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On-Street vs. Off-Street Parking: An Urban Economic Analysis

VON ANNA STRAUBINGER, STEFAN TSCHARAKTSCHIEW UND GEORG HIRTE

Abstract

On-street parking is suggested to be associated with congestion due to cruising for parking. Against this background, we examine a full switch from on-street parking to off-street by means of a spatial urban CGE model. Hereby, we model cruising for parking, on-street and off-street parking together with location decisions, land and labor markets. We consider different funding schemes for infrastructure: lump-sum taxation, congestion tolls and parking fees. We find that prohibiting on-street parking generates a positive social net benefit if it is financed by the urban society as whole (lump-sum), and not by car users alone. Further, urban welfare declines in any case due to the effects on the land markets. This may help to explain why local policymakers are reluctant to foster off-street parking. In all cases, distributional effects are substantial with landowners being the main beneficiary of the measure.

1 Introduction

Increasing transport demand poses various problems for many European cities. Congestion in the surroundings of the urban region is calculated to cause losses of 100 billion Euro, respectively 1% of the European gross domestic product (GDP). For this reason, a reduction of congestion, accidents and pollution is supposed to increase the attractiveness of urban mobility for users and non-users. (EUROPEAN COMMISSION, 2017).

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The majority of these problems arise from motorized private transport but, surprisingly, parking issues play a subordinate role even though an average car is parked 23 hours a day (SHOUP, 2011, p. 621) and, as a consequence, takes up a lot of space without being used. Furthermore, the market for parking is subject to different disruptions. In the USA up to 99% of parking is free of charge (SHOUP, 2011, p. 621) and all over the world the price for parking is usually very low. But how can that be? After all, whoever owns the land could earn money if it were used for other purposes.

A major part of public parking space is on the curb and free of charge for the user. Yet even off-street parking often is at zero cost. DELUCCHI (1997) shows that only 1 % to 4 % of costs for parking are paid by parking fees, while the rest is funded via subsidies or cross-subsidization. These cost is financed by public budgets, shops and offices, house owners or the employers but eventually leads to rising taxes, good prices and rents or lower wages. In all cases, private households pay the land for parking but not necessarily those who use off-street parking (SHOUP, 2011). Additional costs arise because the jurisdictions impose heavy regulation on off-street parking to avoid land-use for on-street parking (LEHE, 2017). In the case of employer paid parking, even tax revenue might be negatively affected as employers offer lower wages (which are taxed) in exchange for the provision of free parking at the workplace (VAN OMMEREN and WENTINK, 2012). These effects decline the relative price of private car use much below the social costs and, thus, imposes inefficiencies in the transport markets. For these reasons, an economic consideration of parking considering interdependencies between public budgets, transport, land-use and economic decisions is essential.

The literature not only considers parking in general but also addresses the problem of cruising for parking. SHOUP (2006) shows that up to 30% of urban traffic result from searching for parking. The marginal costs of cruising for parking may have the same magnitude as the external costs of congestion. Nevertheless, they often stay unconsidered even though an efficient parking policy can minimize the deadweight loss resulting from it (INCI ET AL., 2017). Anderson and de PALMA (2004) and INCI (2015) emphasize the common property characteristics of parking (tragedy of commons) and the excess demand arising from it[1]. They state that in a case with congestion due to searching for parking monopolistic pricing of garage owners can lead to an optimal allocation. PIERCE et al. (2015) propose to vary parking garage fees according to the demand to achieve an optimal solution. Two types of parking – on-street and off-street – are examined by CATHROP and

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[1] Parking is a textbook example for the tragedy of commons (INCI, 2015). While pure public goods can be characterized by non-rivalry in and non-excludability from consumption, this is not the case for commons where only non-excludability applies. For public parking that is free of charge this is exactly the case. No one is excluded from using it while there still is rivalry among the users (OSTROM, 1999). But, even if there are parking fees excludability is below the optimal level as long as there is underpricing of parking in particular on the curb. This results in an excess demand and, thus, in cruising for parking caused by a lack of available parking lots (INCI, 2015).

PROOST (2006). Each user can decide whether to search for cheap on-street parking or whether to use a parking garage which is more expensive. In this case the optimal fee for on-street parking equals the marginal costs at the optimal quantity and is the same as the price for off-street parking.

We study a full switch from on-street parking city to an off-street parking city where on-street parking is fully prohibited and off-street parking is offered and subsidized by the city. This experiment is instructive because it provides the strongest consequences and, thus, the upper bound of the effects of regulating on-street parking.

The model borrows from models of cruising for parking and monocentric city approaches. A basic model for cruising for parking, which will be thoroughly regarded in the following, was introduced by ARNOTT and INCI (2006). ARNOTT and ROWSE (2009) refine the model by considering ARNOTT (2006) who shows that increasing the prices for on-street parking seems to increase social welfare in the presence of spatial competition between different parking garages and congestion due to cruising for parking. INCI and LINDSEY (2015) examine a similar setting. Due to the spatial considerations the parking garage owners have market power. This leads to an instable equilibrium. Differentiated on-street parking fees can be one feasible solution. MARTENS ET AL. (2010) pursue a different approach. They model cruising for parking by implementing an agent-based model for cruising. Hereby, the agents simulate the car drivers' decisions while parking in order to determine the share of parking lots that have to remain vacant to prevent cruising for parking.

Another approach considering the spatial distribution of parking was pursued by GALLO ET AL. (2011). Applying a multi-layer network supply model they simulate different phases of parking including walking to the final destination. The spatial aspect for cruising for parking is also emphasized by VAN OMMEREN ET AL. (2012). They propose peak load pricing in order to minimize deadweight loss resulting from congestion. Further literature is discussed in INCI'S (2015) review of the economics of parking. This short review emphasizes that the major part of research is on congestion due to cruising for parking and on spatial competition between different parking locations.

To the best of our knowledge there is no study that accounts for the trade-off between on-street parking, cruising for parking, congestion and off-street parking as well as land-use and economic markets when moving from on-street to off-street parking. We, thus, consider simultaneously the major effects of parking: (i) the congestion externality from cruising for parking, (ii) the substitution effects imposed by different funding options and subsidization (full subsidization vs. parking fees), e.g. on induced travel mode choices, as well as (iii) multiple market interactions in good, labor and housing markets. We fill this gap and study these effects simultaneously while allowing for endogenous location choices of households and firms by applying a spatial computable general equilibrium (SCGE) model of a city.

We also study how several funding schemes of the land required for off-street parking work in the spatial equilibrium: a general lump-sum tax used to offer off-street parking free of charge vs. user financing in the form of congestion tolls and user financing through parking fees.[2]

We consider lump-sum funding to consider the pure case of getting rid of the externality from cruising-for-parking while going on with offering parking at zero costs for users and without adding tax distortions when funding parking. In the second scenario we add the user-pay principle for parking which also reduces the parking subsidization of car using. This also should reduce the congestion externality from commuting trough reducing the parking subsidy. Eventually, we introduce congestion tolls to directly tackle the congestion externality from car driving and use their revenue to finance off-street parking infrastructure.

Our spatial modelling borrows from FRANCO (2016) and BRUECKNER and FRANCO (2017) who study parking in a monocentric partial equilibrium model. The former considers parking at the Central Business District and residential parking while the latter consider different types of parking. However, neither of them models cruising for parking. In contrast, we consider cruising as well as on-street and off-street parking.

Section 2 will set up the problem in the light of the existing literature. Section 3 describes the main features of the urban CGE model followed by a brief description of its calibration for an average German city (Section 4). Section 5 presents the results of the policy simulations and the final Section 6 concludes.

2 The Market for Parking

In the following we illustrate on-street and off-street parking and summarize the main impacts both parking modes cause in an urban economy.

2.1 ON-STREET PARKING - THE BENCHMARK

We, first, define the benchmark where all parking is on the curb due to missing off-street parking infrastructure. Figure 1 illustrates this benchmark where the outer lanes of the road are offered for on-street parking. In the figure, demand equals supply and all available on-street parking lots are fully occupied by parking cars. The middle lanes are used for driving symbolized by the arrows. Hence, main parts of the road infrastructure are used for parking, which approximately halves the potential capacity for driving vehicles even without considering interference through parking procedures.

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[2] Some research views both options as substitutes in terms of their potential to mitigate congestion (e.g. CALTHROP ET. AL, 2000; GLAZER and NISKANEN, 1992). However, as we will show in the present paper, spatial economic effects may induce non-negligible differences between these measures.

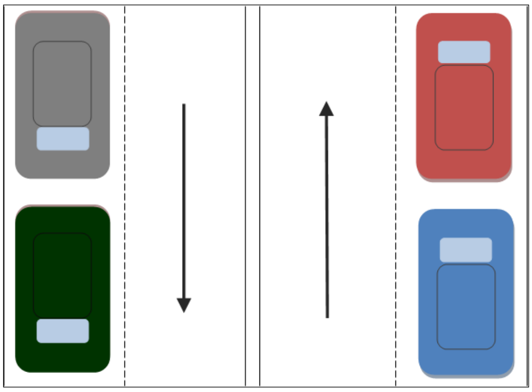

Figure 1: Parking in the Benchmark

If we add cruising for parking congestion may arise. This is an important issue in urban transport. For instance, SHOUP (2006) reports that roughly 30% of urban traffic relates to cruising for parking while an average search for parking takes 8.1 minutes. The main reason for cruising is excess demand resulting from too low prices of parking given the scarce parking supply (INCI, 2015). Usually, off-street parking is mainly privately owned and parking there is charged. As long as the private cost for cruising is lower than the private cost for parking, cruising will exist (SHOUP, 2006). There are two reasons why users do not consider true prices. First, many car users neglect their own costs for parking search resulting from time, fuel and wear costs (SHOUP, 2006), and, second, they do not take account of the adverse impacts on other drivers and the environment (VAN OMMEREN ET AL., 2012). Interestingly, the congestion externality from car use is even stronger in the presence of on-street parking as cruising cars increase congestion over-proportionally compared to vehicles in transit (INCI, 2015).

2.2 OFF-STREET PARKING – THE POLICY CASE

Our focal point of interest is to study the spatial and welfare effects of a policy that imposes a full switch from on-street to off-street parking. Figure 2 visualizes this case. Road infrastructure is now fully available to driving vehicles while parking procedures exclusively take place in the dedicated off-street parking lots that imply a reduction of land available for other purposes (housing, office space etc.).[3]

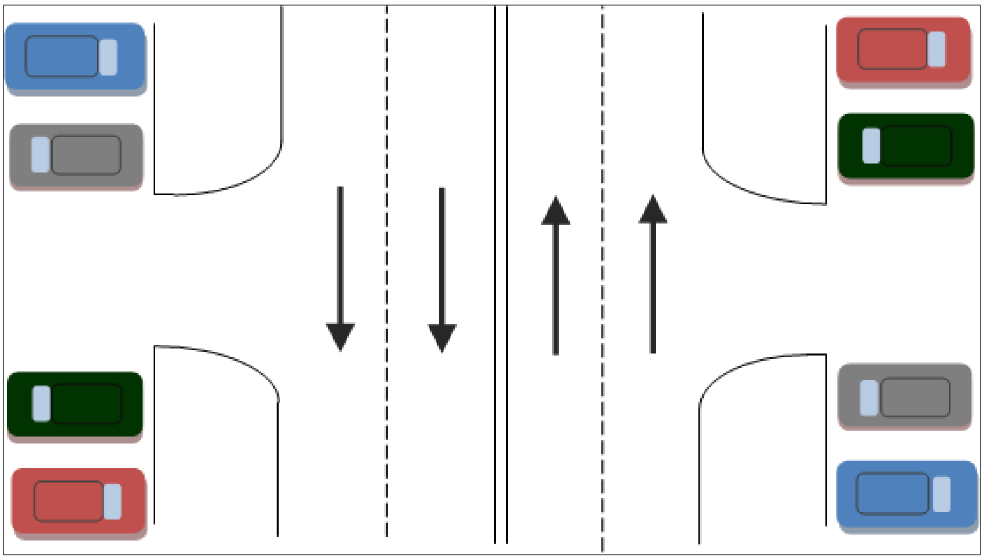

Figure 2: Parking in the Policy Case

At first sight, a prohibition of curbside parking seems reasonable and efficient as it not only lowers congestion due to parking search but also increases the capacity of roads, thereby increasing throughput by making the prevailing floating traffic less congested. On the other side, the spatial economic (general equilibrium) impacts of additional off-street parking infrastructure has to be considered. This, however, is usually neglected in existing studies. The potential impacts are manifold and, as a consequence, may induce a wide range of interesting feedback effects.

First, because urban land is scarce, the additional parking lots beyond the road will exacerbate competition on the urban land market and thus drive up land rents. This makes housing and office space more expensive causing substitution effects away from land use. For example, firms might substitute labor for land as a response to the provision of off-street parking. The increase in labor demand in turn positively affects urban wages and so

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[3] We do not consider spatial competition for (private) parking spaces. Off-street parking spaces are provided publicly and viewed as homogenous by drivers within the same location (but parking spaces are heterogeneous across space as parking in the city center might be more expensive than in the suburbs).

income of city residents. On the other side, since higher rents increase production cost the provision of urban goods and services is getting more expensive, ceteris paribus, which reduces final good demand.

Second, the increase in road capacity makes car driving more attractive. This induces a change in mode choice in favor of private car use. While a higher road capacity per se reduces congestion, ceteris paribus, more car use induces a negative feedback effect on congestion. The net effect determines the parking policy´s contribution to congestion.

Third, off-street parking lots will crowd out other land use, thus, forcing residents and firms to relocate and to lower housing demand and reduce plant size. This diminishes utility and decreases the production of urban goods/services and, as a result, deteriorates welfare and income in the urban economy.

Fourth, as off-street parking lots are assumed to be supplied by the city funding issues come into play. Depending on whether parking lots are financed by all citizens or by road users alone, the policy´s impact may differ substantially.

Fifth, given the wide range of potential policy impacts on travel decisions – which may (partly) stem from household relocations – travel related environmental effects can be expected. Here, we capture environmental effects by carbon emissions from car driving at the extensive margin, i.e. via changes in distance traveled, and at the intensive margin, i.e. via changes in emissions per kilometer traveled.

In the next section we describe the main features of the spatial urban CGE model. The model has been described extensively in previous studies so that we primarily pay attention to novel model features with special focus on integrating cruising for parking and the physical presence of parking infrastructure.

3 An Urban CGE Model with Parking

We apply and extend the framework of ANAS and XU (1999) and Anas and RHEE (2006). The spatial computable general equilibrium (SCGE) model considers three players: households, firms and the public household. Households and firms choose their utility and profit maximizing location in the city that consists of two zones: the city center and the suburbs. The model's equilibrium is reached if all local markets for labor, land and goods are cleared and the current account is zero (ANAS and RHEE, 2006).

We assume a nested utility tree implying that utility maximizing choices of a typical household follow a three stage decision process. In the upper stage, they choose their optimal work and home location considering random utility

$$\widetilde{U}_{ij} = U_{ij} + e_{ij}, \tag{1}$$

where U_{ij} is deterministic utility of a household residing in i and working in j and e_{ij} is the idiosyncratic constant that denotes individual preferences for the location combination ij. The household determines his utility maximizing location choice, i.e. choice of household type, by comparing random utilities for all location bundles of available location bundles.

In the second decision stage, households choose consumption of a composite good, housing lot size q_{ij} and leisure l_{ij} in order to maximize their deterministic utility subject to the budget constraint. Utility is assumed to be of the Cobb-Douglas type

$$U_{ij} = \alpha \ln \left(\sum_{k=1}^{K} z_{ijk}^{\eta} \right)^{1/\eta} + \beta \ln q_{ij} + \gamma \ln l_{ij}. \tag{2}$$

The composite good, i.e. the first term in (2), is defined as a constant elasticity of substitution (CES) index over consumer goods z_{ijk} bought in zone k. The decision on these goods is made in the third stage by maximizing CES utility subject to the budget available for consumption of goods. There is love of variety over spatially differentiated local consumer goods because the quasi-concavity of CES utility ensures that consumption of different goods – here from different zones – generates a larger utility than repeatedly consuming the same good (ANAS and XU, 1999).

Utility maximization is subject to two constraints that are closely related: the monetary budget and the time budget.

$$L_{ij}D + l_{ij} + \sum_{k=1}^{I} 2t_{ik}z_{ijk} + 2t_{ij}D = E \tag{3}$$

is the time-budget restriction in annual terms. Total available time, E, is used for working, $L_{ij}D$, where D is the fixed number of working days per year and L_{ij} is daily working hours, for leisure time, l_{ij}, and for travelling to shops $\sum_{k=1}^{I} 2t_{ik}z_{ijk}$ and to work $2t_{ij}D$ (ANAS and XU, 1999). t_{ik} is one-way travel time which is symmetric.

The monetary budget constraint is

$$\sum_{k=1}^{I} p_{ijk}\, z_{ijk} + r_i q_{ij} + \tau^{ls} + c_{ij}D = (1-\tau^{w})w_j L_{ij}D + R. \tag{4}$$

Monetary income consists of the annual net salary $(1-\tau^{w})w_j L_{ij}D$ and income from land rents, R, which is the same for each household. $L_{ij}D$ is time spent working per year, τ^{w} is the wage tax rate and w_j is the hourly gross wage. This income is spent for consumption goods including shopping trips, housing, lump sum taxes τ^{ls} and travel costs. p_{ijk} is the full consumer price.

The use of the random utility approach and the assumption that idiosyncratic location-preference parameter e_{ij} is extreme value distributed allows us to apply a multinomial logit model (ANAS and XU, 1999) to the location decision. Therefore, we can interpret expected values (choice probabilities) as shares of the household types ij in the household population, denoted as ψ_{ij} in the following.

The model is closed by the public budget constraint, zero profit conditions of location specific firms following from perfect competition, a current account and market clearing conditions of local labor, land and good markets.

The government levies a labor income tax to finance lump-sum transfers and road infrastructure cost. The latter are opportunity costs of land used for roads.

Good market clearing

$$N \sum_{i,j=1}^{I,J} \psi_{ij} z_{ijk} + EX_k = X_k \tag{5}$$

states that local good supply X_k in zone k equals the demand of all households ij (first term on the LHS), plus export EX_k from this zone.

Labor market clearing requires

$$N \sum_{i=1}^{I} \psi_{ij} L_{ij} D = M_j. \tag{6}$$

Annual labor demand in zone j, M_j, equals total labor supply that consists of the number of people working in j multiplied with their annual working time (Anas and Rhee).

$$N \sum_{j=1}^{J} \psi_{ij} q_{ij} + Q_i + S_i = A_i \tag{7}$$

is the clearing condition of the land market. It states that the land demand of households, firms, Q_i, and for infrastructure, S_i, equals fixed land supply A_i in zone i (ANAS and RHEE, 2006). Further, we assume that there are absentee landlords. To balance the current account, exports of local goods have to have exactly the same value than the payments of all land rents to absentee landlords and of monetary transport costs to the outside-city transport sector.

A representative local firm uses local land and local labor as input factors to produce the profit-maximizing number of local goods. This approach is equivalent with assuming that a large and variable number of equally sized firms producing a fixed output level choose their optimal location in order to maximize profits (ANAS and XU, 1999)[4].

The model's transport sector is of special interest since congestion and traffic volume are endogenous. We use the BPR congestion function to calculate speed, thus, congestion (ANAS and XU, 1999). Travel time on the route from i to j, t_{ij}, strongly depends on the infrastructure's capacity, C_{ij}, and the traffic volume on this link, F_{ij}. The parameters of this function are the inverse of the free-flow travel speed, d, and the parameters b and a required for calibration. This gives[5]

$$g_{ij} = d\left[1 + b\left(\frac{F_{ij}}{C_{ij}}\right)^{a}\right]; \quad d, b > 0, \qquad a \geq 1 \tag{8}$$

This basic structure of the spatial CGE model closely follows the framework developed by Anas and coauthors (ANAS and RHEE, 2006; ANAS and XU, 1999). In order to make it suitable for the parking issue considered here we need some extensions: mode choice, cruising for parking and an additive land-use category for parking infrastructure.

Parking infrastructure is financed by the government and, thus, enters the public budget constraint, the land market clearing condition, S_i in Eq. (7), and the current account via rents paid to absentee landlords.

The inclusion of mode choice into the model is essential to consider substitution effects among transport modes. We model mode choice close to ANAS and LIU (2007). The household can choose between car, public transport and walking. This choice is modeled using a multinomial logit-model that includes monetary and time costs for each mode.

Our major extension of the model is the modeling of cruising for parking. The literature proposes different approaches, most of them including on- and off-street parking[6]. We use some ideas of ARNOTT and INCI (2006) who focus on on-street parking. In their model, traffic flow is the sum of cars in transit T to a final destination (transit pool) plus the

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[4] Note that the model is silent on whether changes in good production occur on account of relocation and market exit and entry of firms or changes in output of existing firms.

[5] This approach is not able to depict peaks because it assumes an equal distribution during the day (ANAS and RHEE, 2006).

[6] E.g. CALTHROP and PROOST (2006), INCI and LINDSEY (2015), SHOUP (2006), THOMPSON and RICHARDSON (1998), VAN OMMEREN ET AL. (2012).

cruisers for parking (cruising pool) C. In steady state, entry into both pools per unit of time equals the number of cars leaving the on-street parking lots (the parking pool) per unit of time. We use the basic ideas of their approach and adjust it so that it fits to our models' CES structure.

To simplify issues, we assume that only commuters are affected by congestion whereas shopping is free of it. We justify this by the dominant morning and evening peaks stemming mainly from commuting traffic (INFRAS and DLR, 2010). This implies the assumption that cruising for parking is an issue only during peak hours. Hence, only commuters have problems to find a parking lot and may cause congestion through cruising. In contrast shoppers who need a parking lot instantaneously find an available one without any search time. The reason for this is that parking lots near shopping areas are not filled up by commuters. As a consequence, there is no cruising for parking and, thus, no link between parking and congestion outside the peaks.

As our model considers two zones, there is no real transit traffic as in ARNOTT and INCI (2006) because all trips at least start or end in a considered zone. Due to this fact, we modify the assignment of the vehicles to the different pools (transit and cruising).

All vehicles used for commuting, starting in zone i and traveling to any zone belong to the pool of transit vehicles:

$$T(i) = \sum_j Flow(i,j). \tag{9}$$

We further assume that each commuting vehicle whose destination is in i is assigned to the pool of cruising vehicles because there is on average no parking without cruising. In contrast to ARNOTT and INCI (2006) who assume a continuous entry and exit into parking, there are enough on-street parking lots in our model and each commuter will eventually find a parking lot. Nonetheless, available parking lots are scarce at a specific address and commuters have to cruise around to find one. However, not the whole zone area will be used for cruising and since some vehicles are able to find a parking lot rather fast, the traffic volume of the cruisers is weighted with the factor 0.5, implying an average number of cruising vehicles of

$$C(i) = 0{,}5 \cdot \sum_j Flow(j,i). \tag{10}$$

Traffic volume in zone i is the sum of cars in transit plus traffic due to cruising. However, cruising cars travel around and, thus, are more than proportionally contributing to traffic flow. To specify that we adapt the traffic flow function from ARNOTT and INCI (2006) who assume that cruising vehicles contribute 1.5 as much to traffic volume TF as the transit vehicles do, implying:

$$TF(i) = T(i) + 1{,}5\ C(i). \qquad (11)$$

This benchmark model is modified in the policy scenarios. We examine a switch from on-street to off-street parking. In this case, we assume that there is no cruising for off-street parking and entrance is fast enough[7]. However, offering off-street parking requires additional land used for parking.

In addition, we consider two ways of financing the infrastructure for off-street parking. In a first scenario, the city finances the infrastructure through lump-sum taxation. In the second scenario, there is full user financing. Users pay parking fees so that the revenues just equal the expenses for parking infrastructure. In that case, we assume that parking fees during working are four times the fees for shopping. This implicitly considers that on average parking for working is much longer than parking for shopping. In the third scenario, there is a congestion toll modeled as the difference between private and social time costs as proposed in ANAS and RHEE (2006, p. 520). The welfare effects of introducing these policies are evaluated using equivalent variation in order to monetarize utility losses or gains.

4 Calibrating the model

The model is calibrated to fit a German city with approximately 500.000 inhabitants (DESTATIS, 2015) and an area of 400km², from which one fifth is the city center (DESTATIS, 2016c, 2016d). 45% of the inhabitants own apartments whereas 55% are owned by absentee landlords (DESTATIS, 2014B).

The utility function's parameter are chosen in order to fit existing data (α=0.35, β=0.18 and γ=0.40) (ANAS and XU, 1999; STATISTISCHES BUNDESAMT, 2013; TSCHARAKTSCHIEW and HIRTE, 2010). The constant elasticity of substitution depicts the love for variety and for this reason was set to 2.5 (TSCHARAKTSCHIEW and HIRTE, 2010).

The scale parameters are set to 0.7 and inner city production is more labor intensive than production in the suburbs (ANAS and XU, 1999; TSCHARAKTSCHIEW and HIRTE, 2010).

Free-flow speed for cars is set to 40 km/h with regard to junctions that decrease the speed from the maximum limit. The congestion function is calibrated following the Bureau of Public Roads (BPR)-function (SMALL and VERHOEF, 2007). The fuel costs are chosen to be 1.39 €/l, 0.51 €/l being the gross price (BUNDESMINISTERIUM FÜR VERKEHR UND DIGITALE INFRASTRUKTUR, 2015, p. 294; STATISTA, 2017a). Public transport speed is set to 18km/h, walking speed to 6 km/h (NITZSCHE, 2015). Marginal damage costs of CO2 emissions is

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[7] This would be the case if the city installs a well-working car-park routing system.

145€/t (BUNDESMINISTERIUM FÜR VERKEHR UND DIGITALE INFRASTRUKTUR, 2015).

Table 1 shows some results and compares them to empirical values.

	i=1, *j*=1	*i*=1, *j*=2	*i*=2, *j*=1	*i*=2, *j*=2	Empirical values
GDP [billion €]	24.9				23[8]
Wage [€/hour]	21.95		18.04		19.65[9]
Working hours per day	8.0	7.5	7.2	7.2	8[10]
rent [€/m^2]	7.52		3.09		7.39[11]
Disposable income [€]	47.376				44,750[12]
Marginal congestion costs [€/km]	0.34				0.30[13]
Daily commuting time car (one-way) [h]	0.35	0.81	0.91	0.55	
Fuel consumption commuting [l/100km]	10.32	8.58	9.29	8.73	
Fuel consumption shopping [l/100km]	7.22				7.6[14]
Modal Split (Car/ Public Transport/ Walking) per trips	63 % / 35 % / 2 %				63 %/ 35% / 2%[15]
Price elasticity w.r.t fuel prices	commuting	–0.11	shopping	–0.08	–0.1 - –0.3[16]
Price elasticity wr.t. fares	commuting	–0.21	shopping	–0.18	–0.0 - –0.8[17]

Note: If there is a value only in the first column it is the city average.

Table 1:Some Benchmark Results.

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[8] (Stadt Nürnberg, 2014, p. 6).

[9] (Destatis, 2014b).

[10] (Destatis, 2014a).

[11] (Immowelt, 2017).

[12] (Destatis, 2016a), calculated with an average household size of two (children, partner etc.) (Statista, 2016).

[13] (Anas & Rhee, 2006, p. 527).

[14] (ADAC, 2016).

[15] (Destatis, 2016b, p. 342).

[16] (Small & Verhoef, 2007; Tscharaktschiew & Hirte, 2012, p. 295).

[17] (Oum, Waters, & Yong, 1992; Tscharaktschiew & Hirte, 2012, p. 295).

5 Policy analysis

All scenarios (lump-sum tax, congestion toll and parking fee) examine the prohibition of on-street parking. The city government offers off-street parking that is fully funded. The different scenarios concern the refinancing schemes are: lump sum tax, parking fee, congestion toll.

We first have to specify supply of off-street parking. Parking at the home location stays totally unconsidered in this work. We assume an off-street parking lot requires on average 25 m² of land (KORDA, 1999).[18]

The policies have different spatial, economic and ecological impacts. We first give a short intuition on the major effects before we will move on to the simulation results.

5.1 EXPECTED RESULTS

We give an intuition on the expect outcomes of the three scenarios in Figure 1.

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[18] A rough calculation gives us an idea of how much land is required to substitute all on-street parking in the benchmark. The initial model split is 63%. Assume this increases to at most 70%. Let us assume that on average a maximum of 85% of all commuters by car need a parking place at the same time, for instance, since there is some shift operation. If each household only owns one vehicle that makes $500{,}000 \cdot 0.70 \cdot 0.85 = 297{,}000$ parking lots. Calculating this adds up to 7.5km² for parking. The full reduction of on-street parking will increase the road-capacity parameter from 51% to 61%.

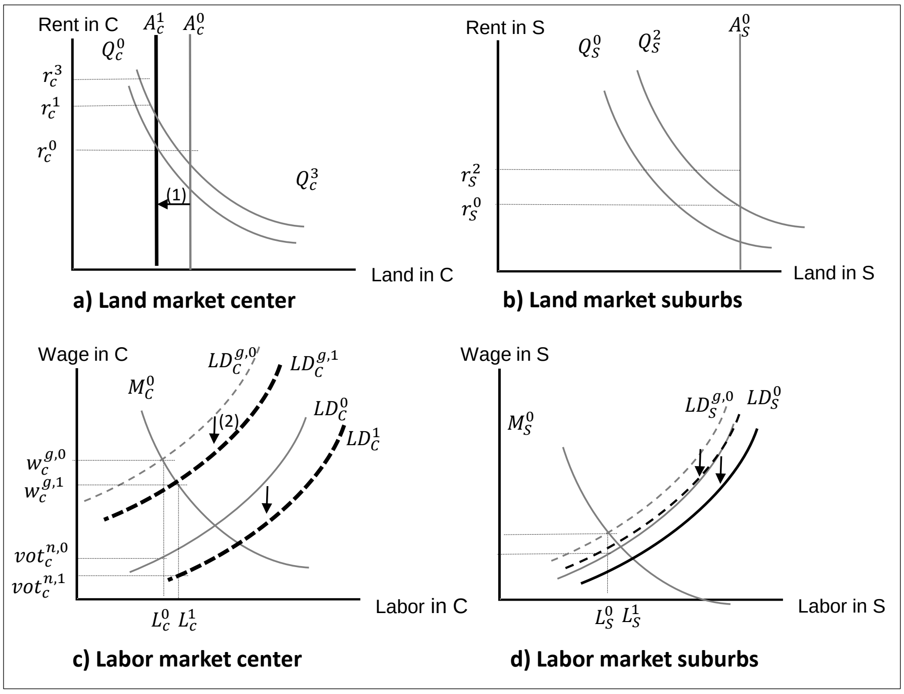

Figure 3: Policy Effects on the Land and Labor Markets

Panel a) and b) of Figure 1 display the center's and suburbs' land markets, respectively. The benchmark equilibrium is denoted by indices '0', 'C' denotes the center and 'S' the suburbs. A_C^0, respectively, A_S^0 are fixed land supply available for use by households and firms and Q_C^0 and Q_S^0 are their aggregate land demands implying benchmark land rents r_C^0 and r_S^0, respectively. At the center's labor market, M_C^0 denotes local labor demand and LD_C^0 local labor supply in the absence of price distortions. The income tax rate drives a wedge between the gross wage $w_C^{g,0}$ and the value of time (VOT) vot_C^0, that is equal to the net wage. Labor supply in terms of the gross wage is $LD_C^{g,0}$ and local employment in the benchmark is L_C^0.

Now, consider the switch to off-street parking financed by a lump-sum tax. To simplify matters we assume for the time being that this happens only in the center. In that case, land supply for housing and offices declines to A_C^1 (see shift (1)). This shocks the land market in the center and implies a rise in the land price to r_C^1. As a consequence, housing demand declines and some households move to the suburbs. This shifts the land demand curve at the suburbs' land market to the right to Q_S^2. This relocation lowers labor supply in the center and increases labor demand in the suburbs (shift the labor supply curves, not drawn).

Introducing off-street parking causes a positive shock on the center's labor market because it reduces income through lump-sum taxation but raises time available for leisure and working due to the reduction in congestion. Both increase labor supply, the first is a negative income effect on leisure and the second is a positive wealth effect of time endowment that increases both leisure and labor supply. This shifts the gross and net labor supply curves to the right, see shift (2). However, the wedge between the gross wage and the value of time (VOT) stays constant.

To summarize: off-street parking funded by lump-sum taxes leads to relocation of households to the suburbs, relocation of firms to the center, higher employment at the center and the suburbs, higher income and lower gross wages. Relocation implies additional commuting.

Next, consider the case of parking fees used for funding parking supply. In that case the shock on the land market stay almost the same, see shift (1). Higher land rents cause higher costs of road infrastructure which implies higher lump-sum taxes and, thus a shock on the labor markets that is similar to that caused by lump-sum taxation but smaller. In addition, parking fees add a reduction in income and, thus, a further right movement of labor supply curves. Again the value of time stays constant. In contrast to lump-sum taxation, parking fees are also paid for shopping. Hence, there is a distortion in consumer prices implying a substitution in favor of housing demand and leisure. As a consequence, labor supply increases less than with lump-sum tax funding. This is the reason why the shift of the labor supply curve is smaller than under lump-sum tax funding, a shift smaller than (2) in panel c).

What happens with congestion tolls? In comparison to parking fees that account only for parking costs and indirectly internalize the congestion externality, congestion tolls fully internalize the congestion externality and, additionally, finance a major part of parking costs. Whether they have a stronger effect than parking fees depends on the relative size of infrastructure costs to congestion costs. Besides, there are two main differences between both instruments. The congestion toll is a tax on distance while parking fees 'tax' each trip equally. Hence, with congestion there might be less relocation to the suburbs compared to the case of parking fees while parking fees favor longer trips. While the congestion toll does not affect the value of time nor the consumer price of local goods, it makes traveling by car more expensive and, thus, induces an increase in mode share of public transport. Because public transport is slower, people lose time available for leisure. This reduces wealth and imposes a negative effect on leisure but also labor supply for commuters. If this effect offsets the labor stimulating effect of lower income, leisure supply declines otherwise it increases. In any case, the right shift of labor supply curves is considerably lower than with parking fees or lump-sum tax funding.

Next, we move to the simulation results. Table 2 displays some results which we discuss in the following.

	Benchmark	Lump-Sum	Toll	Parking fee
Percentage of housing in center	37.0 %	–0.3 %	–0.5 %	–0.6 %
Percentage of jobs in center	57.5 %	+0.1 %	+0.2 %	±0 %
Rent center [€/m^2]	7.52	+5.7 %	+3.9 %	+4.9 %
Wage center [€/hour]	21.95	–0.6 %	–0.4 %	–0.4 %
Annual disposable income [€]	47,376	+0.8 %	–2.6 %	+1.4 %
Lump-sum transfer [€]	3,720	–27.2 %	–38.2 %	–8.0 %
Price for goods in suburb [€]	67.39	+1.6 %	+0.4 %	+1.4 %
Income absentee landlords [m. €]	10,495	+4.3 %	+2.4 %	+3.9 %
Marginal congestion costs [€/km]	0.34	–61.8 %	–91.2 %	–70.6 %
Annual travel distance [km]	22,388	+0.2 %	–0.3 %	–0.3 %
Emissions per HH [kg CO_2]	2,238	+0.3 %	–27.6 %	–7.2 %
Modal split (car/ PT/ walking)	0.63 /0.35 /0.02	0.67 /0.31 /0.02	0.53 /0.44 /0.02	0.62 /0.36 /0.02
Modal split commuting	0.56 /0.41 /0.03	0.68 /0.30 /0.03	0.32 /0.65/0.03	0.58 /0.39 /0.03
Modal split shopping	0.67 /0.31 /0.02	0.67 /0.31 /0.02	0.67 /0.31 /0.02	0.64 /0.34 /0.02
Road infrastructure costs [Mio.€]	4,306	+4.8 %	+2.9 %	+4.2 %

Table 3: Policy Impacts

5.2 REFINANCING VIA LUMP-SUM TAX

Because lump-sum taxes do not distort prices, they should be a relatively efficient method of financing off-street parking.[19] Table 2 shows that some effects coincide with the graphical reasoning in section 5.1. The effects on the land market are pretty clear: land rents increase more in the center (+5.7%) than in suburbs (+ 3.7%). This causes relocation to the suburbs and a decline in average land demand per household (−3.2% to −5.5%). The higher land rents induce an increase in road infrastructure costs (+4.8%) in addition to the parking infrastructure costs. This lowers lump-sum transfers by 27.2%.

There is strong decline in marginal congestion costs of 21 cents per km, i.e. about 61.8% despite the feedback effects that imply more traffic. Less congestion also lowers fuel consumption by 9.9%-23% per km. The decline in travel costs makes car travel more attractive. This explains the increase of the modal split of car use for commuting from 56% to 68%. This leads to more emissions from transport of yearly about 0.3% per household.

The strong decline in income caused by lump-sum tax funding implies a strong income effect strengthened by the wealth effect from more available time, hence, labor supply increases by 6 to 19 minutes per day. That raises the GDP and overall income increases despite lower wages.

One nice issue of our simulation results is that the calculated costs for parking infrastructure are close to the level of these costs found in the literature. The additional monthly expenses for parking add up to 123.77 € in our simulation compared to 127 $ calculated by SHOUP (2011).

In order to assess the impacts of the different policies, equivalent variation (EV) was performed. This method monetarizes the different utility levels and therefore allows to gauge the differences (KLEINEWEFERS, 2008, p. 216)

Table 4: Welfare Effects displays the welfare effects, showing that the city’s GDP increases by 2.4% and overall welfare by 0.44% of initial GDP. However, there is strong redistribution in favor of absentee landlords (+374€m) arising due to the increase in land rents. The higher rents in turn lowers welfare of households despite higher income and in total deteriorates welfare of the city by 259 million Euro (EV all households). Obviously, even though the travel speed for private motorized transport and income increases this

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[19] Some authors reason that the equality of the burden imposed on all households makes it a suboptimal measure (HINDRIKS & MYLES, 2006). SHOUP (2011) states that this form of refinancing shifts a higher burden to poorer households. His argument mainly stems from a reduced car ownership rate of poorer households. Some redistribution is included in the model because the marginal utility of income differs across household types. This affects welfare in this type of model as has been shown by HIRTE and TSCHARAKTSCHIEW (2013). In addition, we explicitly account for redistribution between landlords and working households.

cannot compensate for the welfare losses resulting from the lump-sum taxation and higher rents.

	Lumpsum	Toll	Fee
Change in GDP [million €]	+600	–200	+300
EV per household [€]	–515	–1,076	–747
EV all households [million €]	–258	–538	–374
EV absentee landlords [million €]	+374	+222	+322
Benefit from emission cost reduction [million €]	–0.5	+44.5	+11.5
Total impact [million €]	+115.5	–271.5	–40.5
Total welfare change in % of GDP	0.44%	–1.1%	–0.16%
Change in GDP in %	2.41%	0 %	–0.80%

Table 4: Welfare Effects

5.3 REFINANCING VIA CONGESTION TOLL

The second funding scheme is a congestion toll as a mean to implement user financing. The congestion toll aims at internalizing the external congestion costs of traveling[20].

The spatial effects are similar to the previous scenario and follow the discussion in 5.1. In contrast to the case of lump-sum funding, the impact on labor supply is ambiguous. Labor supply of commuters declines due to mode switch in favor of public transport that lowers

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[20] Mathematically, the congestion toll is the difference between social and private marginal costs (see e.g. VERHOEF, NIJKAMP and RIETVELD, 1995). We follow this definition to calculate the toll in the model. In reality, it would be more difficult to determine an efficient level for the toll and transaction costs would reduce its impact (LEHMANN, 2007).

available time while labor supply of non-commuters increases due to the income effect of higher taxation.

What are the consequences for transportation? The congestion toll only applies to commuting trips causing a strong decrease of car usage for commuting. The modal share of commuters drops from 56% to 32% leaving 65% of all commuting trips to public transport. Accumulated over both trip purposes this leads to a modal share of private motorized transport of 53% that is 18% below the benchmark level. Considering existing research on city tolls this seems to be a realistic effects. London and Stockholm, for example, faced a decrease of modal split of car usage up to 25% (ELIASSON ET AL., 2009; TRANSPORT FOR LONDON, 2008). Together with the reduction of the traveled kilometers, we calculate an immense decrease of emissions by 27.6% in our scenario.

Yet, it has to be put forward that the toll revenue does not equate the additional expenses stemming from the parking infrastructure and the increased costs of road infrastructure and so, the lump-sum transfer is reduced by 38.2%.

All in all, we find a clear welfare loss of 1.1% in terms of GDP compared to the benchmark despite the unchanged GDP and the positive decline in congestion and emissions (see Table 4). The city welfare declines by 538 million € (–2.2% of GDP) while there is strong redistribution in favor of absentee landlords. The welfare effect of the congestion toll is negative compared to positive effect of lump-sum tax funding. The reason is the strong wealth effect caused by the huge time loss arising on account of the model switch to public transport. This effect more than offset the internalizing effect on congestion and emissions.

5.4 REFINANCING VIA PARKING FEES

The second form of user financing examined is parking fees. The literature considers parking fees as a transport-planning tool. GLAZER and NISKANEN (1992) and VERHOEF ET AL. (1995) see parking fees as a substitute for congestion tolls. CLATHROP ET AL. (2000) state that a combination of policies delivers the most efficient results. If only one policy is to be applied, parking fees should be implemented. We should, however, note that in our case where commuting and shopping is considered, parking fees tax shopping as well as commuting while a congestion toll is only levied on commuting. In addition parking fees is a price per trip while the congestion toll tax distance that is endogenous on account of relocation in our approach.

In this scenario, the fees were modeled in order to equal the additional costs caused by the parking infrastructure. Hereby, the parking fee for commuters add up to four times that of shopping. This resulted in a fee of 4.26€ for a working day and 1.07€ for shopping. Compared to literature values of more than 1€ per 30 minutes (STATISTA, 2017b) this is rather cheap. However, our model city has a very low rent level.

Once more, the policy results in a clearly increasing price for housing which again results in the same spatial trends as the other policies and a strong redistribution in favor of absentee landlords. The higher land price causes additional infrastructure cost that leads to an increase of the lump-sum tax, higher housing costs and relocation of household to the suburbs.

Due to congestion toll and parking fee, both being user financed scenarios, one would assume that the impacts of both scenarios are very similar. This, however, is not the case. The change in the modal split is very small. The car usage for commuting even increases while it decreases a bit for shopping trips leading to an overall decrease of car usage from 63% to 62%. These developments have different reasons. First of all, the congestion toll only applies for commuting traffic, while both trip purposes are influenced by parking fees. Furthermore, the congestion toll strongly depends on the travel distance, as it is a kilometer based toll. In contrast, every car user has to pay the same parking fee no matter how far he travels.

Overall the influence on the transport sector is not as strong as in the case with the congestion toll. Still the emissions are strongly reduced, mainly due to a decrease in travelled kilometers per year. Overall welfare and the GDP slightly decline and city's (households') welfare declines while absentee landlords benefit. Overall, the effects are comparable to the lump-sum funding case on account of two effects: first, there is a slight increase in public transport use that lowers time available for leisure and working; second, there is a substitution effect because parking fees increase the consumer price for shopping.

Next, we summarize the results as follows: all policies make the average city household worse off compared to the benchmark while the absentee landlords always are better off. Regarding the total impact, the lump-sum policy is the most efficient because it stimulates labor supply implying also an increase in GDP and income. However, due to redistribution to the landlords worker households lose. They lose even more with parking-fee funding despite additional labor supply. Because labor supply of commuters declines congestion tolling imposes the strongest welfare loss for worker households and diminishes even social welfare. In addition, to offset the decline in income tax revenue, lump-sum taxes increases even more than with lump-sum tax funding. This imposes an additional income effect on labor supply. Further, lump-sum tax funding is rather unlikely to be implemented on account of redistribution issues. The second best alternative concerning overall welfare is refinancing via parking fees.

Concerning environmental issues, emission decline the most with congestion tolls. But parking fees imply also a clear reduction of emissions at much less welfare costs. Therefore, parking-fee funding seem to be a more efficient policy than congestion tolling when moving from on-street to off-street parking. This is the reason why we study different levels of parking fees in the following. This shows us the trade-off between emissions, congestion and welfare. In particular, we are interested in the optimal level of parking fees.

5.5 IS SEARCH OF AN OPTIMAL PARKING FEE?

In order to find out whether there is an optimal parking fee level, we vary the parking fees in the following.

Figure 4: Utility Change with Varying Parking Feesdepicts the effects of parking fees on average household utility. It shows that there is an almost linear relationship between average utility and average parking fee, indicating that a higher parking fee always results in lower average utility. Accordingly, the maximum average utility of city households is achieved at zero parking fees implying that parking fees always lower urban welfare. Therefore, switching to off-street parking makes the average household always worse off and, thus, may not be accepted in the city. Even households not traveling by car will lose because rents increase.

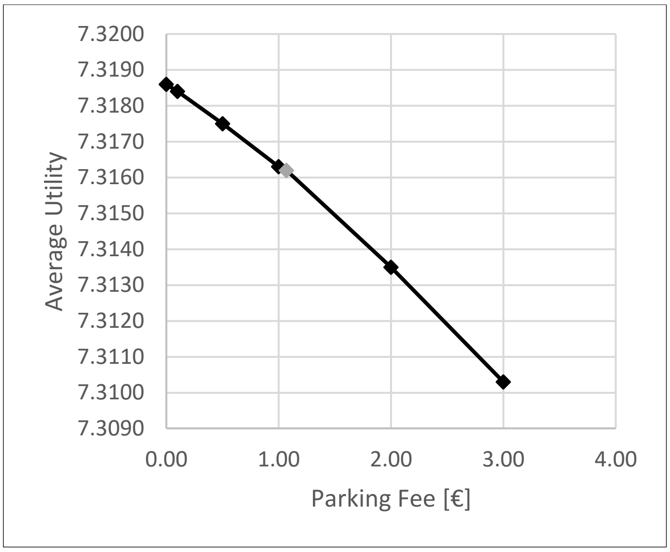

Figure 4: Utility Change with Varying Parking Fees

From the perspective of society, the benefits of landlords and from reduced emission costs have to be compared to the losses of urban households. Hence, from the society's perspective a modified version of the parking-fee funded switch to off-street parking could be to set the fees at a level where the overall welfare equals that of the benchmark, i.e. a welfare-neutral policy. This case is achieved with parking fees for shopping of 0.82 € and for commuting of 3.28 €. However, this would lead away from pure user financing.

6 Conclusion and Discussion

The switch from on-street to off-street parking generates benefits due to the reduction of congestion made possible from less cruising for parking and the increase in road capacity made possible by prohibiting on-street parking. On the other hand, costs arise due to additional infrastructure costs, higher land prices and relocation of households to the suburbs. The main reason for these costs is the huge amount of land required for offering off-street parking that reduces land available for other purposes and, thus, implies a strong increase in land prices. As we have shown above, the costs exceed the benefits from the perspective of the city households independent from the funding scheme. In contrast, social welfare that additionally accounts for absentee landlords' utility and the decline in emission costs improves if off-street parking is financed by an efficient-neutral lump-sum tax.

We have further shown that in our second-best world user-financing worsens the case for city households but also implies losses of social welfare. This is interesting, given the idea that user-financing is well-suited to internalize externalities and, thus, should improve the case compared to lump-sum tax financing. However, because we model a general equilibrium with endogenous labor supply, this positive internalizing effect is more than offset by the negative effect of user-financing on labor supply[21]. This effect is stronger for congestion tolls that are a pure tax on commuting while parking fees also tax shopping. As a consequence, imposing parking fees is more efficient than congestion toll for funding off-street parking.

The main outcome of our study is, thus: switching from on-street to off-street parking is welfare deteriorating in the absence of lump-sum tax funding even from the society's point of view due to the distortionary effects of funding schemes. If, however, the reduction of congestion and emission is the most important aim parking fees might be more efficient than congestion tolls on account of lower welfare costs. But to study whether this holds if both measures are compared at the same level of changes in congestion and emissions is left to future research.

Refinancing via congestion toll is only in parts user financing, as the toll revenue does not balance the infrastructure expenses, extra revenue from the lump-sum tax have to be added. Nevertheless, the user financing characteristics of the policy are dominant enough to lead to large-scale displacements concerning the mode choice and the transport sector. As the policy solely affects commuting traffic changes can only be seen on these trips. Yet, the impact is so strong that it induces the most drastic environmental improvements.

Parking fees, in contrast, completely balance the additional expenses for parking infrastructure and therefore the policy is totally user-financed. Furthermore, this policy affects commuting and shopping and therefore, does not favor some trip purposes. Therefore, the modal share changes occur for commuting trips and the increasing travel speed is only due to higher capacities on the road.

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[21] Concerning distortions in the labor market, the specific modeling of labor supply may be relevant (HIRTE and TSCHARAKTSCHIEW, 2015). This can be considered in further research. However, the case considered here imposes the least negative effect because substitution effects through a change in the value of time are not implemented. If one would endogenize workdays, the value of time would depend on congestion tolls and parking fees. In that case, congestion tolling or parking fees would reduce the VOT and, thus, causes a further decline in labor supply. In that case, the welfare would decline even more (HIRTE and TSCHARAKTSCHIEW 2015).

This research leaves room for further investigation. Parking at home as well as privately financed off-street parking have been fully disregarded. Furthermore, scenarios with a mixture of on- and off-street parking would be interesting to be evaluated, too. Additionally, this model only considers commuting and shopping trips while leisure trips and work-related shopping travel stay completely unobserved.

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