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THE ENVIRONMENTAL EFFECTS OF PARKING: EMPIRICAL EVIDENCE AND POLICY IMPLICATIONS

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This report was authored by Dr. Antonio Russo (ETH Zurich) and Professor Jos van Ommeren (VU University Amsterdam). The report discusses the environmental and economic consequences of parking and current parking policies, and proposes parking policy reforms that could lead to environmental benefits and increases in social welfare. To this end, it relies on a literature review and an empirical application to the Dutch city on Amsterdam.

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EXECUTIVE SUMMARY

It is widely recognised that there are important external costs associated to car travel. Parking is an often neglected, but highly important, dimension of car use: the average car is parked roughly 95% of the time. This report argues that parking generates substantial externalities. First, the availability of free or underpriced parking stimulates car use and ownership, contributing to congestion, pollution and emissions of greenhouse gases. Second, the oversupply of parking contributes to consumption of land and urban sprawl, with negative repercussions on the environment.

The report follows a twofold approach. First, it reviews the relevant literature to provide a comprehensive overview of the main environmental and economic issues associated with parking, and of current policies in different parts of the world. Secondly, it provides novel empirical evidence regarding the external costs of parking in downtown areas. Furthermore, it uses this evidence to identify the welfare costs of certain parking policies.

Based on the findings of the literature and on the empirical analysis, the report stresses the importance of pricing available curbside and garage parking to maintain high occupancy levels, while also avoiding saturation. Furthermore, it proposes that governments consider removing all fiscal incentives that induce provision of free parking to employees. The report also suggests that it is important to review minimum parking regulations for residential buildings, to eliminate parking overprovision. Finally, it suggests that free parking permits to residents in city centres have substantial hidden costs and could, therefore, be restricted to certain purposes.

1. INTRODUCTION

1. Cars are the primary mode of transportation in modern economies. It is widely recognised that there are important external costs associated to car travel, such as road congestion and pollution (Small and Verhoef, 2007). However, travel is not the only car-related activity that generates negative externalities. Another such activity is parking. The average car is parked roughly 95% of the time (Inci, 2015) and huge amounts of land are consumed by parking. For instance, in the United States, total land allocated to parking is roughly equal to the size of the state of Massachusetts (Jackle and Sculle, 2004). The estimated social cost of a parking space varies significantly across space, but it is particularly high in urban areas. In the United States, according to Shoup (2005), the average social cost of a parking space was at least 1 500 USD per year (measured in 2005 prices). De Groote et al. (2016) find that, on average, provision of a residential parking permit in the city of Amsterdam produces an external cost of EUR 270 per year.

2. The social cost of parking is not only related to the consumption of land. Parking also contributes to traffic congestion. According to Shoup (2005), about 30% of downtown traffic consists on average of cars that are driving around in search of a parking spot. Shoup defined this phenomenon as “cruising for parking”. Yet, parking is often underpriced, so that users neglect the external costs of this activity. This distortion results in an excessive amount of car travel, because it implies that individuals underestimate the overall cost of using cars. Furthermore, cars cruising for parking make congestion worse because they tend to slow down other vehicles. These effects often compound each other in contributing to excessive emissions of greenhouse gases and other air pollutants. Indeed, not only do additional kilometers driven increase emissions, but driving in congested streets creates more emissions than driving on a free road. Therefore, parking contributes to climate change as well as local pollution.

3. The objective of this report is to provide evidence of the environmental and economic consequences of current parking policies, and propose parking policy reforms which could help tackle these issues and increase social welfare. To this end, the report uses a twofold approach. The first step is to review the relevant literature to provide a comprehensive overview of the main environmental and economic issues associated with parking, and of current policies in different parts of the world. As a second step, the report provides new empirical evidence regarding the external costs of parking in downtown areas. Specifically, it investigates the effects of policies regulating curbside parking in congested commercial streets. Using administrative parking data from Amsterdam, the largest city in the Netherlands, it focuses on two types of instruments: reductions in the supply of curbside parking spaces, and (maximum) parking duration restrictions. The aim of the analysis is to estimate the impact of these policies on cruising for parking and parking occupancy rates. Based on these estimates, it discusses the implications of these policies in terms of time losses (due to traffic congestion), emissions from car use and reductions in economic welfare.

4. This report proceeds as follows. Section 2 discusses the main environmental effects of parking. Section 3 reviews current parking policy practices in urban areas, and discusses their main implications for the environment and social welfare. Section 3 provides an empirical case study, focusing on the assessment of the effects of policies to regulate parking supply in the city of Amsterdam. Section 5 proposes possible policy reforms to tackle the problems identified in the previous sections. Section 6 concludes.

2. THE EFFECTS OF PARKING ON THE ENVIRONMENT

5. In this section, we discuss the main environmental implications of parking. We first discuss the relation between parking, car ownership and car use, taking into account the related effects on congestion and emissions of greenhouse gases and pollutants. We then turn to the implications of the provision of parking space for the costs of housing supply and the loss of open space.

2.1 Effects of parking on car ownership and use

6. Following a simple economic reasoning, it is easy to see that car use and ownership are stimulated by the availability of parking space, particularly when individuals do not pay for the full social costs of parking. The (scarce) available evidence suggests that the effect is significant. Using data from central Amsterdam, De Groote et al. (2016) show that reducing the price of parking increases car ownership. They find that the demand for car ownership by central residents is quite elastic with respect to the price of residential parking (they estimate an elasticity of -0.8). Obviously, this result may depend on the fact that parking prices are relatively high in central Amsterdam (see Section 3.1), so the elasticity may be lower in cities where parking is cheaper. This being said, the result suggests that underpricing of parking may contribute significantly to stimulating car ownership. In a study based on residents of New York City, Guo (2013) also finds a positive relationship between availability of parking spaces and car ownership.

7. To get some sense of the relevance of the implicit subsidies to parking for car ownership, it is useful to do some back-of-the-envelope calculations. For concreteness, focus only on employer-provided parking. According to Litman (2016) the cost firms sustain to provide parking in typical European and North American urban areas is between EUR 5 to 10 per day per parking spot. To be conservative, one can take the lower bound of this interval. Assuming 200 working days per year, the implicit subsidy to a car commuter is EUR 1 000 per year. Given an average vehicle lifetime of 10 years, the total implicit subsidy is EUR 10 000. This value is almost as high as the sale price of medium-size car. In fact, it is comparable to the size of taxes that many countries impose on car ownership. For instance, the Dutch government imposes a tax equal to up to 45% of the value of a new vehicle upon registration. In principle, these taxes serve the purpose of internalising some of the external costs of car ownership (among other possible objectives). However, given the above calculation, the implicit parking subsidies completely undermine this purpose.

8. The impact of parking subsidies is also relevant for car use. Weinberger (2012) shows that car commuters in New York City are more likely to commute by car when they have access to free parking in proximity of their home. Again, a simple calculation suggests that the effect is quantitatively important. Taking the conservative cost estimate of EUR 5 per day per parking spot that was used above, and assuming that individuals face private travel costs of the same size when commuting by car, the supply of free parking to employees implies a subsidy equal to roughly half the private trip costs. Assuming a demand elasticity of car use with respect to private trip costs equal to -0.5 (Litman, 2017), the above implies that demand for car commuting is inflated by 20 to 25 percent due to provision of free parking at the workplace. One can also try to evaluate the effect in terms of additional emissions. According to the US Environmental Protection Agency, a typical passenger vehicle emits about 4.7 metric tons of carbon

dioxide per year (EPA, 2017).[1] Assuming (rather conservatively) that 50% of yearly kilometres driven are for commuting purposes, the above estimates imply an increase in emissions of at least 0.47 metric tons per vehicle per year.[2] Given a registered base of 183 million passenger vehicles in the US (BTS, 2012), this implies that the implicit parking subsidy at the workplace produces extra emissions of about 86 million metric tons per year in the United States alone.

2.2 The effects of parking on land use

9. Land consumption is one of the major implicit costs of parking. The available data suggests that this cost is substantial. Road infrastructure, including parking, covers between 2% and 3.5% of total land area in France, Germany, the UK and Japan. This is roughly equivalent to between 20 and 30% of total urban land in these countries (VTPI, 2015). There are, of course, several costs of allocating space to parking. On top of physical resources, there are environmental costs, such as the loss of open space and biodiversity. The costs also include the opportunity cost of unpursued alternative uses for parking land, such as housing and commercial property. These are compounded by the loss of potential revenue for local governments. Obviously, the resources allocated to parking might be better spent otherwise. For instance, they may be used to improve the city's transportation system, ideally in more environmentally friendly ways (e.g. by improving public transportation).

10. As Section 3 discusses in more detail, the costs of land consumption associated to parking are to some extent related to inefficient policies. For instance, several cities provide free parking permits to central city residents. Therefore, additional parking space is needed to accommodate non-residents (e.g. shoppers). Private firms invest in downtown parking garages that are costly to build and thus profitable only because of the extra demand by non-residents (whose willingness to pay is high). Using data from Dutch shopping districts, van Ommeren et al. (2014) show that residential permits are responsible for a 15% increase in parking provision costs, on average, and the associated social loss is about EUR 275 per permit per year.

[1] This assumes the average gasoline vehicle on the road today has a fuel economy of about 9.2 kilometers per liter and drives around 18 300 kilometers per year. Every liter of gasoline burned creates about 2.35 grams of CO2.

[2] This is obtained by multiplying the annual emissions by the assumed share of commuting kilometers by the lower bound of the increase in demand estimated in the previous paragraph (0.2).

3. A REVIEW OF POLICY PRACTICES

11. This section provides a review of the main parking policy practices and their implications. We begin by discussing curbside parking. We then turn to the provision of parking to commuters by employers. Next, we discuss residential parking policies. We then focus on commercial parking in shopping centers and downtown areas. Finally, we briefly discuss additional policy issues, including enforcement and support for alternative energy vehicles.

3.1 Curbside parking

12. One of the most important aspects of parking in urban areas is its interaction with road congestion, primarily due to cruising for parking. This phenomenon is very common: according to studies surveyed by Shoup (2005), that mostly refer to US cities, up to 74 percent of cars in traffic are searching for a parking spot, spending on average 8 minutes cruising for parking per trip. This problem is fundamentally due to an underpricing issue. When the demand for on-street parking exceeds supply (that is, the monetary price of parking is too low), saturation of parking space occurs. Thus, some cars have to drive around looking for a free spot. This is inefficient for two reasons: first, parkers pay with their time, rather than with their money, depriving the local government of a non-distortionary source of revenue. Second, cruising aggravates road congestion. In fact, because cruising cars tend to drive slower than in-transit traffic, cruising contributes disproportionately to congestion, on top of increasing fuel consumption and air pollution. Using data from Istanbul, Inci et al. (2017) show that the external cruising costs of parking can be of the same order of magnitude as the external congestion costs generated in transit from origin to destination.

13. Arnott and Inci (2006) provide a theoretical framework to analyze cruising for parking. Their model makes a simple recommendation: because curbside-parking capacity is fixed in the short run, the optimal parking price should be high enough that at least one parking spot is always available (in practice, most regulators aim for an occupancy rate around 85%). In other words, no cruising should take place in equilibrium. Inci and Lindsey (2014) analyze the interaction between curbside parking pricing and parking garages. The issue is important because garages provide additional capacity that can alleviate curbside parking congestion. However, privately owned garages have market power, and may therefore charge inefficiently high tariffs. Nevertheless, Inci and Lindsey show that the government does not need to regulate parking garages as long as it sets curbside parking prices optimally. Using data from the Netherlands, Kobus et al. (2013) show that drivers are willing to pay a premium for curbside parking, in the range of EUR 0.37-0.6 per trip.

14. In most cities around the world, on-street parking in busy downtown areas is saturated, indicating that prices are too low. This is typically the case in North American cities, although these cities impose certain time restrictions (e.g. one-hour parking). In principle, optimal pricing would make time limits unnecessary. However, when pricing of parking spaces is not optimal, time limits can eliminate cruising by discouraging long-term parkers (Arnott, 2013). Recently, the city of San Francisco started a pilot project that applies some of the ideas outlined above: the *SFpark* experiment, described in more detail in Box 1.

Box 1. The SFpark Experiment in San Francisco, CA, USA

SFpark is a system for managing on-street parking, run by the San Francisco Municipal Transportation Agency. It employs smart parking meters that change prices according to location, time of day, and day of the week. Parking usage is monitored via sensors placed in the asphalt, and users can check the availability of parking and prices via the internet and on mobile apps. Prices are designed with the objective of keeping an occupancy rate of about 85% on any given block. The idea is to eliminate cruising by making sure that drivers are always able to find a parking spot.

In April 2013, prices ranged from USD 0.25 to USD 6 per hour during normal hours. In addition to on-street parking, fourteen city-owned garages are included in the program. See Pierce and Shoup (2013) for a detailed description of the scheme. The first evaluations indicate that parking tariffs have decreased on average, yet the average time spent searching for parking has decreased (Inci, 2015). This implies that, overall, drivers are better off thanks to the introduction of the system.

The experiment has attracted attention from other cities (e.g. Los Angeles, Milan and Mexico City). The City of Calgary, Canada has been using a similar demand based pricing model since 2008.

Sources: Inci, 2015; Pierce and Shoup, 2013.

15. The low curbside parking prices in American cities contrast sharply with the policy adopted in several Asian cities (e.g. Tokyo, Singapore, Seoul), where on-street parking is severely restricted (ADB, 2011). Box 2 briefly draws on some aspects of parking policy in Japanese cities. Curbside parking prices also tend to be higher in European cities. For instance, in central Amsterdam, non-resident parkers pay between EUR 20 to 40 per day for curbside parking.

Box 2. Japan's proof-of-parking rule

Japanese law requires motorists to prove they have access to a local parking space. To register a car, or when changing address, motorists need to obtain a "parking space certificate" ("garage certificate") from the local police. The rule was enacted in 1962 and initially applied only to the large cities (Steiner, 1965). However, it has gradually been extended also to smaller ones.

On top of requiring proof of parking, Japanese law puts stringent restrictions on on-street parking. It essentially bans parking on streets. Exceptions allow some daytime and evening on-street parking, but not overnight parking.

Although these measures are effective at curbing car use and ownership, their stringency may have unintended consequences. For example, one result of Japan's proof-of-parking regulation has been to foster a market for off-street parking places for lease.

Source: Steiner (1965)

16. Several cities try to coordinate the on-street and off-street parking prices and supply. The French city of Strasbourg, for example, has implemented a harmonised pricing structure with curbside parking in the inner city charging the highest hourly tariffs, and off-street parking in the outer city charging the lowest prices. This procedure required extensive negotiations and the establishment of public-private partnerships with garage owners (Kodransky and Hermann, 2011).

3.2 Employer-provided parking

17. In most countries, employers provide parking to their employees for free (van Ommeren and Wentink, 2012). Just like for curbside parking, economics suggests that free provision is inefficient. Although employers do internalise the cost of parking spaces, they provide parking at a cost that exceeds commuters' willingness to pay. In addition, free parking provision aggravates the external costs of car trips

(e.g. congestion and pollution), because it incentivises commuters to drive to work instead of using more environmentally friendly transport modes, such as public transport and non-motorised means.

18. The academic literature has pointed out that free provision of workplace parking may be due to perverse policy incentives. First, several countries tax fringe benefits at reduced rates compared to wages (Inci, 2015). Therefore, employers have incentives to provide part of employees' compensation in the form of such benefits. Second, land developers are often required to provide a minimum amount of parking space per unit of office space. Because this minimum requirement is often binding, the restriction implies that there is an excess supply of parking, incentivising free provision (Shoup, 2005). Van Ommeren and Wentink (2012) quantify these losses using Dutch real estate data. They show that tax policies induce deadweight losses equal to about 10% of parking resource costs. Furthermore, minimum parking requirements induce an additional loss equal to about 18% of resource costs.

19. Although there may be some justification for imposing minimum parking requirements (for example, to ensure the availability of sufficient off-street parking space and alleviate cruising), as anticipated above, these requirements are most likely responsible for substantial overprovision of parking space. On top of distorting commuters' modal choice, this distortion causes excessive land consumption, contributing to urban sprawl (Brueckner and Franco, 2017). By increasing the distance between destinations, excessive parking also leads to increased traffic and excessive emissions of greenhouse and polluting gases.

20. Minimum parking requirements are ubiquitous in OECD countries, but also in emerging economies. For example, the cities of Kuala Lumpur and Bangkok have high requirements, averaging above 2 spaces per 100 square meters of floor space. However, these are well below the very high parking requirements in suburban areas of the United States or Australia, which range between 3 and 4.3 spaces per 100 square meters (ADB, 2011). As argued by Shoup (2005), a likely explanation is the concern over possible parking shortages. Note that this issue is related to the management of on-street parking spots. For instance, cities that handle on-street parking effectively, e.g. by ensuring low saturation levels, should also be less concerned about shortages of residential parking. Therefore, they should be less prone to adopting high minimum parking requirements.

21. Recognising that perverse fiscal incentives may cause overprovision of parking, several cities have considered taxing companies that provide free parking to employees. For instance, the city of Nottingham recently adopted a tax of up to GBP 250 per year per parking space provided by companies to their employees. Other cities are revising their minimum parking regulations. For example, the city of Hamburg relaxes minimum parking regulations for companies that provide public transit passes to employees (Kodransky and Hermann, 2011).

3.3 Residential parking

22. Many cities provide residents with preferential access to curbside parking space. Specifically, they issue parking permits to residents (in the area in proximity to their home) at much lower price than the curbside rates charged to non-residents. This is the case also for cities that charge high curbside parking fees, such as London. For example, in the wealthy borough of Kensington and Chelsea, 82% of the 34 000 on-street parking spaces are allocated to residential permit holders only, and the number of permits exceeds the number of street parking spaces. While residents pay GBP 0.30 per day for a parking permit, the parking costs for non-residents are 100 times higher, i.e. GBP 30 per day (Kensington and Chelsea, 2012).

23. There are at least two major inefficiencies associated with underpriced residential permits. First, in areas that attract substantial non-residential traffic, discounted residential parking implies that parking space is potentially misallocated: residents' willingness to pay for parking might be much lower than the opportunity cost of occupying the parking space (including the willingness to pay of non-residents and the

external costs of cruising). However, residents' willingness to pay may be smaller than the price they pay for permits. In an empirical study based on Amsterdam, van Ommeren et al. (2011) show that these inefficiencies matter: on average, residents are willing to pay about EUR 10 per day for a reserved curbside parking spot, although they pay only EUR 0.4. Furthermore, the tariff charged to non-residents is much higher (between EUR 20 and EUR 40 per day). Given the presence of cruising for parking, this observation implies that non-residents are willing to pay much more than residents for curbside parking. The reason is that non-residents stay only for a few hours, so their marginal willingness to pay per hour is larger than that of residents.

24. The second major inefficiency associated with underpriced residential parking permits is that they drive up the costs of providing parking spaces. Because curbside parking is granted to residents almost for free, additional parking space is needed to accommodate non-residents (e.g. shoppers). Local administrations and private firms invest in downtown parking garages that are costly to build and thus profitable only because of the extra demand by non-residents (whose willingness to pay is high). Using data from Dutch shopping districts, van Ommeren et al. (2014) show that residential permits are responsible for a 15% increase in parking provision costs, on average, and the associated social loss is about EUR 275 per permit per year. A negative by-product of this parking overprovision is that the resources allocated to parking might be better spent otherwise. For instance, they may be used to improve the city's transportation system, ideally in more environmentally friendly ways (e.g. by improving public transportation).

25. In most OECD countries, minimum parking requirements apply not only to office buildings, but also to commercial and residential ones. Historically, residential buildings had to include at least one parking space per residential unit, and commercial developments had to build a minimum number of parking spaces per square meter. Unfortunately, this policy created a perverse incentive for developers to build more parking than the market required and stimulated car use.

26. Some cities are beginning to rethink the provision of free residential parking permits. In London, the boroughs of Islington and Richmond have adopted a policy of charging for residential permits according to the CO_2 emissions levels of the applicant's car. Richmond also experimented with charging curbside parking fees based on emissions (Kodransky and Hermann, 2011). The city of Amsterdam uses free parking as an incentive for the adoption of electric cars. Parking a conventional car in an electric charging point is not allowed, while electric vehicle users can park their car at any charging location, as long as their vehicle is plugged in (City of Amsterdam, 2015). In addition they are granted a priority ranking in order to get a residential parking permit which, given the lack of parking spaces within the city, is particularly valuable (the waiting time for a parking permit can be of several years for conventional cars). Nonetheless, although they incentivise residents to choose cars with lower tailpipe emissions of CO_2, these policies do not address directly the problem of parking oversupply in central areas. Furthermore, it is not entirely clear that their net effect is to reduce traffic and, thus, congestion and emissions. Indeed, it is possible that, by making access to parking cheaper, these policies induce car owners to drive more.

27. Some European cities have pioneered radically different approaches to manage, rather than accommodate, residential parking. An interesting example of such an approach comes from Zurich, Switzerland, and is described in Box 3.

Box 3. Parking caps in Zurich

Since 1996, the city of Zurich, Switzerland, adopted the "Historic parking compromise". This policy entails a series of measures, including a progressive increase in on-street and off-street parking tariffs. However, perhaps its most notable aspect is the overall cap on parking spaces for each zone (Kreis) of the city. In the city centre, no new off-street parking space can be built unless the city agrees to remove an equal number of on-street spaces, allocating them to other purposes (e.g. bikeways).

In less central areas, the city recognises the connection between parking management and overall transport policy. Locations with good public transport access must reduce the maximum number of parking spaces allowed in new developments. Furthermore, developers are allowed to build new parking spaces only if they can attest that surrounding roads can absorb additional traffic without congestion, and the additional induced traffic does not bring air quality below the required standards (Kodransky and Hermann, 2011).

Source: Kodransky and Hermann, 2011.

3.4 Commercial parking in shopping malls and downtown shopping areas

28. Shopping is one of the main activities associated with parking. As Hasker and Inci (2014) put it, “other than money and credit cards, parking is probably the most important intermediate good in the modern economy”. Shopping malls are one of the largest contributors to the stock of parking space. There are over 100 000 shopping malls in the United States. A typical shopping mall has four to six parking spaces per 1000 square feet of gross leasable area, suggesting that there is more parking space in the average mall than space for stores (ICSC and ULI, 2003). An interesting related stylised fact is that the large majority of malls provide free parking. Can this behaviour be rationalised? Hasker and Inci (2014) show that free parking in suburban malls is justified when consumers are uncertain about the availability of the goods they are looking for. They also provide a rationale for minimum parking requirements.

29. Although suburban malls are important, in European cities a substantial share of retail activity is located in downtown shopping districts. According to the literature, there are important issues with downtown commercial parking. As mentioned above, some cities charge high parking tariffs for non-residents. However, in many other cities, even for non-residents, parking charges are low enough to generate substantial cruising. De Borger and Russo (2016) rationalise these inefficiencies in a political economy framework: they show that the conflicting interests of downtown retailers (who lobby for low parking charges) and downtown residents can explain inefficient pricing.

3.5 Additional policy issues

Enforcement

30. Although the academic literature has devoted little attention to the issue, the enforcement of curbside parking tariffs and regulations is important. Obviously, parking prices cannot be an effective tool to avoid cruising if they are not properly enforced. Yet, enforcement is a critical issue in several cities, because it requires substantial resources and because cities may not have sufficient incentives to enforce tariffs. Some countries in Asia and Europe (e.g. Japan and the United Kingdom) have recently taken measures towards better enforcement. These include outsourcing of enforcement duties to private contractors and reforming the local public finance system to allow local governments to keep a larger share of the revenue collected from parking, in a bid to strengthen incentives. Some cities have adopted more direct enforcement mechanisms. For example, Amsterdam has implemented a system where a van photographs and scans license plate numbers using Automated Number Plate Recognition technology (Kodransky and Hermann, 2011). By dramatically reducing the costs of monitoring parked vehicles, these measures increase the effectiveness of parking enforcement.

Car-sharing

31. A sensible strategy to reduce the need for parking spaces is to reduce the quantity of cars in the city. Car-sharing offers some promise in this sense. There is a two-way connection here because several cities are using parking to incentivise car-sharing. In Amsterdam, as in many other cities, car-sharing

companies get dedicated parking spaces. In Antwerp, Belgium, residents who are members of car-sharing schemes receive the equivalent of a residential permit so that they can park shared vehicles near their residence. In London, shared cars are permitted to park for free on the street.

Street design

32. Some cities have implemented policies to rearrange street design in order to discourage driving, while improving walkability. In Zurich, alternating parking spaces on two sides of a narrow street acts as a chicane that slows down vehicle speeds. Amsterdam has similar zones called *woonerfs* to force vehicles to move at a very slow pace. Many neighbourhoods of Paris and Copenhagen use parked cars as a barrier between the cyclists and moving traffic.

4. AN EMPIRICAL APPLICATION IN THE CITY OF AMSTERDAM

33. This section presents an empirical analysis of parking policies implemented in the city of Amsterdam. Specifically, it focuses on two policies that are often observed in practice and were discussed in the previous section. These two policies are adjustments to curbside parking capacity and parking duration restrictions. These policies are particularly relevant for parking in commercial streets. Accordingly, they are analysed using data from a main commercial street in Amsterdam.

34. Economists tend to recommend the use of time-varying parking prices to allocate street parking to car drivers (Small and Verhoef, 2007). In contrast, cities employ too low time-invariant parking prices and rely on quantity policies to regulate this market, such as changes in parking supply and maximum parking durations. The objective of this section is to examine the welfare consequences of these policies. To this end, it makes use of a two successive policy changes, whereby for a prestigious shopping street in Amsterdam parking supply was reduced, to create more walking space for pedestrians. Subsequently, a one-hour parking restriction was introduced. Following a similar methodology to Inci et al. (2017), the analysis demonstrates that cruising for parking was already infrequent on the street, and the capacity reduction did not affect it substantially. Nevertheless, the local government later imposed a maximum parking duration of one hour. The analysis presented here demonstrates that the latter policy brought to a substantial increase in user costs, as well as to a significant loss of revenue for the local government, without substantial benefits in terms of reduced cruising: the average parking occupancy sharply fell, causing an annual welfare loss of about EUR 3000 per parking space.

4.1 Empirical strategy

35. The empirical strategy follows Inci et al. (2017). They devise an empirical methodology to estimate the number of drivers who cruise for a parking space. To guide the estimation, consider an environment with rational drivers that have a demand for parking at a certain location. Aggregate parking demand is decreasing in the full price of parking, i.e. including time costs and parking tariffs. Before arriving at the location, drivers do not know the actual parking occupancy rate, but they have rational expectations. Drivers base their demand on these expectations.

36. When arriving at the location, drivers sample the parking spaces until they find an available spot. The full price of parking is equal to the parking fee plus the value of time spent cruising, which depends on the occupancy rate, i.e. the probability of finding a parking spot. The analysis measures the number of additional cars that have to cruise when the occupancy rate goes up. An empirical strategy is thus envisaged, where the occupancy rate is exogenously – from the individual driver's point of view – varied in a random way. This random variation may occur because the actual occupancy rate at the time of arrival differs from the expected rate. This variability may be due, for example, to the fact that the duration of parking is heterogeneous across drivers. Suppose now the occupancy rate exogenously increases at a certain moment of time. The inflow of cars into parking spots has to decrease and, thus, the number of cruising cars goes up. The increase in cruising cars is thus equal to the decrease in the inflow.

37. To implement this theoretical framework, the analysis proceeds as follows. Time is measured in intervals of a quarter-hour, indexed by t. Recall that, by assumption, before arriving at the parking location, a driver is unaware of the actual occupancy. However, she has some expectation about the occupancy over an interval that encompasses the arrival time t. It is assumed that this interval, indexed by τ, is one-hour

long. The actual occupancy level is denoted by $O_{t\tau}$ and the expected one by O_{τ}. Because the street block's parking capacity is given, in the empirical analysis one can measure these variables either in terms of the actual occupancy ratio or in terms of the number of parked cars. Note that, because expectations are rational, expected occupancy is equal to the actual occupancy level at the time of arrival in equilibrium.

38. The inflow of cars parking at the location is denoted by $F_{t\tau}$. This is measured as the number of cars that park during the quarter-hour interval. In the empirical model, inflow is a function of the actual occupancy level, controlling for the expected occupancy. Hence, the analysis controls for factors which are invariant within one-hour time intervals. To this end, it uses time-interval fixed effects T_{τ} (that is, one dummy variable per each hour in our observation period). These fixed-effects address potential endogeneity concerns that the inflow rate depends on the actual occupancy level, because differences in occupancy levels within the one-hour time interval are assumed to be random. The basic specification of the model is as follows:

(1) $$F_{t\tau} = \alpha + \beta O_{t\tau} + \gamma_{\tau} T_{\tau} + \varepsilon_{t\tau},$$

where the last term is a random error component. The main focus of the analysis is on the coefficient β, which measures the marginal effect of occupancy on the parking inflow, and which can be interpreted as the negative of the marginal effect on the number of cruising cars.

39. Finally, to capture possible nonlinear effects of occupancy on inflow, the following equation is estimated:

(2) $$F_{t\tau} = \alpha + \sum_{O} \beta_{O} I(O_{\tau}) + \gamma_{\tau} T_{\tau} + \varepsilon_{t\tau}.$$

40. The coefficients of interest are the β_O, which measure the effect of the dummy variables $I(O_{\tau})$. Note that there is one dummy for each level of occupancy.

41. As Inci et al. (2017) point out, the inclusion of hourly fixed effects may not be entirely sufficient to deal with possible endogeneity issues. For example, it is possible that unobserved short-term shocks during a given quarter hour have a positive (or negative) effect on both inflow and occupancy. To address this problem, Inci et al. (2017) use an instrumental variable approach, exploiting the discrete time variation in the price paid for parking.[3] This discrete variation allows computing the share of cars that leave the parking space because they face a discrete price increase. However, this method cannot be used for most of the observation period in this study, because tariffs applied on the street analysed involved no discrete variations. The sensitivity analysis of Section 4.5 discusses this point further.

42. In what follows, equation (2) is estimated in three different policy regimes, described in the next subsection. The preliminary objective is to provide evidence of cruising (or lack thereof) in each regime. Some welfare implications of the adopted policies can then be analysed.

4.2 Descriptive statistics

43. The dataset used for the analysis contains administrative records of micro-level parking transactions on a main shopping street in central Amsterdam. The analysis focuses on a segment of the street where no residential parking spots are available. Curbside parking in this area is managed by the city

[3] On the commercial street they examine in Istanbul, the payment due is a step function of parking time.

of Amsterdam, which provided data recorded from curbside parking meters and a pay-by-phone platform. The period of observation spans from September 2013 to May 2016.

44. The dataset includes 337 832 parking transactions. For each transaction, there is information on time of arrival and departure, the mode of payment, the price paid and the location of the parking spot at the curbside block level. The average parking duration is roughly two and a half hours (144 minutes), while the median duration is one hour and a quarter (74 minutes). Parking transactions data are linked with another dataset which provides information on the curbside parking capacity at the curbside block level (i.e. the number of spots available to the public, excluding reserved spots for public vehicles, disabled persons and deliveries). Information about formal parking capacity is reported in Table 1. Based on this information, it is possible to compute the inflow and outflow of cars in curbside parking spots, the number of cars parked and the average occupancy rate at each time point. Data are aggregated at the quarter-hour level.

45. During the period of observation, we can identify three periods, distinguished by the conditions of curbside parking regulation. Specifically, in the period before July 2015, visitor, short-term, parking was allowed on both sides of the street. Although we have no precise information on the formal capacity of parking spots, we estimate it to be equal to 72 spots, which is the 95th percentile of the distribution of cars parked in our sample for that period. The parking tariff was EUR 4 per hour, enforced between 9 am and 7 pm during weekdays and Saturdays, with no duration limit. There was no parking fee charged on Sundays and public holidays. This policy is denoted as “Policy 1”. In July 2015, the city adjusted the supply of parking, closing one side of the street to visitor parking. Again, we have no precise information about the official capacity, so we assume it is equal to the 95th percentile of the distribution of parked cars in that period, i.e. 45. This implies a reduction of about 38% of available capacity (Policy 2). Finally, in January 2016 the city introduced a parking duration limit of one hour (Policy 3), without further adjustment in capacity. There were no other changes in parking tariffs throughout the period of observation. Table 1 summarises this information. In the following, variation in policy conditions is exploited to empirically estimate the relationship between policy, parking costs and the associated externalities.

Table 1. Summary of parking policy changes on a main shopping street in Amsterdam

	Dates	Capacity (n. parking spots)	Duration restrictions
Policy 1	up to June 2015	72	No
Policy 2	July 2015 - December 2015	45	No
Policy 3	January 2016 - May 2016	45	Yes, 1hr

Note: capacity refers to the quantity of spots not reserved for police, deliveries, etc.
There is no resident reserved parking in the road segment under analysis

46. Transactions occurring on Sundays and holidays are excluded from the analysis because shops are closed and occupancy levels are much lower than during working days. Furthermore, parking is free on these days. Observations between June 2015 and August 2015 are also excluded because the city was carrying out works to restructure the street’s parking configuration during those months. These works resulted in the closure of the street to cars for a few days, on top of alternate closures of parking spots to allow for the restructuring. The selections imply that observations for 754 days are retained. Finally, the analysis focuses on the hours of the day between 12 am and 5 pm, which is the busiest time of the day for the street under consideration. As a result, the analysis is based on information from about 15 080 quarter-hours (754 days x 5 hours x 4 quarter-hours).

47. Descriptive statistics (means and standard deviations) for inflow, outflow and occupancy are provided in Table 2, where observations are distinguished according to policy. The table suggests that there are non-negligible differences between policies and between Saturdays and weekdays. As expected for a

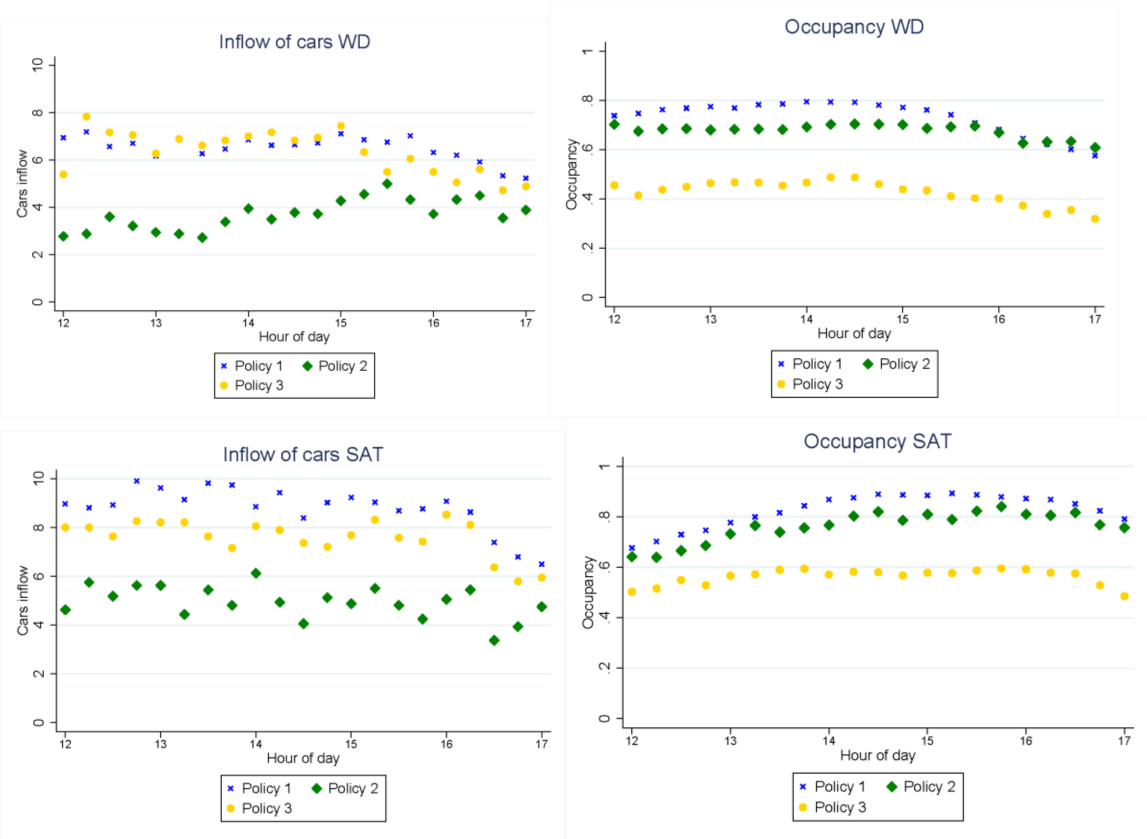
shopping street, inflow, outflow and occupancy are higher on Saturdays than on weekdays. A general observation is that, even during the least restrictive parking conditions (Policy 1), there was little evidence of saturation of parking spaces. Thus, substantial evidence of cruising is not expected. The change from Policy 1 to 2 led to a reduction in car inflows (and outflows), as well as a reduction in occupancy, which further went down with adoption of Policy 3. Given the low occupancy levels, no cruising is expected under this policy. Figure 1 depicts average inflow of cars and occupancy rates on weekdays and Saturdays, aggregated at the quarter-hour level.

Table 2. Descriptive statistics

Policy 1	Weekday						Saturday					
	Inflow		Outflow		Occupancy rate		Inflow		Outflow		Occupancy rate	
Hour	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
12	6.65	*0.59*	5.88	*0.79*	0.76	*0.04*	9.15	*0.44*	7.34	*0.38*	0.71	*0.03*
13	6.55	*0.42*	6.27	*0.50*	0.79	*0.02*	9.58	*0.26*	7.93	*0.05*	0.81	*0.02*
14	6.83	*0.50*	7.08	*0.62*	0.80	*0.02*	8.92	*0.37*	8.63	*0.32*	0.88	*0.01*
15	6.92	*0.51*	8.61	*0.61*	0.76	*0.03*	8.93	*0.22*	9.15	*0.31*	0.89	*0.01*
16	6.18	*0.58*	7.70	*0.64*	0.66	*0.03*	7.97	*0.92*	9.43	*0.27*	0.85	*0.02*
17	5.37	*0.64*	7.43	*0.30*	0.61	*0.03*	6.49	*0.87*	10.84	*0.65*	0.79	*0.01*
Policy 2	Weekday						Saturday					
	Inflow		Outflow		Occupancy rate		Inflow		Outflow		Occupancy rate	
Hour	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
12	3.35	*0.44*	3.20	*0.44*	0.70	*0.02*	5.30	*0.44*	4.28	*0.45*	0.66	*0.02*
13	3.20	*0.37*	3.11	*0.44*	0.71	*0.02*	5.08	*0.48*	4.69	*0.58*	0.75	*0.01*
14	3.55	*0.43*	3.64	*0.44*	0.71	*0.03*	5.06	*0.73*	4.58	*0.59*	0.79	*0.02*
15	4.40	*0.61*	5.05	*0.75*	0.69	*0.03*	4.86	*0.44*	4.86	*0.86*	0.82	*0.02*
16	4.07	*0.54*	4.57	*0.59*	0.64	*0.03*	4.45	*0.83*	5.05	*0.42*	0.80	*0.02*
17	3.68	*0.26*	5.13	*0.59*	0.61	*0.02*	4.75	*0.78*	6.63	*0.38*	0.76	*0.01*
Policy 3	Weekday						Saturday					
	Inflow		Outflow		Occupancy rate		Inflow		Outflow		Occupancy rate	
Hour	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
12	6.84	*0.64*	6.38	*0.87*	0.44	*0.04*	7.97	*0.22*	7.26	*0.81*	0.52	*0.02*
13	6.57	*0.53*	6.76	*0.56*	0.46	*0.02*	7.80	*0.44*	7.75	*0.34*	0.58	*0.01*
14	6.88	*0.44*	6.94	*0.69*	0.46	*0.03*	7.63	*0.35*	7.55	*0.51*	0.58	*0.01*
15	6.35	*0.74*	6.94	*0.69*	0.43	*0.02*	7.75	*0.34*	7.59	*0.24*	0.58	*0.01*
16	5.48	*0.71*	6.08	*0.74*	0.38	*0.04*	7.20	*1.15*	8.39	*0.51*	0.57	*0.02*
17	5.01	*0.39*	5.77	*0.32*	0.35	*0.04*	5.95	*0.34*	8.26	*0.62*	0.49	*0.02*

Note: Occupancy rate is the ratio between cars parked and measured capacity. All values computed at the quarter-hour level

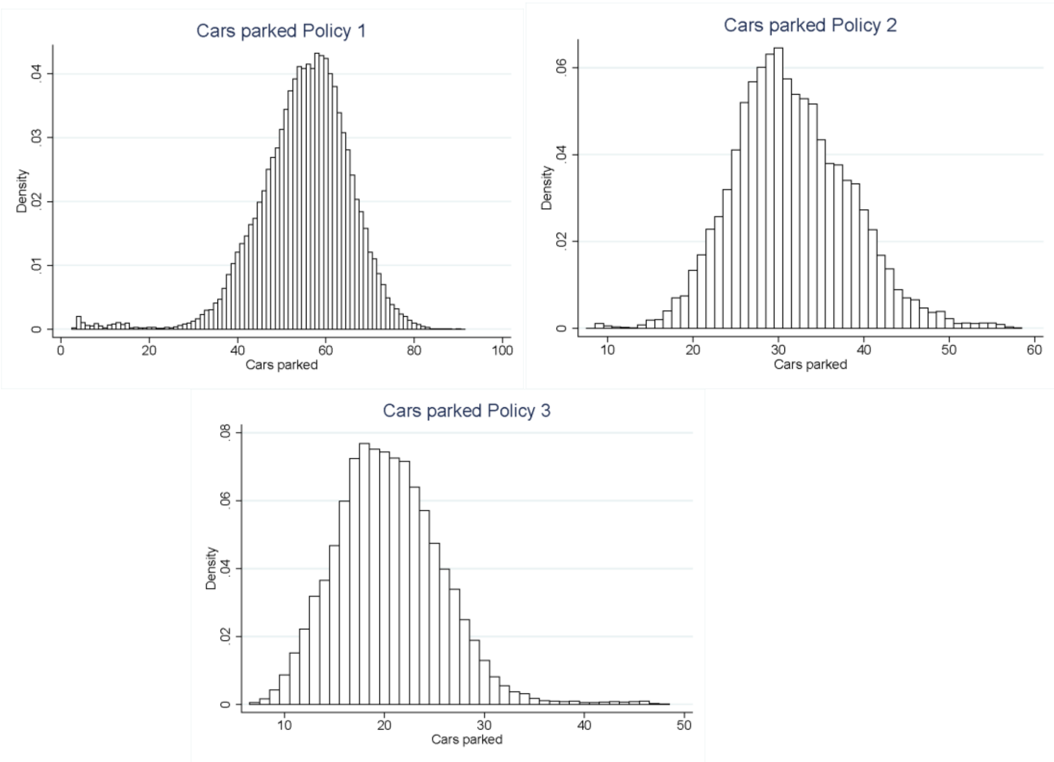
Figure 1. Average inflow of cars and occupancy by quarter hour.



Note: The top panel refers to Weekdays; the bottom panel refers to Saturdays.

48. Figure 2 provides percentages of the number of cars parked on the street in our sample. Not surprisingly, there are differences between the three policies. Again, though, a common trait is that parking is rarely saturated. Occupancy is below 90% for about 85% of the time in Policy 1, 90% of the time in Policy 2 and always in Policy 3. For about 3% of the time, the number of parked cars exceeds the measured capacity in Policy 1 and 2, though by no more than two cars. Observe that, because we aggregate observations as the quarter-hour level, it is possible that there is some measurement error in the quantity of cars parked.

Figure 2. Relative frequencies of parked cars under the three policies, weekdays and Saturdays

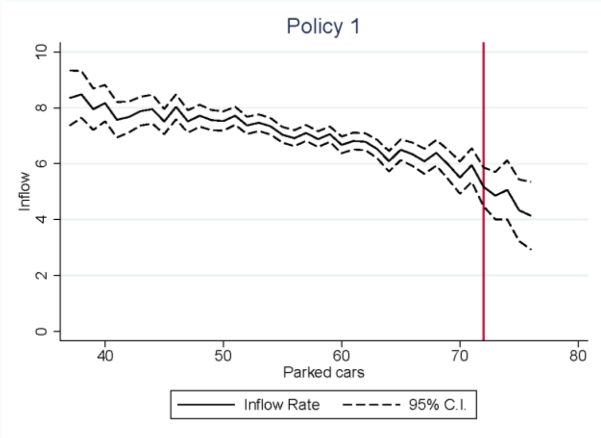


4.2 Empirical estimates

49. This subsection presents preliminary results from the estimation of the model specified in Equation (2). Because of the differences in the three policies outlined above, results are discussed separately for each policy.

50. Figure 3 reports the estimated relationship between the car inflow per quarter of hour and the quantity of cars parked, based on Equation (2). The solid black curve presents the point estimates, while the dashed line represents confidence intervals at the 95% level. The red curve represents the (measured) capacity. Hardly any decrease in car inflow is observed up to 60 parked cars, which is slightly less than 85% of the formal capacity in Policy 1. The decrease is sharper beyond that level, but the inflow does not drop below 5 cars per quarter-hour until about 70 cars are parked, which is an extremely rare event in the sample. Overall, there is little evidence of cruising for parking.

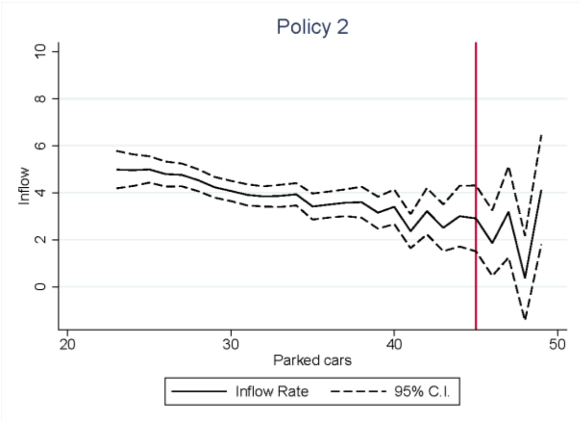
Figure 3. Inflow rate as a function of the occupancy level, Policy 1.



Note*:* The red line depicts the parking capacity.

51. Figure 4 presents the results for the same model specification as Figure 3, but for Policy 2. The figure shows that there is some decrease in the inflow rate when the number of cars parked approaches capacity at 45 cars parked. Then again, this event is rare. Hence, there is again very little evidence of cruising, despite the reduction in capacity.

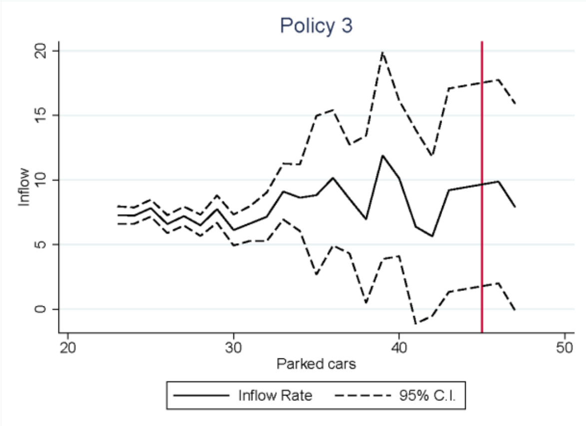
Figure 4. Inflow rate as a function of the occupancy level, Policy 2.



Note*:* The red line depicts the parking capacity.

52. The results for Policy 3 are presented in Figure 5. This figure clearly shows that there is no statistically significant effect of the occupancy level on the inflow of cars. This result indicates that, if any cruising was taking place in the previous policies (and previous results suggest almost no cruising), it completely disappeared after the introduction of the one hour parking time restriction.

Figure 5. Inflow rate as a function of the occupancy level, Policy 3.



Note*:* The red line depicts the parking capacity.

4.4 Welfare implications

53. This section exploits the results from the above empirical analysis to quantify the welfare losses that can be generated by inappropriate parking restrictions. The empirical results suggest that there was little evidence of cruising for parking under Policy 1, and that the same conclusion applies for Policy 2. The reduction parking capacity did not result in additional cruising. Furthermore, Table 2 suggests that the occupancy rate decreased only slightly between the two policies. It seems reasonable to think that the demand for accessing the commercial street by car did not drop suddenly as a result of the policy change. Therefore, the findings imply that part of the existing demand shifted to alternative parking spots adjacent to the street in question (e.g. garages) as a result of the policy change. Provided that these alternative parking spaces are appropriately priced, this shift involves no welfare losses. However, because data on parking quantities and prices around the street is not available, it is not possible to draw additional conclusions.

54. It is more instructive to consider the implications of the introduction of the 1-hour parking restriction (policy 3). Recall that this change was not combined with changes in parking capacity. The empirical analysis suggests again no cruising under this policy. Furthermore, Table 2 indicates that occupancy rates dropped substantially when this policy was introduced. Hence, it is quite likely that the restriction produced a welfare loss, causing underutilisation of the available parking capacity.

55. To confirm the above intuition, it is useful to introduce the following theoretical framework. Consider a set of potential parkers who differ in their willingness to pay to reach the shopping street by car. Assume that the (inverse) demand for visiting the street is linear and that its slope is time invariant. In the following, we consider different values for the slope, corresponding to local demand elasticities ranging from 0.5 to 2.[4] The intercept of demand may vary over time, but it is assumed to be identical under policies 2 and 3 for a given hour of a given day of the week (say, Saturday at 3pm).

56. In terms of user costs, assume that there is no time cost of searching for parking, at least if capacity is unsaturated (a condition that is largely satisfied in the case under analysis). Following Arnott

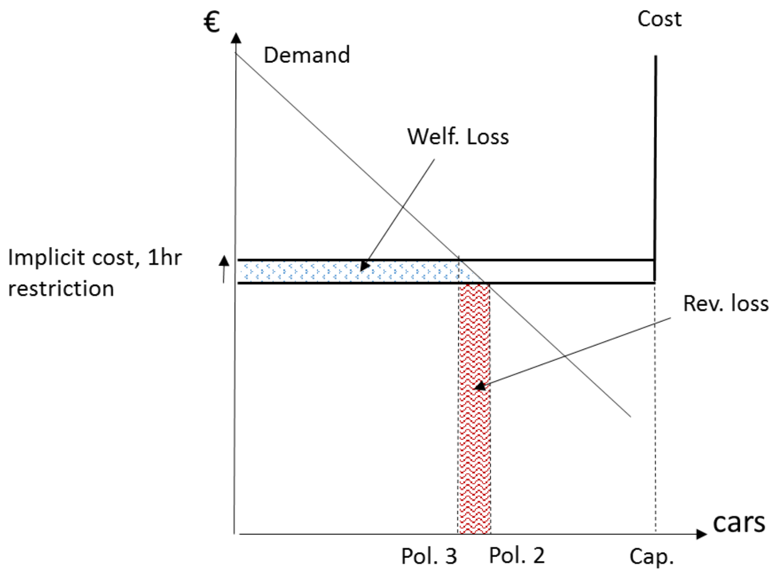
[4] According to the literature surveyed in Litman (2015), parking demand elasticities for different locations within a city range from 0.1 to 2. For curbside parking in central locations, the average elasticity is about 0.5.

and Inci (2006), the parking cost becomes vertical once capacity is saturated, but this situation is not of interest given the previous observations. Therefore, in Policy 2, the only relevant component of the generalised cost is the parking tariff set by the government.

57. Assume for simplicity that, conditional on visiting, all individuals want to stay parked for the same amount of time. To make the model interesting, assume this amount of time exceeds one hour, so the restriction of Policy 3 is binding. The introduction of the one-hour parking restriction thus introduces an extra cost. This cost could, for example, capture the nuisance caused by having to interrupt the shopping trip to move the car to another parking spot after one hour. Conceptually, this cost is equivalent to an increase in the parking tariff. Obviously, though, it does not bring any extra revenue to the government: if there is no saturation of parking spaces, the implicit cost is a pure deadweight loss.

58. Figure 6 depicts the cost and demand curves, as well as the quantity of cars parked under Policies 2 and 3. The figure highlights that the restriction produces two kinds of losses. First, there is a loss in user surplus due to the implicit cost increase (blue trapezoid). Second, there is a loss in government revenue, because fewer cars park even though there was no increase in the tariff (red rectangle). Note that, because capacity is unsaturated, there is no external cost under either policy. Thus, if one ignores the cost of public funds for simplicity, the welfare loss coincides with the loss in user surplus.

Figure 6. Welfare effect of one-hour parking restriction with unsaturated capacity



59. Using the available data, it is possible to quantify the changes introduced by the one-hour parking restriction, as described in Figure 6. As a first step, one can compute the reduction in the (average) quantity of parked cars per hour of a given day of the week, before and after the restriction (for consistency with the empirical analysis, attention is restricted to hours in weekdays and Saturdays, from midday to 5 pm). The result is reported in the first three columns of Table 3. The average quantity of parked cars per hour declines by about 11 cars per hour. Under the assumption that this variation is entirely due to the policy change, it is possible to obtain the implicit increase in user cost due to the one-hour restriction, multiplying this difference by the slope of the demand function. The last four columns of Table 3 report the results given four different assumptions on the elasticity of demand. The results indicate that the implicit cost per parked car per hour ranges from EUR 0.72 to EUR 2.87, equivalent to an increase in the hourly parking fee between 18% and 70%.

Table 3. Effect of 1-hour parking restriction on quantity of parked cars and user costs.

Average parked cars per hour			Average extra user cost of 1hr restriction (euros per veh-hr)			
			Demand Elasticity (assumed)			
Policy 2	**Policy 3**	**Difference**	**0.5**	**1**	**1.5**	**2**
31.12	19.89	11.22	€ 2.87	€ 1.43	€ 0.96	€ 0.72

60. Table 4 computes the aggregate welfare (user) losses and revenue losses for the government, by hour and by year. The user loss corresponds to the blue trapezoid in Figure 7. Not surprisingly, the hourly measure varies substantially depending on the slope of the demand function: the range goes from EUR 18.29 to EUR 73.18. The yearly figure is obtained assuming that parking charges are enforced 250 days per year (recall that there are no charges on Sundays and public holidays). However, the measure only focuses on the five hours per day considered in the empirical analysis, hence the actual yearly figure is certainly larger (given that tariffs are enforced from 9am to 7pm). Finally, given a parking tariff of EUR 4 per hour, the average reduction in the quantity of parked cars results in a loss of about EUR 44 per hour, or slightly more than EUR 56 000 per year, irrespectively of the slope of demand. Therefore, the revenue loss for the municipality is not negligible.

Table 4. Hourly and yearly losses from the one-hour parking restriction

	Demand Elasticity (assumed)			
	0.5	**1**	**1.5**	**2**
Total user loss per hour	€ 73.18	€ 36.59	€ 24.39	€ 18.29
Total user loss per year	€ 91,470.27	€ 45,735.14	€ 30,490.09	€ 22,867.57
Revenue loss per hour	€ 44.89	€ 44.89	€ 44.89	€ 44.89
Revenue loss per year	€ 56,116.33	€ 56,116.33	€ 56,116.33	€ 56,116.33

61. Taking a more conservative approach, one could assume that those who decide not to park on the street end up parking nearby, either on the street or on garages. In that case, the revenue loss for the government, and the loss in user surplus, would be smaller. Unfortunately, the available data does not allow testing this hypothesis. In a similar vein, one could assume that those who actually park on the street are willing to reduce the duration of their visit, with no extra cost. Under this assumption, the user loss would be smaller than that calculated above. In the extreme, with no extra user cost for those who decide to park, the only user loss would be given by the small blue triangle in Figure 6. In quantitative terms, assuming a demand elasticity of 1.5, the user loss would be reduced to EUR 5.37 per hour. However, the revenue loss for the government would not change. See the sensitivity analysis in Section 4.5 for further discussion.

62. In sum, the results suggest that the introduction of the one-hour parking restriction in the commercial street under analysis brought to non-negligible welfare losses. Indeed, while there was no apparent gain in terms of reducing cruising for parking and the associated externalities, the restriction brought a reduction in user welfare, as well as significant forgone parking revenue for the government. As we discuss below, given the commercial nature of the street, the policy may have also had negative repercussions on local businesses by reducing accessibility to shoppers.

4.5 Sensitivity analysis and discussion

63. This section briefly discusses how the previous results may be affected by some issues that have been ignored in the analysis. A first robustness test is to run a different specification of the empirical model. Consider the model described in equation (1). Following Inci et al. (2017), in order to focus on

situations such that parking availability is relatively low, we restrict the dataset to observation such that occupancy is equal to at least 75% of capacity in each period. The results are reported in Table 5. They confirm the previous results indicating that there is little relation between the quantity of cars parked and inflow. Again, there is little evidence of cruising. In fact, under Policy 1, the relation between inflow and occupancy is positive and statistically significant. This result is most likely due to some endogeneity issue, see below.

Table 5. Regression results, linear model.

	(1) Policy1	(2) Policy2	(3) Policy3
Cars Parked	0.0734***	0.0354	0.0831
	(0.00786)	(0.0269)	(0.109)
Hour F.E. Included	YES	YES	YES
Observations	6,249	743	30
R-squared	0.024	0.075	0.658
Standard errors in parentheses		*** p<0.01, ** p<0.05, * p<0.1	

Note: The dependent variable is the inflow of cars in a given quarter hour. The data is restricted to observations such that occupancy is equal to at least 75% of capacity in each period.

64. Another important issue that the empirical analysis has not dealt with is the potential endogeneity of occupancy to inflow, for example due to common unobserved shocks at the quarter-hour level. Examples of these shocks include sudden changes in weather conditions or road accidents. Unfortunately, for the most part, the data of this study does not allow to perform an instrumental variable approach as in Inci et al. (2017). The reason is that under Policy 1 and 2, the parking tariff is not a discrete function of parking duration. Hence, one cannot exploit the discrete jumps in the tariff to generate exogenous variation in occupancy. To generate this variation, one could, in principle, exploit the introduction of the one-hour parking restriction during Policy 3. However, as the previous section as shown, given the low levels of occupancy when this policy was introduced, it seems highly unlikely that the results are driven by endogeneity.

65. Turning to the welfare analysis, a critical assumption is that there is no variation in hourly parking demand between policies 2 and 3. This is a relevant assumption because policy 2 covers months in the summer and fall of 2015, up to the month of December. By contrast, the available data for Policy 3 cover months in winter and spring of 2016 (see Table 1). Therefore, it is possible that seasonal changes in demand may determine some of the change in the equilibrium quantity of parked cars, unrelated to changes in policy. In this case, the welfare analysis in Section 4.4 may overestimate the implicit cost due to the one-hour restriction. Furthermore, the results are strongly dependent on the elasticity of the demand function, which is unobserved. Nevertheless, given the size of the effects measured, it seems fair to state that the estimated impact would be significant even if seasonal changes in demand are important. For example, suppose just half of the decrease in the quantity of parked cars per hour were due to the policy change. Taking the upper bound of the elasticities of demand considered above, the implicit extra user cost per car-hour would be equal to about EUR 0.36, i.e. 9% of the hourly tariff. Finally, recall that the aggregate welfare effects are calculated only focusing on the five busiest hours in the afternoon, which implies that the effects for an entire day are probably larger.

66. Another issue is the presence of additional externalities related to car traffic. Although no evidence of cruising was found, it is possible that changes in parking conditions, by simply reducing car traffic in the area, may have helped to reduce congestion and pollution externalities. However, given that

traffic data is unavailable, it is not possible to quantify these effects. Finally, changes in parking policy have, of course, an impact on the accessibility of the commercial area to shoppers. A possible interesting path for future research is to collect data on footfall, prices and profits of local businesses to analyse the relation between parking policy changes and retail activity.

5. POLICY RECOMMENDATIONS

67. In light of the information collected in this report, a number of good practices for parking policy can be highlighted:

- It is important to *design the prices of curbside parking and parking garages accurately*. While idiosyncratic conditions may imply deviations from optimal occupancy targets, the literature emphasises aiming for occupancy targets ranging from 80 to 90%, in order to avoid cruising for parking. Given possible fluctuations in demand, achieving these targets may require adapting tariffs over time, using information on occupancy in surrounding areas, as in the *SFPark* experiment (see Box 1). In many situations, introducing these policies may imply an overall increase in parking tariffs. However, as the empirical analysis in Section 4 shows, this is not necessarily the case in all cities: imposing too strict parking conditions may be detrimental.
- Attention should be devoted to limiting the provision of free or subsidised parking by employers. The literature suggests that this provision has substantial effects on modal choice and, consequently, car use and ownership. It is therefore important to *consider removing fiscal incentives that induce employers to provide free parking to employees*.
- It is also important to *review minimum parking regulations for residential buildings*, following a proper assessment of the actual parking needs of residents and accounting for the perverse effects of overprovision on car usage and ownership. Cities such as Zurich (see Box 3) have shown how to implement this approach in an effective way.
- *Free parking permits to residents of central cities have substantial hidden costs.* As the literature suggests, this policy may substantially increase the costs of parking supply and land consumption. Furthermore, it deprives local governments of valuable parking revenue. In addition, by forcing additional supply of parking for non-residents, it implies that funds that could possibly be directed to improve the transport system are consumed for parking.

6. CONCLUSIONS

68. This report provided an overview of the main external costs associated with parking, and of the main policy failures that aggravate these costs. Based on the findings of the literature and on the empirical analysis, the report stressed the importance of pricing available parking capacity to maintain high occupancy levels, without leading to saturation. Furthermore, it proposed that governments consider removing fiscal incentives that induce provision of free parking to employees. The report also suggested that it is important to review minimum parking regulations for residential buildings, in order to eliminate parking overprovision. Finally, it suggested that free parking permits to residents in city centres have substantial hidden costs and could, therefore, be restricted to certain purposes.

69. The report also presented an empirical analysis of parking policy, based on data from one of the most important commercial streets in Amsterdam, the Netherlands. The results suggest that, partly because curbside parking prices are already quite high in Amsterdam, parking capacity on the street was underutilised. Therefore, the adoption of a one-hour parking restriction did not increase welfare, but instead produced a non-negligible deadweight loss. These results indicate that parking policy should be designed with great care, and that, while saturation is inefficient, restrictions when parking is underutilised can also have unintended effects.

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