/o taxi meter, radio set, and roof sign
Depreciation period (years)	6	6	BZP (2010)
Kilometers per year	40,000	40,000	BZP (2010)
Depreciation per km (€)	0.118	0.123	
Fuel			
Diesel consumption (liter/100km)	8.6	8.6	Urban fuel consumption of Mercedes-Benz E 200 CDI, European driving cycle
Diesel price per liter (€)	1.119	1.119	Oil Bulletin of European Commission
Fuel cost per km (€)	0.096	0.096	
Maintenance and repair (M&R)			
M&R cost per year ($€_{2018}$)	1,798	1,798	ADAC car cost calculator
M&R cost per year (€)	1,394	1,394	Deflated using price index for maintenance and repair of vehicles from Destatis
M&R cost per km (€)	0.035	0.035	
Insurance			
Liability ins. per year (€)	1,695	1,695	BZP (2010), 50% no-claims discount assumed
Comprehensive ins. per year (€)	1,158	1,158	BZP (2010), 50% no-claims discount assumed
Occup. accident ins. per year (€)	368	368	BZP (2010)
Legal expenses ins. per year (€)	183	183	BZP (2010)
Insurance cost per km (€)	0.085	0.085	

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Costs	TNC	Taxi	Source and remarks
Vehicle tax			
Vehicle tax per year (€)	340	340	BZP (2010)
Vehicle tax per km (€)	0.008	0.008	
Financing			
Financing rate (%)	0.99	0.99	BZP (2010)
Financing cost per year (€)	143	148	
Financing cost per km (€)	0.004	0.004	
Other costs			
Cleaning cost per year (€)	409	409	BZP (2010)
Garage rent per year (€)	480	480	Bonn Rent Index 2011
Taxi meter calibration fee per year (€)	0	53	BZP (2010)
Phone costs per year (€)	420	420	BZP (2010)
Other costs per km (€)	0.033	0.034	
Total costs			
Total costs per km (€)	0.379	0.385	

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