Regional Science and Urban Economics 45 (2014) 33–44

Contents lists available at ScienceDirect

Regional Science and Urban Economics

journal homepage: www.elsevier.com/locate/regec

Residential parking permits and parking supply☆

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ARTICLE INFO

Article history:
Received 4 February 2013
Received in revised form 21 November 2013
Accepted 25 November 2013
Available online 20 December 2013

Keywords:
Parking supply
Residential parking permit
Deadweight loss

ABSTRACT

We estimate welfare losses of policies that provide on-street parking permits to residents almost free of charge in Dutch shopping districts that are predominantly downtown. Our empirical results indicate that parking supply is far from perfectly price elastic, implying that there are substantial welfare losses related to underpriced parking permits. Our results suggest that the provision of residential parking permits in downtown shopping districts induces a yearly welfare loss of about €275 per permit, which is about 15% of the supply cost of a parking place.

1. Introduction

On-street parking pricing receives much attention in economic theory (e.g., Arnott et al., 1991; Verhoef et al., 1995). Theory recommends that parking prices should be used to allocate on-street parking places to users with the highest willingness to pay (Vickrey, 1954). In many parts of the world, this recommendation is not followed. For example, in the US, minimum parking requirements and below-market street parking prices are the norm. In the Netherlands, this principle is widely used, particularly in downtown cities, except when it comes to residential parking. Dutch cities allocate street parking to downtown residents by supplying residential parking permits almost free of charge to all residents in paid parking areas. As a consequence, the number of residential parking permits is non-negligible. For example, in the historic city center of Amsterdam, the number of residential parking permits is almost equal to the number of street parking places (about 100,000), see Gemeente Amsterdam (2000). Arguably, the provision of residential permits distorts the parking market through demand, because (street) parking places are occupied by residents with a willingness to pay for parking that is lower than the visitors' willingness to pay, and through supply, as it encourages supply of expensive (garage) parking to address visitors' demand.

Residential parking permits are not only common in the Netherlands but can be observed in many European countries. For example, in the UK, 'residential permit holders only' districts, where nonresidents are not allowed to park, can be observed in the smallest villages as well as in the main cities. A good example is the wealthy borough of Kensington and Chelsea (London, UK), where 82% of the 34,000 on-street parking places are allocated to residential permit holders only, and the number of permits exceeds the number of street parking places. While residents pay £0.30 per day for a parking permit, the parking costs for nonresidents are £30 per day (Kensington and Chelsea, 2012).[1]

We can only speculate why we observe parking permit policies which make parking cheap for residents but not for nonresidents. One potential explanation is that residents are voters, whereas visitors do not vote. It then makes sense for local governments to maximize residents' welfare at the expense of nonresidents by differentiating parking tariffs. Our empirical results later on are consistent with this. We find that residential parking permits decrease the consumer surplus of nonresidents. Note that we ignore general-equilibrium effects, which may occur because high nonresidents' tariffs might be detrimental to profits of downtown shops.

We are not aware of any estimates in the literature about the induced welfare losses of residential permits. In the current paper we aim to derive these costs for parking permits that are offered to Dutch residents who live within large shopping districts that are predominantly downtown. These districts are usually mixed in the sense that they contain both shops and residential housing, so shoppers and residents both have a demand for parking in the same location. Frequently, the parking

☆ We would like to thank Goudappel Coffeng BV, and in particular Niek Bosch, for providing Parkeermonitor data and two anonymous referees, Richard Arnott, Donald Shoup, the participants of seminars at the Tinbergen Institute, VU University and Kuhmo Nectar in Berlin for their useful comments.
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[1] Residential parking permits are apparently not extremely common in the US, perhaps because minimum parking requirements usually induce an oversupply of off-street parking (Shoup, 2005; Cutter and Franco, 2012). Nevertheless, they can be found in San Francisco, Chicago and Boston and have recently been approved in New York. In New York politicians are concerned that the recently opened Brooklyn Barclays Centre, a sports arena with limited parking, might have negative consequences for residents parking (CBS New York, 2011).

0166-0462/$ – see front matter
http://dx.doi.org/10.1016/j.regsciurbeco.2013.11.003

demand by shoppers and residents occurs at the same time. A recent poll for the West of Amsterdam indicates that 50% of households with a residential parking permit use the car at most one day per week (Trajan, 2009), suggesting that their cars remain parked for most of the time.

Residential parking permits are particularly distortionary if the parking supply is not fully elastic, because residents consume more on-street parking and shoppers consume less on-street parking than would be optimal. Knowledge of the parking supply function within shopping districts is then useful to derive the order of magnitude of the welfare effects of residential parking permits. In the current paper, we estimate the long-run (inverse) parking supply function using a dataset of about 300 of the largest shopping districts in the Netherlands, most of them (about 80%) being downtown shopping districts. Importantly, we employ a unique dataset with detailed information about street and garage capacity. Our main finding is that parking supply is quite elastic in downtown shopping districts, but possibly perfectly elastic in suburban and out-of-town shopping districts. This suggests that parking policies that provide parking permits to residents increase parking costs for nonresidents in downtown shopping districts, which has negative implications for welfare.[2] Our results suggest that the Dutch residential parking permits policy induces an annual welfare loss of about 100 to 140 million euro per year, which is about 15% of the parking supply costs in downtown shopping districts. 80 to 90% of this loss is borne by nonresidents.

The outline of the rest of the paper is as follows. In Section 2, we will discuss the main theoretical considerations to estimate the welfare losses of a residential parking permit policy. In Section 3, we discuss the institutional context and will focus on the empirical results. Section 4 discusses the welfare implications and Section 5 concludes.

2. Theory and welfare

2.1. Theoretical considerations

The welfare loss of a residential parking permit policy depends on the properties of the residents' and nonresidents' demand and supply functions. In the current paper, we will estimate the (inverse) supply function relevant to nonresidents. By making assumptions on the demand function we are able to determine the boundaries of the welfare loss.

There is a large empirical literature on parking demand.[3] However, as far as we know, there is only one empirical study about parking supply which does not apply to shopping districts.[4] Parking supply is likely perfectly price elastic in out-of-town shopping malls with large outdoor car parks (Hasker and Inci, 2011), but this is unlikely to be true for parking within mixed downtown shopping districts which combine street and garage parking places. When parking supply includes garage parking, it is unlikely that parking supply is perfectly elastic.[5] Note that it is a misconception that street parking is perfectly inelastic, even within historical city centers, because parking places may be converted into pedestrian areas or street lanes, which reduces traffic congestion (Arnott and Inci, 2006).

In order to identify the parking supply curve, we make a few strong assumptions. First of all, we assume that street and garage parking are perfect substitutes for nonresidents. Furthermore, we assume that parking suppliers are free to set parking prices and that they apply marginal cost pricing.

One may argue that street and garage parking are not perfect substitutes, for example because they are not at exactly the same location. This is consistent with Kobus et al. (2013), who show that drivers have a preference to park on-street. However, the average drivers' willingness to pay to park on-street is small and equal to only €0.25, so the perfect-substitution assumption is a reasonable approximation. Arguably, garage parking represents a safer place to park the car compared to on-street parking. So, drivers with more expensive cars might prefer off-street parking. As far as we are aware, this issue does not play a role in shopping districts particularly during shopping hours. When street and off-street parking are perfect substitutes (and freely compete with each other within a shopping district), then, despite any difference in construction costs, their prices are equal to each other (Calthrop and Proost, 2006). So, we will estimate the parking cost function ignoring the type of parking (garage or street parking) that is supplied.

There are many reasons to believe that the marginal cost pricing assumption does not hold. One fundamental criticism of the marginal cost pricing assumption is that local monopolistic behavior by commercial parking garages is likely present when local governments keep street prices low (Arnott, 2006; Arnott and Rowse, 2009a). As we shall see, the consequences for pricing of this behavior is not important in the Netherlands, because on-street and garage prices are roughly equal, and street parking is the dominant form, so as a simplifying assumption we believe that the marginal cost pricing assumption is reasonable.

Another criticism is that the presence of second-degree (nonlinear) price discrimination is strongly suggested by the well-known observation that parking usually occurs at a price discount for longer parking durations (National Parking Association, 2009).[6] Prices for short durations then exceed marginal costs, whereas prices for long durations equal marginal costs.[7] However, particularly when parking duration restrictions are applied, parking may be free for the first hour(s), the opposite may be true. Hence, to deal with second-degree price discrimination, we will use prices *per day* rather than per hour. There are however also other reasons to use prices per day. In particular, it does not require additional information about the average daily occupancy rate. As we lack this information, it makes more sense to focus on day prices. In the sensitivity analysis, we will show that using prices of the first hour parking generates almost identical results.

So, given the strong competition of suppliers within and, in particular, between shopping districts, the marginal cost pricing assumption seems reasonable.[8] However, differences between price and marginal costs are expected to exist, for example due to unexpected strong or weak demand. When these differences are random, we will still obtain consistent estimates of the inverse supply function. So, the marginal cost pricing assumption generates consistent estimates when parking is not systematically over- or undersupplied.

The welfare loss of a residential parking permit policy depends not only on the number of residential parking permits issued, but also on other local government policies, like the setting of on-street prices and the regulation of commercial parking prices. It is well known that setting the street prices far below garage prices will induce cruising

[2] In this paper, we ignore the effect of residential parking permits on car ownership. As the costs of car ownership decrease, car ownership and car use may increase, which may cause additional parking and traffic congestion problems.

[3] About 25 years ago, reviews by Feeney (1989) revealed 20 revealed parking demand studies. For more recent contributions, see for example, Kelly and Clinch (2006, 2009). Stated-preference studies are also common, see e.g. Axhausen and Polak (1991) and Hensher and King (2001).

[4] This study reports that the long-run supply function of employer-owned parking near office buildings is perfectly elastic (Van Ommeren and Wentink, 2012).

[5] Garage parking implies substantial fixed cost. In addition, marginal building costs for underground parking increase steeply with the number of parking levels. Arguably, there are constant returns to scale in terms of number of garages. So, in districts that contain *only* garage parking, parking supply may be perfectly elastic (see Arnott and Inci, 2006). These districts are rare in our dataset.

[6] The observation that prices vary within the day (e.g., night prices are often zero) is *not* evidence of third-degree price discrimination, because the daily parking supply costs are fixed.

[7] Local governments may set parking charges above marginal costs for shorter durations for a completely different reason: i.e. to charge for car congestion, (see Glazer and Niskanen, 1992).

[8] The empirical finding that shoppers' choice of parking is very price elastic for longer parking durations (Kobus et al., 2013) also suggests that monopolistic competition is not so much an issue when using parking prices for long durations.

for parking (Shoup, 2005; Calthrop and Proost, 2006). Although price regulation does occur in the Netherlands, it is rare, as commercial suppliers hardly ever have a dominant position, so they have little market power. Price regulation only occurs in shopping districts with only one or two dominant commercial garage parking suppliers and little street parking (e.g., within the inner cities of Almere and Maastricht). In these shopping districts, price regulation is likely applied to induce marginal cost pricing. We will document for our data that on-street prices in the Netherlands are approximately equal to garage prices, so we will assume away any cruising externalities.[9]

Local government policies aim to deal with a number of negative externalities related to parking. It is relevant here to distinguish between negative externalities of the *parking site* (as car parked, as well as garages, are considered to be ugly) and any negative externalities related to *car travel* (e.g., congestion, pollution).

Many districts are in historic centers (built before 1930), where construction of residential, and particularly nonresidential, buildings is strongly regulated to protect historic amenities which create substantial benefits, as they attract tourists and increase house prices (Leichenko et al., 2001). For this reason, in Dutch shopping districts over the last 30 years, with few exceptions, the construction of parking sites has been heavily regulated, and in practice only *underground* parking garages have been allowed. This type of regulation must have strongly increased the private cost of parking provision (although land prices in many shopping centers are sufficiently high to justify underground parking garages even in the absence of regulation). So, this type of regulation shifts the private supply curve upward, but this has furthermore no consequences for our estimation strategy.

The other negative externality related to parking is that negative externalities of car use are not priced. These negative externalities can be (partially) internalized using restrictions on parking using maximum norms regarding the number of parking places. Given appropriate pricing of on-street parking, maximum requirements may *improve* welfare when traffic congestion is not internalized (Shoup, 2005; Arnott and Rowse, 2009a). Minimum requirements may improve welfare when street parking is underpriced (as it reduces cruising), but this is less applicable in the Netherlands.[10]

In the spirit of Arnott and Rowse (2009a), the use of maximum requirements may be interpreted as a welfare-improving (but second-best) policy when pricing of traffic congestion is not feasible. We focus on nonresidential parking only, as we assume them to be the only contributors to traffic congestion and we assume that parking demand and traffic congestion are one-to-one related to each other.

Traffic congestion induces a difference between the private cost curve of parking and the social cost curve of parking. In equilibrium, the market number of parking spaces exceeds then the socially optimal number of parking spaces (conditional on the residential parking permits policy), so a standard deadweight loss (the triangle) arises due to the traffic congestion externality. Therefore, the government may restrict the number of parking places to the socially optimal number of parking spaces.

Note that this policy is welfare improving, but prices exceed the marginal cost of parking provision, causing private suppliers to make additional profits. When these profits are passed onto the local government (or passed to inhabitants as a lump sum), the socially optimal equilibrium offers a higher welfare to the population of residents and nonresidents.[11] This is usually the case because most parking supply (all street parking and about half the garages places) are owned by the local government. So, most additional revenues due to maximum parking requirements go to the local government. In addition, governments extract profits from private operators by granting building concessions. In the welfare analysis, we will assume that local governments determine the socially optimal number of parking places, which means there are no welfare losses due to overprovision of parking. So we aim to estimate the social, not the private, cost curve.

2.2. Calculation of the welfare loss

Our welfare analysis will be based on the crucial assumption that the total number of parking places in each shopping district is optimally chosen by the government (see Section 2.1), but there is a welfare loss because too much parking is allocated to residents through parking permits. Furthermore we will assume that the willingness to pay by shoppers exceeds the willingness to pay of current residents with a residential parking permit.[12] If this assumption does not hold for all residents in the short run (for example, just after a shopping center is extended), it is likely to hold in the long run when residents with cars will relocate to other residential locations where there are fewer shops.[13] We emphasize that our welfare calculations do not include any welfare loss for residents parking, which means that we underestimate the welfare loss.

To derive the long-term welfare loss, it would be ideal to have information about the demand function for parking by residents as well as nonresidents (shoppers). We lack this information, so we proceed by making assumptions about the shape of the demand function, so we are able to give the range of welfare loss due to residential parking permits. The welfare loss depends then on the number of residential parking permits per district. In the Netherlands, when paid parking is introduced, residents are entitled to at least one permit.[14] The number of residential parking permits provided is usually close to the number of street places. We will assume there are R street parking places occupied by residents at times when shoppers aim to park. In addition, we assume that Q_r garage parking places are used by nonresidents who visit the shops. The remaining M street parking places are assumed to be used some part of the day by residents with permits, but the deadweight loss of these M permits is assumed to be negligible. In this way, we obtain (extremely) conservative estimates of the welfare loss. Later on, we will make assumptions on the numerical values of R, Q_r and M.

We will assume furthermore that the combined willingness to pay of the permit holders is equal to the combined supply costs of the parking places. This is a reasonable approximation, because willingness to pay by the residents with a permit as well as the supply costs of the *first* R street places will be low relative to the equilibrium price.[15]

Given these simplifying assumptions, the welfare loss due to residential parking permits can be derived assuming first the absence of

[9] This is in line with Van Ommeren et al. (2012), who show that the average on-street cruising time for shopping activities is less than one minute.

[10] Maximum requirements refer to the upper limit of the amount of parking space supplied imposed by the (local) government, while minimum requirements refer to the lower limit of the amount of parking space supplied.

[11] For example the largest Dutch parking operator is largely owned by the pension-fund for civil servants.

[12] In principle, one would like to take into account that some residents may do their shopping with their car so they are also nonresidents. Because the fraction of time spent on shopping is small compared to the overall parking time by residents near their house, this issue can be ignored.

[13] In the long run, except when residential parking permit policies subsidize residents, shopping districts will predominantly contain households who have a low demand for residential parking.

[14] In smaller cities, the number of permits is equal to the number of cars owned. However, if the parking occupancy rate is close to 1, which is more common in residential areas of large cities built before 1930, then it is common to restrict the number of parking permits to avoid cruising (e.g., the number of permits is restricted to maximally one or two per household).

[15] When residents do not receive parking permits, residential parking close to shopping districts will be less attractive to residents with a strong preference for cars. So, it seems reasonable to assume that the residents' willingness to pay for street parking is low, given the presence of a parking permit. The provision of parking permits reduces the cost of parking for households, preventing efficient household sorting across residence locations (see, similarly, Kim, 2012), so the presence of car-loving residents in shopping districts is likely the result of parking permit policies.

the parking permit policy, and then allow the inverse parking supply curve to shift to the left by R units. This shift is indicated in Fig. 1 as a shift in the supply function from S to S′. P_r and P_u denote the parking prices in the regulated and unregulated equilibrium.

This shift in supply affects the nonresidents, who are assumed to be the high-demand consumers, indicated by the bold demand curve in Fig. 1. In this figure the welfare loss is indicated by the shaded area between the supply curve S and the shifted supply curve S′. Given linear nonresidents' demand and supply functions, the total welfare loss per day per shopping district is equal to (see Appendix A2 for details):

$$\text{Welfare loss} = \frac{1}{2} s\mathrm{R} \cdot (Q_r + Q_u), \tag{1}$$

where Q_r denotes the number of nonresidents in the regulated optimum, Q_u denotes the number of parking places provided to nonresidents in the absence of the provision of parking permits, s denotes the marginal effect of parking supply on parking prices (per day) and R denotes the number of residents' cars parked at times when shoppers aim to park. Q_u is endogenously determined and depends on the price elasticity of demand, the number of nonresidents and the number of residents cars parked.

Given the nonresidents' price elasticity of demand, we can calculate the welfare loss.[16] Because most nonresidents (excluding commuters) park for a short duration, it is usually thought that the demand for parking is rather inelastic. A price elasticity of demand of −0.3 is sometimes suggested, see Litman (2012).[17] We will use this figure in the welfare analysis, along with the extreme cases of perfectly elastic and perfectly inelastic demand.

3. Empirical results

3.1. Institutional context

In Dutch city centers, only a small percentage of residences have a private parking place. Despite the small number of private parking places, most households own a car. So, the large majority of residents rely on on-street car parking. In districts with residential permits, residents may apply for parking permits at a price which is only a tiny fraction of the price paid by nonresidents. This permit allows them to park for free in the area close to the residence but does not offer any other advantages. The permit is predominantly used for residence parking and seldom for other purposes. Application of a permit requires one to have a registered address in the district for which the permit is issued and requires car ownership. Revenue generated from parking permit fees is usually earmarked to cover the administrative costs of providing parking permits. Other parking revenues are either not earmarked or used for transport-related municipality expenses.[18] Residential parking policies are ubiquitous: virtually everywhere in the Netherlands residents in paid-parking districts can receive on-street parking permits. In contrast to many other cities in the world (e.g. London, Paris), permit-only parking areas are uncommon, so on-street parking places are in principle available to both residents and nonresidents.

In the US, when street parking prices are below of-street parking prices, it is common to have street parking time limits (Arnott and Rowse, 2009b). In contrast, in the Netherlands, there are usually no parking time limits. The proportion of parking places occupied by residents with permits is unknown for most areas, but is generally high. For example, in Amsterdam, on average, between 69 to 80% of parking places are occupied by residents with permits (Gemeente Amsterdam, 2005). Local governments aim to avoid cruising for parking by nonresidents through the setting of street prices (particularly in large municipalities) and avoid cruising for parking by residents in the evening by limiting the number of residential permits (usually by putting constraints to the number of permits per household).

In the Netherlands, mixed shopping districts are the norm, so there are both shops and residents in almost each street within a shopping district. Most shops are located downtown, usually within historic city centers (about 80%), or within suburban residential districts (about 15%). The remaining 5% are out-of-town shopping malls. In these shopping districts, the shoppers' willingness to pay for parking *per unit of time* is almost always an order of magnitude higher than the residents' willingness to pay. For example, in Amsterdam, the residents' willingness to pay for parking is maximally nine euro per *day* (but usually much less), whereas for nonresidents who park it is at least five euro per *hour* (Van Ommeren et al., 2011). The main reason for this difference is that the willingness to pay per unit of time is a decreasing function of parking duration and nonresidents typically park for a much shorter duration than residents. For example, the average parking duration for nonresidents is about one hour in Almere, a city of about 200,000 inhabitants in the Netherlands, see Kobus et al. (2013), whereas many residents park all day.

3.2. Data and descriptives

We use a dataset about parking in 308 of the largest shopping districts of the Netherlands for the year 2007 based on the survey Parkeermonitor, 2007–2008. The data include only large shopping districts. On average, a shopping district contains about 31,000 square meters of floor area, containing about 200 shops on average. The total floor area in our dataset comprises 34% of *all* floor area in the whole country (about 28 million square meters).

Parking refers to all garage and street parking places up to one hundred meters from the shopping district boundary that are available to the public.[19] We ignore parking places owned by residents for two reasons: first, the number of privately-owned parking places is small (for example, in Amsterdam about 5 to 10% of residents in shopping districts possesses a privately owned parking place, see Van Ommeren et al., 2011). Second, these parking places are unavailable to shoppers.

On average, there are about 1700 parking places per district: 1200 on-street and 500 in garages.[20] Garage parking is present in about half of the districts, whereas street parking is almost always (94% of the shopping districts) present. Descriptives are reported in Table 1, including descriptives about three subsamples (only garage parking; garage parking present; only street parking). Table 1 shows that the average garage parking share, defined as the ratio of garage capacity to total capacity, is equal to 0.22 (in districts with garage parking, the average is 0.42, so also then street parking outnumbers garage parking). The average number of parking places per 100 square meters of shopping area is slightly more than six. This value is roughly the same when garage parking is present, indicating that the relationship between number of parking places and floor area is not fundamentally dependent on the presence of garage parking. We have information about parking prices per hour (for the first hour) and per day. In about half

[16] In the Netherlands, parking demand is likely more elastic than in other countries, because the majority of shoppers do not travel by car, but travel by bicycle or public transport (Mingardo and Becker, 2012).

[17] The relevant parking demand sensitivity here is the one that captures changes both at the extensive (the decision to park) as well as the intensive margin (the duration of parking).

[18] For example, it has been proposed to use revenues to finance a traffic safety plan, see Gemeente Amsterdam (2011).

[19] The consultancy firm which collected the data defines shopping districts by a minimum number of shops or minimum floor area. Although the boundaries of these shopping districts are subjectively chosen, in most cases it is perfectly feasible to define shopping district boundaries rather precisely. This is particularly easy when the shopping area is largely pedestrianized.

[20] In our data, we are not able to distinguish between street parking and outdoor car parks, so street parking includes outdoor car parks.

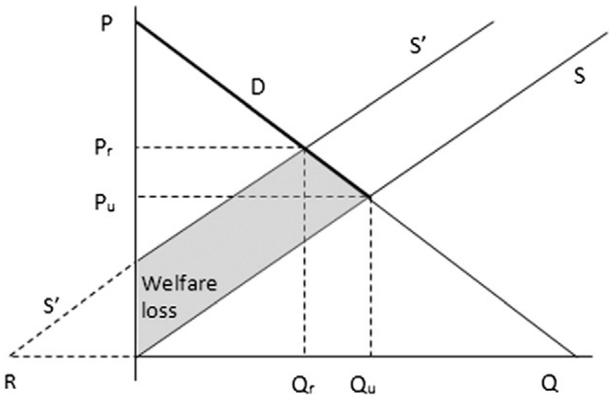

Fig. 1. Welfare loss of residential parking permits. Note: the nonresidents are the high-demand consumers (bold line).

of the districts, prices are zero (but in only 20% of districts with garage parking).

The average street price is €0.69 per *hour*, slightly below the average garage price of €0.93. Given paid parking, the average street price is €1.50 per hour, in line with other sources, see Van Dijken (2002). When garage and street parking are both present in the same district the average street price is €1.06 per hour, which slightly *exceeds* the average garage price of €0.93 per hour. To measure supply costs, we will ignore any existing difference between these prices, consistent with the assumption that the street and garage parking are perfect substitutes. We will use the maximum of street and garage prices per district, which will be referred to as the 'parking price'. The average hour parking price is €0.81 (see Table 1). Using the maximum per district is rather arbitrary, but using other measures, such as the average per district, generates almost identical results.

The average parking price *per day* is €5.13, about seven times higher than the price for the first hour (implying that parking for longer than seven hours occurs at a discount). The data allow us to distinguish between different shopping districts locations within cities: downtown (e.g., at least 400 shops in the largest inner cities), suburban and out-of-town shopping malls (containing few, but large shops). As emphasized in the introduction, in our data, downtown shopping is the dominant form of shopping, as about 80% of all districts are downtown (the share of downtown shopping floor space is even slightly higher).

In addition to parking prices and quantities data from Parkeermonitor, we use data about median annual rent for shop space (per square meter) *per district* to proxy land prices within cities. The shop rent is plausibly the best indicator for land prices in our context of nonresidential parking, because the main opportunity cost of a car park is to forego the benefits of a building that contains shops. These data are obtained from transaction data provided by PropertyNL (see also Van Ommeren and Wentink, 2012). We also use data about municipality population as well as population density per municipality obtained from Statistics Netherlands (2008).

The Dutch nongovernmental organization CROW recommends shops to provide between 2.5 and 4 parking places per hundred square meter floor space (CROW, 2008). Note that it is not clear to what extent

Table 1
Descriptives.

						Garage parking only				
	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Hour street price	290	0.69	0.83	0	4.6					
Hour garage price	161	0.93	0.93	0	5.2	18	0.57	0.89	0	2
Hour price difference	143	0.09	0.75	−3.7	2.1					
Hour parking price	308	0.80	0.95	0	5.2	18	0.57	0.89	0	2
Day street price	276	3.84	6.10	0	41.4					
Day garage price	159	7.00	7.66	0	47.5	18	7.39	10.51	0	36
Day price difference	138	−0.98	5.57	−14	18.4					
Day parking price	292	5.13	7.04	0	47.5	18	7.39	10.51	0	36
Street parking places	308	1172	1018	0	8000					
Garage parking places	308	501	1000	0	7561	18	829	1757	52	7561
Parking places	308	1673	1675	30	11,167					
Garage parking share	308	0.22	0.29	0	1					
Floor area (×1000)	308	30.6	31.0	4.1	238.2	18	27.5	27.7	5.7	98.6
Parking places/100 m^2 floor area	308	6.44	4.03	0.30	24.59	18	2.16	2.32	0.39	9.65
Downtown	308	0.78	0.42	0	1	18	0.50	0.51	0	1
Suburban	308	0.19	0.39	0	1	18	0.39	0.50	0	1
	Garage capacity present					On-street parking only				
	Obs.	Mean	SD	Min	Max	Obs.	Mean	SD	Min	Max
Hour street price	143	1.06	0.90	0	4.6	147	0.33	0.58	0	2.1
Hour garage price	161	0.93	0.93	0	5.2					
Hour price difference	143	0.09	0.75	−3.7	2.1					
Hour parking price	161	1.23	1.02	0	5.2	147	0.33	0.58	0	2.1
Day street price	139	5.79	7.07	0	41.4	137	1.86	4.08	0	18.9
Day garage price	159	7.00	7.67	0	47.5					
Day price difference	139	−0.98	5.57	−14	18.4					
Day parking price	155	8.02	7.81	0	47.5	137	1.86	4.08	0	18.9
Street parking places	161	1373	1281	0	8000	147	952	535	30	3279
Garage parking places	161	958	1216	24	7561					
Parking places	161	2331	2052	52	11,167					
Garage parking share	161	0.42	0.29	0.04	1					
Floor area (×1000)	161	42.5	37.6	5.4	238.2	147	17.6	12.3	4.1	82.7
Parking places/100 m^2 floor area	161	6.40	4.02	0.39	23.84	147	6.48	4.05	0.30	24.59
Downtown	161	0.77	0.42	0	1	147	0.79	0.41	0	1
Suburban	161	0.19	0.39	0	1	147	0.18	0.39	0	1

Note: price difference = street price–garage street price. Parking price = max (street price, garage price).

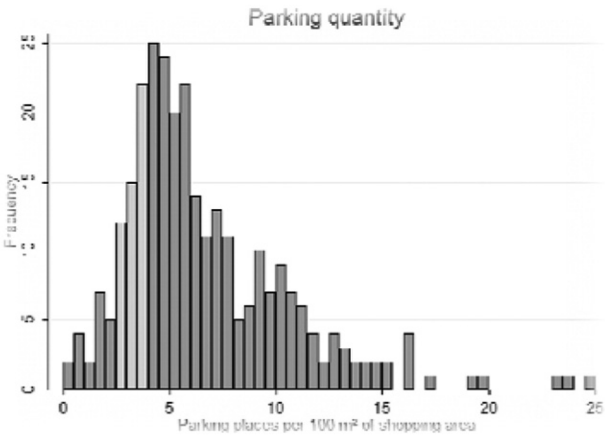

Fig. 2. Number of parking places per 100 square meter of shopping area. Note: Highlighted bars indicate observations within advised parking requirements range of CROW.

the use of price of parking is included in these minimum and maximum requirements. Although this organization has no legal power, most Dutch municipalities follow its recommendations, so these requirements allow us to do some consistency checks on the data. The parking places in shopping districts we focus on are also used by residents, so the total parking supply must usually exceed the maximum requirement for shopping (Fig. 2). When garage parking is present, shoppers still make use of street parking, *garage* supply must be usually less than the minimum requirement for shopping, see Fig. 3. We see that both figures suggest that our data are consistent with these statements.

3.3. Empirical approach

We estimate the *inverse* supply function for nonresidential parking, so we estimate the price of a parking place as a function of the number of parking places. We will use a cross-section of observations. Hence, we will identify the long-run supply function. We estimate the inverse parking supply function rather than the supply function, because only for the inverse function we are able to find valid instruments to deal with endogeneity, as discussed later on. We assume a linear specification, so:

$$p_{im} = \alpha + \beta q_{im} + \gamma x_{im} + \delta x_m + \varepsilon_{im}, \tag{2}$$

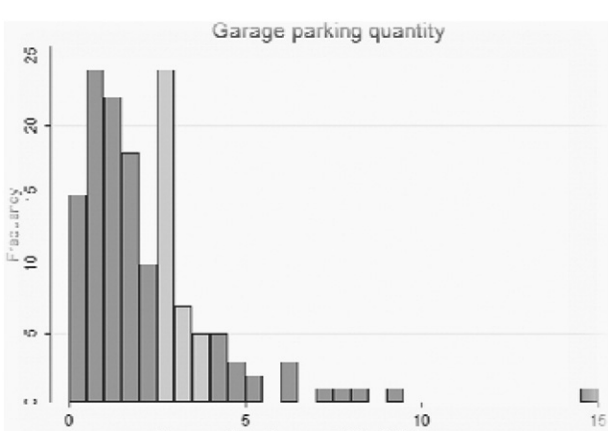

Fig. 3. Number of garage parking places per 100 square meter of shopping area. Note: Areas with garage parking only. See furthermore Fig. 2.

where p_{im} denotes the parking price of shopping district *i* in municipality *m*, q_{im} denotes the parking quantity, x_{im} denotes district-specific control variables, x_m denotes a municipality-specific control variable and ε_{im} is an error term. Furthermore, α, β, γ and δ are the coefficients to be estimated. We also estimate log–log models where both the dependent and explanatory variables are in logarithms.

One important issue is that the price of parking may vary between districts, because of between-district variation in land prices. Because land prices are unknown, we proxy land prices in several ways. In a basic specification, we use municipality population, municipality population density and within-city shopping district location.

In addition, in a more elaborate specification, we estimate models where we include *municipality fixed effects*, $\delta_{\rm m}$, as well as median rents for shop space per district as a proxy for land prices.[21] So, we estimate:

$$p_{im} = \alpha + \beta q_{im} + \gamma x_{im} + \delta_m + \varepsilon_{im}. \tag{3}$$

To identify the inverse supply function of parking, we have to take into account that q_{im} also depends on demand, so q_{im} is endogenous as it is correlated to ε_{im}. We deal with this issue using an instrumental-variables approach. To identify the inverse parking supply function, we use *floor shopping area* z_{im} as an instrument (so in the first step of the IV, we run a regression of q_{im} on z_{im} while controlling for the other explanatory variables in (2) and (3) respectively). Hence, we argue that the floor shopping area captures the *shoppers' demand for parking*, but does not directly affect the cost of parking, and therefore the inverse parking supply function.[22] This instrument seems plausible, particularly given the range of controls for land prices. We emphasize that the instrument relies on the more fundamental assumption that parking supply costs do not determine the size of the floor shopping area. This assumption seems reasonable, as parking costs are small compared to overall expenses by shops. This is particularly reasonable in the Dutch context where only a minority of shoppers travel by car (e.g., Mingardo and Van Meerkerk, 2012). We also emphasize that this instrument shifts the demand curve and therefore identifies the *social* parking supply curve when regulation is present. So, for example, the instrument is valid given the presence of maximum requirements as long as these requirements are optimal from a welfare perspective.

One issue we have to deal with is that in many districts, parking is free to nonresidents (in our dataset that turns out to be about 50%, in particular when garage parking is absent). Parking may be free because there is excess parking supply, so the marginal costs are zero. Another reason is that these zero prices do not reflect marginal parking costs, either because the local government directly subsidizes parking (by buying land and converting into street or garage parking), or because the shop owners pay for parking (Hasker and Inci, 2011).[23] The third reason is that the (suppliers') transaction costs of charging for parking are not negligible. In the Netherlands, electronic paid-parking machines are virtually everywhere introduced. Van Dijken (2002) reports that these transaction costs are about €350 per place per year, suggesting that it is not cost-effective for suppliers to charge parking when the cost of provision of parking (excluding charging costs) are rather low (e.g. less than one euro per day). The fourth reason is that the local

[21] We do not control for median rents in the specification without municipality fixed effects, because we frequently miss information about rents in smaller municipalities with one shopping district. These observations essentially dropout given municipality fixed effects.

[22] Note that larger shopping districts (in terms of shopping floor area) are almost always larger in terms of streets, so the number of street places is directly related to the size of shopping floor area. Consequently, floor area is invalid as an instrument to estimate parking supply functions, whereas perfectly valid for *inverse* parking supply functions.

[23] Hasker and Inci (2011) show, rather surprisingly, that under some circumstances (which likely do not hold in the shopping districts we analyze) that this is efficient. We ignore this issue here.

Table 2
Inverse parking supply.

Price	IV Tobit				IV Tobit (Log–log)			
			Garage present				Garage present	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Parking places (/1000)	3.168***	3.395***	2.785***	2.843***	0.995***	1.196***	0.880***	0.945***
	(0.284)	(0.321)	(0.320)	(0.392)	(0.132)	(0.183)	(0.156)	(0.249)
Municipality population	14.4***	12.1***	11.1***	11.1***	0.448***	0.324***	0.325***	0.316***
	(2.69)	(3.27)	(3.48)	(4.41)	(0.082)	(0.121)	(0.098)	(0.160)
Municipality population density	0.771	0.636	0.386	0.352	0.142	0.114	0.050	0.043
	(0.408)	(0.413)	(0.476)	(0.483)	(0.089)	(0.092)	(0.105)	(0.106)
Shopping district type	No	Yes	No	Yes	No	Yes	No	Yes
Log likelihood	−2739	−2712	−1496	−1487	−471	−450	−237	−227
No of observations	275	275	138	138	275	275	138	138
No of observations below threshold	141	141	36	36	141	141	36	36
F-test (weak instruments)	754.05	669.77	399.20	284.26	245.24	140.19	161.04	71.74

Note: municipality population in millions. Municipality population density in thousand persons per square kilometer. The censoring threshold is €2 or ln €2 in the log–log specification.
* Significant at 10 percent level.
** Significant at 5 percent level.
*** Significant at 1 percent level.

Table 3
Inverse parking supply functions, alternative specifications.

Price	IV Linear				IV Tobit			
			Garage present				Garage present	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Parking places (/1000)	2.119***	2.627***	2.321***	2.730***	2.856***	2.548***	2.721***	2.639***
	(0.366)	(0.670)	(0.454)	(0.834)	(0.319)	(0.587)	(0.346)	(0.583)
Shop space rent (median)	0.030	0.020	0.039	0.029	0.046*	0.041	0.043	0.038
	(0.027)	(0.028)	(0.033)	(0.035)	(0.023)	(0.023)	(0.025)	(0.025)
Shopping district type	No	Yes	No	Yes	No	Yes	No	yeS
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No of observations	48	48	39	39	76	76	48	48
No of municipality fixed effects	19	19	19	19	21	21	19	19
F-test (weak instruments)	217.27	65.29	161.54	47.89	344.10	103.23	181.44	62.57
Observations with zero prices	No	No	No	No	Yes	Yes	Yes	Yes

Note: Results for municipalities with at least two (observations about) shopping districts. For other notes, see Table 2.

government enforces maximum parking duration restrictions. These restrictions are extremely common in the US, and can be justified as a second-best policy where policymakers do not have the power to raise the street prices to garage prices (Arnott and Rowse, 2009b). However, these restrictions are relatively rare in the Netherlands, and if they apply then they only apply to a few streets within a large shopping district. The main exception is smaller municipalities with one main shopping district. Unfortunately, we cannot distinguish between these four reasons.

The above considerations suggest that it may not be wise to remove these zero-price observations from the estimation procedure, because it is likely that zero prices are observed when the supply costs are low, so removing zero-price observations may create a selection bias. We deal therefore with this issue in three different ways.

First, for observations with parking prices below €2 per day, we do not use information about the exact level of the price, but in the estimation procedure we assume that the marginal cost per day is below two euro (approximately the level of the transaction costs per day of paying for parking).[24] So, we may then estimate Tobit models using a standard maximum-likelihood procedure, where we have left-censored observations with day prices *below* €2.

Second, we deal with this issue by estimating Tobit models on a subsample of observations where garage parking is present. In this case, zero prices are observed in only 20% of the cases. Of course, selecting observations where garage parking is present creates another, and arguably a similar, endogeneity issue which is not addressed. However, the interpretation of the results is now clearer, as the results refer to districts where garage parking is present. These are probably the districts we are most interested in.

Third, we estimate models including municipality fixed effects (and control for within-municipality differences in rents for shop space). This essentially excludes observations for which there is only one observation per municipality from the estimation procedure. The zero-price observations are predominantly in smaller municipalities, in which there is only one dominant shopping district, so for which we only have one observation. For the subset of observations with at least two observations per municipality, the share of observations with zero prices drops to only 20%. For this subset, we estimate Tobit models and linear models after excluding zero-price observations.

3.4. Main results

The use of floor shopping area as an instrument is key to our estimation procedure. We have tested the validity of the instrument in several ways. First, we use an F-test to determine the strength of the instrument. In all specifications, the F-tests were positive, so the instrument is strong. Second, we have estimated models where we do not use the floor shopping area as an instrument, but its two main components: the floor area dedicated to daily shopping (e.g., a supermarket) and the floor area dedicated to non-daily shopping (e.g., clothing). When we use these two instruments, we find almost identical results.

Third, more informally, we have tested whether the size of the floor area increases the *garage parking share*. One expects that floor area has a positive effect on this share, because an increase in demand for

[24] For hourly observations, we assume that the marginal cost per hour is below €0.30.

Table 4
Inverse parking supply: downtown only.

Price	IV Tobit		IV Tobit (Log–log)	
		Garage present		Garage present
	(1)	(2)	(3)	(4)
Parking places (/1000)	4.172***	3.358***	1.689***	1.402***
	(0.428)	(0.526)	(0.233)	(0.333)
Municipality population	−7.09	−0.279	−0.133	−0.083
	(6.66)	(8.29)	(0.171)	(0.238)
Municipality population density	0.817*	0.386	0.094	0.017
	(0.493)	(0.575)	(0.096)	(0.115)
Log likelihood	−2145	−1193	−317	−169
No of observations	219	110	219	110
No of observations below threshold	120	28	120	28
F-test (weak instruments)	398.40	152.28	139.71	52,56

Note: results for municipalities with at least two (observations about) shopping districts. For other notes, see Table 2.

Table 5
Welfare losses and equilibrium price.

	Demand elasticity (ε)					
Share of residents who park (α)	−0.1	−0.3	−0.6	−1.0	Relative loss of CS (ε = −0.3)	Equilibrium price
0.1	63	64	65	65	0.81	2.11
0.2	126	129	133	136	0.83	2.52
0.3	190	196	204	211	0.85	2.92
0.4	254	264	276	288	0.87	3.33
0.5	318	332	350	368	0.88	3.74
0.6	383	402	425	450	0.89	4.15
0.7	448	471	501	534	0.90	4.56

shopping area and therefore for land makes it more beneficial to substitute land for capital (high land prices is normally the main reason that garage parking is supplied). This expectation is confirmed by a two-limit Tobit analysis (with thresholds equal to 0 and 1 and the same explanatory variables as used in the inverse supply function).[25]

The main results are reported in Table 2, with additional analyses in Tables 3 and 4. All specifications show that an increase in parking capacity results in a strong increase in costs of parking.[26] We are particularly interested in the marginal effects of parking capacity, conditional that the price asked exceeds the threshold (when the price below the threshold, the relationship between prices and costs is less likely one-to-one). These marginal effects are equal to the reported coefficients of the Tobit model.

To interpret our results, we find it useful to focus on increases in capacity of 500 parking places. We have chosen 500 parking places, which is the mean number of *garage* parking places. So our experiment is that we want to know what happens to (marginal) parking costs when the number of garage parking places is increased from 0 to 500 as a result of increases in residential parking demand due to parking permit policies. We emphasize that 500 is not a large increase compared with total parking supply per district, which is 1700 on average, as street parking usually dominates garage parking.

According to specification (1) of Table 2, which assumes a linear specification and uses the IV Tobit approach, the marginal effect is about €$3.4 \cdot 10^{-3}$, so to increase the supply by 500 places implies an increase in the daily price of about €1.70. Calculated at the mean, this suggests an inverse price elasticity of supply close to one, so the supply of parking is far from perfectly elastic, suggesting that policies that increase demand (e.g., residential parking permit policies) are quite detrimental for welfare.

Furthermore, these results imply that in larger cities the supply costs are higher. In a large city with 1 million inhabitants (close to the size of Amsterdam), the supply costs per day are about €16.4 higher than in the smallest municipalities, ceteris paribus. When we control for shopping-district location, which is our preferred specification, we find slightly higher point estimates for the effect of number of parking places, see specification (2) of Table 2. When we limit our analysis to districts where garage parking is present, we find slightly lower estimates (see specifications (3) and (4) of Table 2). Given a log-linear specification (see (5) and (6) of Table 2), the effects of parking capacity are very similar: the inverse price elasticity of supply is also about one and even less when we focus on districts that include garage parking.

We have also estimated a range of specifications for models with municipality fixed effects and with the median rent for shop space (see Table 3). Again we find that the supply function is upward sloping, although slightly less steep than before. For the (preferred) specification (2), we now find that the effect is about $2.6 \cdot 10^{-3}$ (compared to $3.4 \cdot 10^{-3}$ in Table 2). Furthermore, we have examined the model for downtown shopping centers only (see Table 4). It appears that the supply costs increase more rapidly with parking capacity in these districts. Hence, this suggests that our results apply to downtown shopping districts and less in out-of-town shopping districts.

3.5. Sensitivity analysis

We have re-examined these results in many ways. The most important ones will be discussed here, and are reported in the Appendix A, but we would like to emphasize that other, non-reported, specifications

[25] One may use the garage parking share as an alternative indicator for the cost of parking using shopping floor area as an instrument for the number of parking places. We find a positive effect of the number of parking places on this share (the full results are in the Appendix A, Table A1): the share increases by about 0.10 when the number of parking places increases by thousand. This result seems reasonable suggesting that floor area is an appropriate instrument when estimating cost functions.

[26] This is, however, only true for downtown shopping districts, the dominant form of shopping in the Netherlands. This effect is absent for suburban and out-of-town shopping districts.

generate very similar results. So, our results are extremely robust to specification and data selection.

First of all, we have re-estimated models using different censoring thresholds. This is relevant, because the level of the threshold can be argued to be quite arbitrary. We find that the results are almost identical if we change the level of the threshold (see Table A2). For example, a 4 or 10-euro threshold does not substantially alter the supply curve.

Second, we have re-estimated the model for different categories of municipality size. Again, the results are quite robust (see Table A3). For example, if we limit the analysis to municipalities with at least 100,000 inhabitants, the slope of the supply curve is somewhat decreased.

Third, we have re-estimated the model using observations for hour prices (see Table A4). To compare the results, it is now more convenient to focus on the log–log specification. It appears that the inverse parking supply elasticity is somewhat reduced, especially when garage parking is present (the reduction in this elasticity is only about 0.2), so the results are not extremely sensitive to the choice of the price measure. Nevertheless, it suggests that parking supply is somewhat less sensitive than reported before.

Fourth, we have estimated models without using any instrumental-variable techniques (see Table A5). This approach may generate consistent estimates of the supply function but only when the supply function is identical for each shopping district (conditional on control variables), otherwise the supply estimates are usually downward biased. In line with this idea, it appears that the coefficients are substantially lower, although we still find a (statistically-significant) positive effect of parking quantity on parking costs in all specifications, except for one (specification (8)).

Fifth, we have assumed the government intervention to be socially optimal (e.g., they may include maximum parking requirements). So we have assumed that underground parking regulation is welfare improving and conditional on this regulation that quantity requirements are optimal. However, this may not always be the case.

For example, let us suppose that some local governments impose minimum garage parking requirements beyond the optimal market equilibrium (e.g., to guarantee sufficient supply for residents with parking permits). We don't know in which districts minimum garage parking requirements are applied. However, the distribution of the garage parking places in Fig. 3 provides some suggestive evidence for the existence of minimum parking requirements in some districts. The remarkably high frequency of shopping districts just above (the minimum requirement of) 2.5 (garage) parking place per 100 square meter suggests that there is some degree of (maybe distortionary) government regulation in these districts. Excluding these districts does not change the empirical results.

4. Welfare analyses

4.1. Main analysis

The welfare losses due to residential parking permit policy depend on the number of cars parked when nonresidents aim to park (R). On average, each shopping district contains about 1200 street parking places and the number of parking permits is roughly the same.[27] However, approximately half of residents with a residential parking permit park their car during the day during weekdays shopping hours (but a much higher share Saturdays), see e.g. Trajan (2009), so we assume R to be only 500. The number of nonresidents is equal to the number of garage parking places, so Q_r is equal to 500.

Let us assume now that nonresidents' parking demand is perfectly price elastic. When removing the residential parking policy, parking prices do not fall, but the demanded quantity for street parking by nonresidents increases (by 500 parking places). Given (1), the welfare loss per parking permit equals €1.06 per day, so €388 per year. When parking demand by nonresidents is perfectly price inelastic, the demanded quantity does not change, and the welfare loss per permit equals €258 per year.[28] Given a moderate price elasticity of -0.3, the implied annual welfare loss is €275 per permit. This is a substantial welfare loss compared to the mean yearly cost of a parking place, which is about €1930.

Given the assumption that the number of on-street parking places is equal to the number of households with a car, and that in these shopping districts, only half of the households own a car (which is a conservative estimate), the welfare loss is about €140 per household living in these districts, or €70 per capita. Nationwide, the welfare loss will be €100 to 140 million per year according to our conservative estimate (assuming an annual loss of €258 to 388 per parking place, 1200 on-street parking places per shopping district and 308 shopping districts).

We emphasize that the above estimate is likely an extremely conservative estimate. For example, in the plausible case that the number of residential parking permits (and demand for parking by nonresidents) is larger than presumed, then the annual welfare loss per residential parking permit is much higher, because the welfare loss increases more than proportionally in the number of parking permits. So, for example if the number of parking permits is twice as high as assumed, then the welfare loss per parking permit is *at least* twice high.

4.2. Sensitivity analysis of welfare analysis

In the welfare analysis we have calculated the welfare loss by varying the price elasticity of demand. In this section we will examine the robustness of our result, by also varying the share of residents who park their car on-street during the day and who receive a parking permit (see Appendix A1 for mathematical details). We keep the number of nonresidents fixed at 500, while we vary the price elasticity as well as the share of residents who park their car on-street during the day as a proportion of street capacity denoted by α (so α = R/total street capacity). Table 5 shows the yearly welfare losses per parking place.

Table 5 shows that the welfare losses are almost proportional to the share of residents who park their car during the day. This result is intuitive, because the higher the share, the more additional parking places have to be supplied for nonresidents and the higher the equilibrium parking price. When nonresidents are more price sensitive (the price elasticity is higher in absolute value), the welfare loss is higher, but the effect of the price elasticity on welfare loss is limited. Even when only 10% of the residents park their car during the day, the annual welfare loss is €63 per parking place. In streets where 70% of the residents park their car, the annual welfare loss can be as high as €534 per parking place.

[27] During the day, when shops are open, cruising by residential is usually negligible. In contrast, the occupancy rate is essentially one in the evening/night, so cruising for street parking by *residents* in the *evening* is common. Using information about house prices, the average cruising cost for residents are estimated to about one euro per day in Amsterdam, see Van Ommeren et al. (2011).

[28] In case of a perfectly elastic price, the welfare loss is equal to 0.5…3.4 10^{-3}…500 (500 + 1000) = €1275 per shopping center per day. Given an average number of 1200 permits (as the number of parking permits is roughly equal to the number of on-street parking places) per shopping district, the welfare loss per parking permit is €1.06 per day, or €388 per year. When the demand is fully price inelastic, the welfare loss per district is equal to $0.5 \cdot 0.0034 \cdot 500\ (500 + 500) =$ €850 per day, implying a loss of €258 per parking permit per year.

The welfare loss is due to a loss of consumer and producer surplus. Much of this welfare loss is borne by nonresidents, who experience a reduction of their consumer surplus. The loss of consumer surplus relative to the total welfare loss is equal to $(P_r - P_u)/(sR)$ (see Appendix 3 for details) and usually close to one. For example, given a demand elasticity of −0.3, the loss of consumer surplus accounts for 80 to 90% of the total welfare loss (see Table 5). This relative loss is less when nonresidents are more price sensitive, but higher when nonresidents are less price sensitive. In addition to the loss in consumer surplus, there is a small loss in the surplus of producers, i.e. the commercial and public parking suppliers.

Finally, the results in our welfare analysis strongly depend on the slope of the supply function. The slope of the supply function was estimated to be $3.4 \cdot 10^{-3}$ in the main analysis (see Table 2). The results of alternative models (see Table 3), suggest that the marginal supply costs are around $2.5 \cdot 10^{-3}$. Given this more conservative estimate, the welfare effects diminish accordingly by about 30%.

5. Conclusion

In the current paper, we aim to provide insight into the welfare losses of policies that provide on-street parking permits to residents almost free of charge. We focus on shopping districts, which are usually downtown, where there is also demand for parking by nonresidents, in particular shoppers. We derive the welfare loss by estimating (inverse) parking supply functions. Our empirical results indicate that downtown parking supply is far from perfectly elastic with an inverse price elasticity of supply of about one. This suggests that the ubiquitous provision of residential parking permits substantially increases the costs of parking supply. Rough welfare calculations indicate that the provision of on-street parking permits induces an annual welfare loss of about €275 per parking permit, which is about 15% of the parking supply costs. 80 to 90% of this loss is due to a loss of nonresidents' consumer surplus.

A parking permits policy provides advantages to local residents that are denied to nonresidents. It is well known that residents have strong incentives to prevent *local* policies that are welfare improving. In the spirit of Kunreuther and Kleindorfer (1986), we suggest that providing residents the option to sell their residential parking permit might be a politically acceptable solution which is welfare improving. To create a market for residential parking permits has a number of attractive properties: the price of the permits will reflect the residents' willingness to pay for parking, households who choose residence locations will internalize the social costs of street parking and local governments may reduce (or increase) the number of parking permits by buying (selling) the permits at market values. This idea is similar in spirit to the idea by Shoup (2004) who proposes to give residents the right to commercially exploit street parking and who may keep local parking revenue.

Appendix A

Appendix A1. The demand function in the unregulated equilibrium

We assume there is a number of nonresidents Q, which use garage parking. R denotes the number of residents who park their car. The demand and inverse supply functions are linear. Due to the presence of street parking, there are no fixed supply costs. The nonresidents are the high-demand consumers, so in the unregulated equilibrium there is only nonresidents parking and $S = sQ$. In the regulated equilibrium $S' = s(Q + R)$. The number of nonresidents Q_r equals 500. Given a point elasticity $\varepsilon = \frac{\partial Q}{\partial P}\frac{P_r}{Q_r}$ (defined for the regulated equilibrium), the slope of the demand function is $\frac{\partial P}{\partial Q} = \frac{1}{|\varepsilon|}\frac{s(Q_r+R)}{Q_r}$ and the intercept is: $C = s(Q_r + R) + Q_r\left(\frac{1}{|\varepsilon|}\cdot\frac{s(Q_r+R)}{Q_r}\right) = s(Q_r + R)\left(1 + \frac{1}{|\varepsilon|}\right)$, so the demand function for parking can be written as $D = -\frac{s(Q_r+R)}{Q_r|\varepsilon|}Q + s(Q_r + R)\left(1 + \frac{1}{|\varepsilon|}\right)$. The number of nonresidents Q_u in the unregulated equilibrium can then be obtained by solving $D = S$. This yields: $Q_u = Q_r\frac{Q_r(|\varepsilon|+1)}{Q_r(|\varepsilon|+1)+R}$.

Appendix A2. Derivation of the total welfare loss

The total welfare loss due to the shift in supply from S to S′ is the reduction of the area between the demand and supply curve in Fig. 1. Hence:

$$\begin{aligned}\text{Welfare loss} &= \int_0^{Q_u}(D(Q)-S(Q))dQ - \int_0^{Q_r}\left(D(Q)-S'(Q)\right)dQ \\ &= \int_0^{Q_u}D(Q)dQ - \int_0^{Q_r}D(Q)dQ - \int_0^{Q_u}S(Q)dQ + \int_0^{Q_r}S'(Q)dQ \\ &= \int_{Q_r}^{Q_u}D(Q)dQ - \int_{Q_r}^{Q_u}S(Q)dQ + \int_0^{Q_r}\left(S'(Q)-S(Q)\right)dQ \\ &= \frac{1}{2}sR(Q_u - Q_r) + sRQ_r = \frac{1}{2}sR(Q_u + Q_r),\end{aligned}$$

as $D(Q_u) - S(Q_u) = 0$ and $D(Q_r) - S(Q_r) = \frac{-s(Q_r+R)}{Q_r|\varepsilon|}Q_r + s(Q_r + R)\left(1+\frac{1}{|\varepsilon|}\right) - sQ_r = sR$.

So $\int_{Q_r}^{Q_u}(D(Q)-S(Q))dQ = \frac{1}{2}(sR + 0)(Q_u - Q_r)$.

Appendix A3. Calculation of the loss of consumer surplus

The loss of consumer surplus is equal to:

$$\begin{aligned}\Delta CS &= \int_0^{Q_u}(D(Q)-P_u)\,dQ - \int_0^{Q_r}(D(Q)-P_r)\,dQ \\ &= (P_r - P_u)Q_r + \frac{1}{2}(P_r - P_u)(Q_u - Q_r) = \frac{1}{2}(P_r - P_u)(Q_u + Q_r).\end{aligned}$$

The relative loss of consumer surplus is then:

$$\frac{\Delta CS}{\textit{Welfare loss}} = \frac{\frac{1}{2}(P_r - P_u)(Q_u + Q_r)}{\frac{1}{2}sR(Q_u + Q_r)} = \frac{(P_r - P_u)}{sR}.$$

Table A1
Garage parking share.

Garage parking share	Two-limit Tobit			IV Two-limit Tobit	
	(1)	(2)	(3)	(4)	(5)
Parking places (/1000)	0.101***	0.069***	0.050**	0.108***	0.094***
	(0.019)	(0.018)	(0.019)	(0.021)	(0.024)
Municipality population		−0.117	0.157	−0.121	0.144
		(0.202)	(0.238)	(0.200)	(0.239)
Municipality population density		0.153***	0.163***	0.139***	0.144***
		(0.031)	(0.031)	(0.031)	(0.031)
Shopping district type	No	No	Yes	No	Yes
Constant	−0.147	−0.303	0.310	−0.340	−0.320
	(0.053)	(0.059)	(0.182)	(0.061)	(0.178)
Log likelihood	−232	−211	−209	−2732	−2721
No of observations	308	308	308	308	308
No of obs., no garage parking	147	147	147	147	147
No of obs., no street parking	18	18	18	18	18
F-test (weak instruments)				707.03	582.26

For notes, see Table 2.

Table A2
Inverse parking supply functions using different thresholds.

Day price	€4 threshold				€10 threshold			
			Garage present				Garage present	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Parking places (/1000)	2.985***	3.228***	2.704***	2.789***	2.786***	2.869***	2.821***	2.941***
	(0.279)	(0.321)	(0.313)	(0.385)	(0.309)	(0.372)	(0.387)	(0.504)
Municipality population	13.7***	11.1***	10.9***	10.4**	15.5***	13.6***	13.5***	11.5**
	(2.63)	(3.21)	(3.38)	(4.31)	(3.04)	(3.89)	(4.17)	(5.60)
Municipality population density	0.978**	0.813**	0.481	0.429	0.455	0.388	0.382	0.338
	(0.409)	(0.413)	(0.467)	(0.475)	(0.490)	(0.484)	(0.613)	(0.612)
Shopping district type	No	Yes	No	Yes	No	Yes	No	Yes
Log likelihood	−2663	−2638	−1467	−1458	−2458	−2438	−1319	−1313
No of observations	275	275	138	138	275	275	138	138
No of obs. below threshold	162	162	45	45	219	219	95	95
F-test (weak instruments)	754.05	669.77	399.20	284.26	754.05	669.77	399.20	284.26

Note: regression on parking price. The censoring threshold is €4 in specification 1–4 and €10 in specifications 5–8. For other notes, see Table 2.

Table A3
Inverse parking supply functions, for minimum city size.

Day price		
	(1)	(2)
Parking places (/1000)	2.727***	2.465***
	(0.538)	(0.460)
Shop space rent (median)	0.027	0.019
	(0.027)	(0.024)
Shopping district type	Yes	Yes
Municipality fixed effects	Yes	Yes
Log likelihood	−419	−495
No of observations	42	50
No of obs. below threshold	10	12
Minimum city size	100,000	50,000
F-test (weak instruments)	130.42	144.96

Note: IV Tobit estimates. For other notes, see Table 2.

Table A4
Inverse parking supply functions (hour price).

Hour price	IV Tobit				IV Tobit Log-log			
			Garage present				Garage present	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Parking places (/1000)	0.381***	0.425***	0.312***	0.310***	0.746***	0.987***	0.570***	0.584***
	(0.041)	(0.047)	(0.044)	(0.053)	(0.098)	(0.149)	(0.093)	(0.138)
Municipality population	0.795**	0.492	0.368	0.584	0.345***	0.196	0.258***	0.294***
	(0.381)	(0.451)	(0.449)	(0.557)	(0.069)	(0.105)	(0.074)	(0.109)
Municipality population density	0.246***	0.237***	0.220***	0.232***	0.153**	0.125	0.099	0.102
	(0.059)	(0.060)	(0.067)	(0.068)	(0.075)	(0.080)	(0.087)	(0.088)
Shopping district type	No	Yes	No	Yes	No	Yes	No	Yes
Log likelihood	−3163	−2804	−1536	−1530	−615	−596	−340	−333
No of observations	308	308	161	161	308	308	161	161
No of obs. below threshold	147	147	42	42	147	147	42	42
F-test (weak instruments)	707.03	582.26	401.60	271.26	215.80	116.86	138.06	62.57

Note: regression on parking price. The censoring threshold is 0.35 in the linear analyses and log (0.35) in the log–log analyses. For other notes, see Table 2.

Table A5
Inverse parking supply functions (no instrumenting).

Day price	Tobit				Tobit (Log-log)			
			Garage present				Garage present	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Parking places (/1000)	2.565***	2.504***	2.044***	1.740***	0.630***	0.525***	0.427***	0.148
	(0.244)	(0.272)	(0.272)	(0.313)	(0.091)	(0.104)	(0.108)	(0.128)
Municipality population	14.5***	15.4***	12.3***	17.1***	0.493***	0.623***	0.401***	0.689***
	(2.72)	(3.31)	(3.43)	(4.19)	(0.080)	(0.105)	(0.091)	(0.119)
Municipality population density	1.037**	1.092**	0.497	0.632	0.191	0.211	0.063	0.090
	(0.411)	(0.413)	(0.471)	(0.469)	(0.086)	(0.084)	(0.098)	(0.093)
Shopping district type	No	Yes	No	Yes	No	Yes	No	Yes
Log likelihood	−508	−506	−361	−358	−264	−258	−162	−154
No of observations	275	275	138	138	275	275	138	138
No of obs. below threshold	141	141	36	36	141	141	36	36

Note: municipality population in millions. Population density in thousand persons per square meter. The censoring threshold is €2 in the linear analyses and log (€2) in the log—log analyses. For other notes, see Table 2.

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