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# Residential Parking Permits and Parking Supply

*Jos van Ommeren*[1,3]
*Jesper de Groote*[1]
*Giuliano Mingardo*[2]

[1] *Faculty of Economics and Business Administration, VU University Amsterdam;*
[2] *Erasmus University Rotterdam;*
[3] *Tinbergen Institute.*

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Jos van Ommeren*

Jesper de Groote*

Giuliano Mingardo**

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Abstract. We estimate welfare losses of policies that provide on-street parking permits to residents almost free of charge in shopping districts. Our empirical results indicate that parking supply is far from perfectly price elastic, implying that there are substantial welfare losses related to under-priced parking permits. Our results suggest that the provision of residential parking permits in shopping districts induces a yearly deadweight loss of at least €500 per permit, which is about 30% of the supply cost of a parking place in shopping districts.

Keywords: parking supply; residential parking permit; deadweight loss JEL: R41, R48

* VU University, FEWEB, De Boelelaan, 1081 HV Amsterdam, the Netherlands; jos.van.ommeren@vu.nl. Jos van Ommeren is affiliated to the Tinbergen Institute

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## 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 contrast to this recommendation, many cities allocate street parking to residents by supplying residential parking permits almost free of charge and by creating 'residential permit holders only' districts. The idea is to make it cheaper and easier for residents to find a vacant parking place, but the residential parking permits distort the parking market, as street parking is inefficiently allocated.[1]

Residential parking permits are particularly common in European countries. In the UK, 'residential permit holders only' districts 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, where 82 per cent 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 non-residents are £30 per day (Kensington and Chelsea, 2012). Similarly, in the pre-1930 district of Amsterdam, there are about 100,000 street parking places, whereas the number of residential parking permits is about the same (Gemeente Amsterdam, 2000).

Residential parking permits seem not extremely common in the US, perhaps because minimum parking regulations usually induce an oversupply of off-street parking (Shoup, 2005;

[1] One potentially politically feasible solution to avoid this inefficiency is to give residents the option to sell their parking permit. We come back to this in the conclusion.

Cutter and Franco, 2012). Nevertheless, they can be found in San Francisco, Chicago and Boston and have recently been approved in New York.[2]

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. These districts are mixed and, almost always, contain both shops and residential housing, so shoppers and residents have a demand for parking in the same location. Frequently, the demand by shoppers and residents occurs at the same time.[3] Residents in shopping districts with paid parking receive parking permits.

In the Netherlands, mixed shopping districts are the norm (see Wheaton, 2004, for a discussion of mixed areas). Most shops are located within (historic) city centres or within suburban residential districts. In these mixed districts, the shoppers' willingness to pay for parking *per unit of time* is likely 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 non-residents 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 non-residents typically

[2] 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).

[3] 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).

park for a much shorter duration than residents.[4] Virtually everywhere in the Netherlands residents in paid-parking districts receive on-street parking permits. Residential parking permits are 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 welfare effects of residential parking permits.

In the current paper, we estimate the (inverse) parking supply function using a dataset of about 300 of the largest shopping districts in the Netherlands. Importantly, we employ a unique dataset with detailed information about street and garage capacity. Our main finding is that parking supply is quite elastic, but far from perfectly elastic. This suggests that parking policies that provide parking permits to residents increase parking costs for non-residents, which has negative implications for welfare. Our results suggest that the Dutch residential parking permits policy induces an annual deadweight loss of about 30% of the parking supply costs in shopping districts, which is about 300 million euros per year.

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

[4] For example, the average parking duration for non-residents is about one hour in Almere, a city of about 200,000 inhabitants in the Netherlands, see Kobus et al. (2012).

## 2. Theoretical considerations

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

In order to identify the parking supply curve, we make the assumption that street and garage parking are perfect substitutes for non-residents (i.e. parking is a homogeneous good). So, we will estimate the parking cost function ignoring the type of parking (garage or street parking) that is supplied.

Although most non-residents will be largely indifferent between on-street and garage parking, one may argue that they are not perfect substitutes, for example because they are not at exactly the same location (as argued by Kobus et al., 2012). However, these differences tend to be small within the same shopping district, so the perfect-substitution assumption is a reasonable approximation.

There is a large empirical literature on parking demand.[5] However, as far as we know, there is only one empirical study about parking supply which does not apply to shopping districts.[6] 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 shopping districts which combine street and garage parking places. When parking supply

[5] About 25 years ago, Feeney (1989) reviews already 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).

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

includes garage parking, it is unlikely that parking supply is perfectly elastic.[7] Note that it is a misconception that street parking is perfectly inelastic, even within historical city centres, because parking places may be converted into pedestrian areas or street lanes, which reduces traffic congestion (Arnott and Inci, 2006).

When interpreting the empirical results, we will assume that parking suppliers are free to set parking prices. As a benchmark assumption, which will be relaxed later on, we start to assume that (public and private) suppliers apply marginal cost pricing, in line with the competitive-market assumption. Given the strong competition of suppliers within and, in particular, between shopping districts, this may be a reasonable assumption.[8] We emphasize however that if suppliers do not apply marginal cost pricing, then we still obtain consistent estimates of the inverse supply function, when this difference is random.[9] So, the marginal cost pricing assumption generates consistent estimates when parking is not systematically over- or undersupplied. There are many reasons to believe that the marginal cost pricing assumption does not hold. We will discuss these reasons one by one and explain how this affects our estimation procedure.

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[7] 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.

[8] The empirical finding that shoppers' choice of parking is very price elastic for longer parking durations (Kobus et al., 2012), also suggest that monopolistic competition is not so much an issue when using parking prices for long durations.

[9] Differences are expected to exist, for example because parking supply may change only slowly over time. Given unexpected strong demand, commercial parking operators may set temporarily prices above marginal costs, but, given unexpected weak demand, the opposite may occur.

One fundamental criticism of the marginal cost pricing assumption is that local monopolistic behaviour by commercial parking garages is likely present (Arnott, 2006; Arnott and Rowse, 2009a). The literature argues that this has substantial consequences for welfare when street parking is priced far below the garage price, so cruising for street parking is common. As we shall see, this situation does not occur in the Netherlands, where on-street and garage prices are roughly equal.

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).[10] Prices for short durations then exceed marginal costs, whereas prices for long durations equal marginal costs.[11] 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.

The welfare loss of residential parking permit policy depends not only on the number of residential parking permits issued but also on other local government policies. First, and most importantly, because street parking is the dominant form of supply, it will depend on its setting of on-street prices. It is well known that setting street prices far below garage prices will induce cruising for parking (Shoup, 2005; Calthrop and Proost, 2006). We will document for our data

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[10] 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.

[11] Local governments may set parking charges above marginal costs for shorter durations for a completely different reason: to charge for car congestion, in line with recommendations by Glazer and Niskanen (1992).

that on-street prices in the Netherlands are approximately equal to garage prices, so we will assume away any cruising externalities (which 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).

Second, the welfare loss will depend on any regulation of commercial garage parking prices. Price regulation of commercial operators is rare, also because commercial suppliers hardly ever have a dominant position, so they have little market power. However, price regulation does occur in shopping districts with only one or two dominant commercial garage parking suppliers and little street parking (e.g., within the innercities of Almere, Maastricht). In these shopping districts, price regulation is applied in order to induce marginal cost pricing.

Third, and most importantly, parking is related to a number of negative externalities which are usually addressed by non-price regulation of parking. It is relevant here to distinguish between negative externalities of the *parking site* (as parking sites are considered ugly) and any negative externalities related to *car travel* (e.g., congestion, pollution).

Many districts are in historic centres (built before 1930), where construction of residential, and particularly non-residential, 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 centres 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. As a second-best solution, these negative externalities can be (partially) internalised 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 under-priced (as it reduces cruising). Minimum requirements are less important in the Netherlands.

Maximum requirements may be interpreted as a (second-best) policy when pricing of traffic congestion is not feasible, because congestion induces a difference between the private cost curve, $S_p$, and the social cost curve, $S_s$, as shown in Figure 3. By restricting the number of parking places ($q_1$ in Figure 3), the government may move away from the market equilibrium, A, to another equilibrium, B. The parking supplier earns an additional profit, C, because there is a difference between the social and private marginal cost. This equilibrium offers a higher welfare when the additional profit is passed onto the local government (or passed to the inhabitants as a lump sum).[12] This is usually 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 and are able to. So we aim to estimate the social, not the private, cost curve.

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

## 3. Empirical Results

### *3.1. Data and descriptives*

We use a dataset about parking in 308 of the largest shopping districts of the Netherlands for the year 2007 (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 per cent 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.[13] 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 per cent of residents in shopping districts possesses a privately owned, see Van Ommeren et al., 2011). Second, these parking places are unavailable to shoppers.

On average, there are about 1,700 parking places per district: 1,200 on-street and 500 in garages.[14] 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

[13] 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.

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

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 district 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.[15] We have information about parking prices per hour (for the first hour) and per day. In about half of the districts, prices are zero (but in only 20 per cent of districts with garage parking).

The average street price is €0.69 per *hour*, slightly below the average garage price of €0.93.[16] 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 six times higher than the price for the first hour (implying that parking for longer than six hours occurs at a discount). The data allow us to distinguish between different shopping districts locations within cities: central locations

[15] However, for the few districts without street parking, this ratio is three times lower, so the amount of parking per floor area is lower.

[16] Given paid parking, the average street price is € 1.50 per hour, in line with other sources (e.g., Van Dijken, 2002)

(e.g., at least 400 shops in the largest inner cities), periphery locations and out-of-town shopping centres (containing few, but large shops).

**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 | 11167 | | | | | |
| Garage parking share | 308 | 0.22 | 0.29 | 0 | 1 | | | | | |
| Floor area (x1000) | 308 | 30.6 | 31.0 | 4.1 | 238.2 | 18 | 27.5 | 27.7 | 5.7 | 98.6 |
| Parking places/100 m² | 308 | 6.44 | 4.03 | 0.30 | 24.59 | 18 | 2.16 | 2.32 | 0.39 | 9.65 |

| | *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 | 11167 | | | | | |
| Garage parking share | 161 | 0.42 | 0.29 | 0.04 | 1 | | | | | |
| Floor area (x1000) | 161 | 42.5 | 37.6 | 5.4 | 238.2 | 147 | 17.6 | 12.3 | 4.1 | 82.7 |
| Parking places/100 m² | 161 | 6.40 | 4.02 | 0.39 | 23.84 | 147 | 6.48 | 4.05 | 0.30 | 24.59 |

Note: price difference = street price – garage street price. Parking price = max (street price, garage price) In addition to parking prices and quantities data from Parkeermonitor, we use data about median rent for shop space (per square meter) per district to proxy land prices within cities, which is 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).

According to CROW (2008), most shops need between 2.5 and 4 parking places per hundred square meter floor space (it is not clear to what extent price of parking is included in this calculation). This allows us to do some consistency checks on the data. The parking places in shopping districts we focus on are also used by residents, so it makes sense that the total parking supply exceeds the maximum requirement in most shopping districts (Figure 1). When garage parking is present, shoppers still make use of street parking, so it makes sense that *garage* supply is usually less than the minimum requirement, see Figure 2.

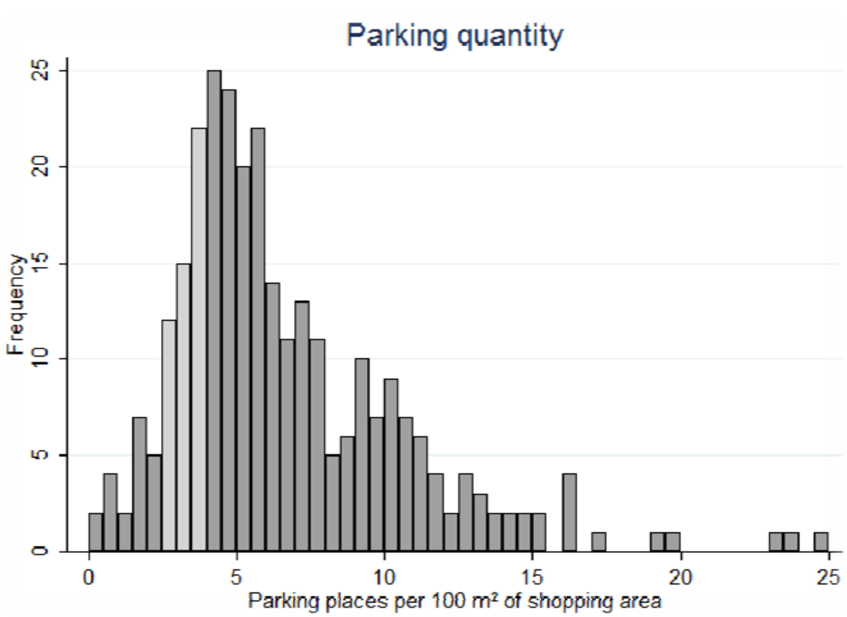


Figure 1. Number of parking places per 100 square meter of shopping area. The highlighted bars indicate the observations that are within the range of adviced parking requirements of CROW (2008).

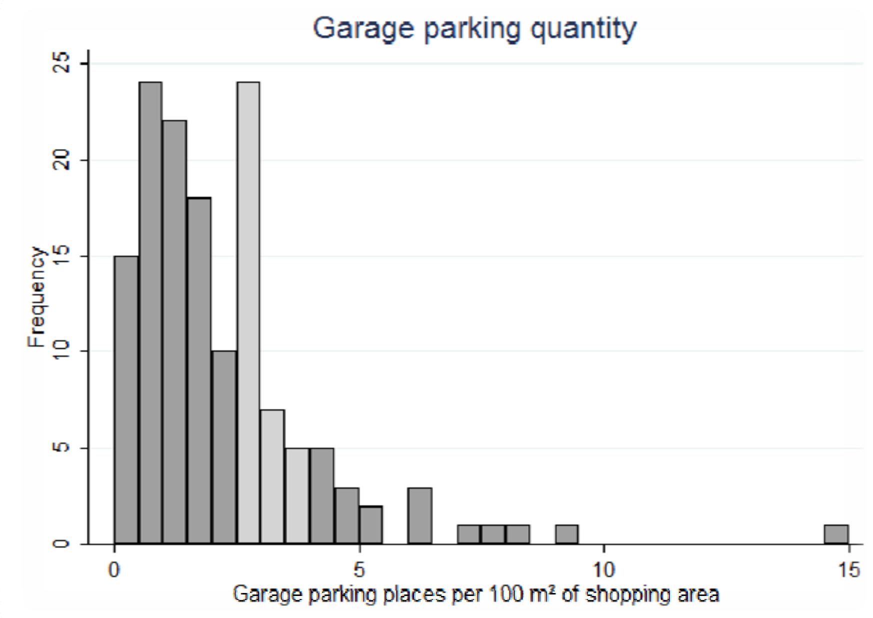


Figure 2. Number of garage parking places per 100 square meter of shopping area. Areas with garage parking only. The highlighted bars indicate the observations that are within the range of adviced parking requirements of CROW (2008).

*3.2 Empirical Approach*

We estimate the *inverse* supply function for non-residents parking, so we estimate the price of a parking place as a function of the number of parking places. 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:

$$p_{im} = \alpha + \beta q_{im} + \gamma x_{im} + \delta x_m + \varepsilon_{im}. \quad (1)$$

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 $\varepsilon_{im}$ is an error term. 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,* $\delta_m$, as well as median rents for shop space per district as a proxy for land prices.[17] So, we estimate:

$$p_{im} = \alpha + \beta q_{im} + \gamma x_{im} + \delta_m + \varepsilon_{im}. \quad (2)$$

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 and $q_{im}$ is correlated to $\varepsilon_{im}$. We deal with this issue using an instrumental-variables approach. To identify the inverse parking supply function, we use *floor shopping area* as an instrument. 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.[18] This instrument seems plausible, particularly given the

[17] 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.

[18] 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,

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. 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 emphasise 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.

**Table 2: Inverse parking supply functions**

| 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 meter. The censoring threshold is €2 or ln €2 in the log-log specification. * Significant at 5 per cent level, ** Significant at 1 per cent level.

One issue we have to deal with is that in many districts, parking is free to non-residents (in our dataset that turns out to be about 50 per cent, in particular when garage parking is absent).

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floor area is invalid as an instrument to estimate parking supply functions, whereas perfectly valid for *inverse* parking supply functions.

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). The third reason is that the (suppliers') transaction costs of paid parking are not negligible (in the Netherlands normally electronic parking machines). Van Dijken (2002) reports that they 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 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. The main difficulty is that 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 two euro 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).[19] So, we may then estimate Tobit models using a standard maximum-likelihood procedure, where we have left-censored observations with day prices *below two euro*.

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 per cent 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 per cent. For this subset, we estimate Tobit models and linear models after excluding zero-price observations.

*3.3 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

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

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 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).[20]

The main results are reported in Tables 2 and 3. All specifications show that an increase in parking capacity results in a strong increase in costs of parking. 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, because the mean number of *garage* parking places is 500. 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

[20] 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, 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.

increase compared with total parking supply per district, which is 1,700 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).

*3.4 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, but we would like to emphasize that other, non-reported, specifications 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 reduced, but only by about 0.2, so the results are not extremely sensitive to the choice of the price measure. Nevertheless, it suggests that parking supply is more sensitive than reported before, so our estimates based on day prices are conservative.

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 (statisticallysignificant) 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. 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 more likely to occur. However, the distribution of the garage parking places in Figure 2 provides some suggestive evidence for the existence of minimum parking requirements. 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.

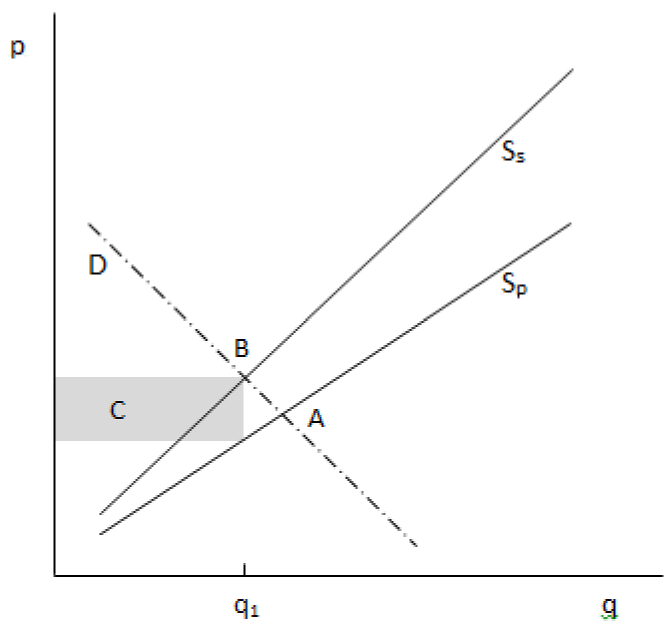
**Table 3: Inverse parking supply functions, alternative specifications**

| 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.

## 4 Welfare analyses

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, 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. If this assumption does not hold for all residents in the short run (for example, just after a shopping centre 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. [21]We emphasise that our welfare calculations do not include any welfare loss for residents parking, which means that we underestimate the welfare loss.




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

Figure 3. The private and social cost curve.

To derive the long-term deadweight loss, it would be ideal to have information about the demand function for parking by residents as well non-residents (shoppers). We lack this information, so we proceed by making assumptions about the shape of the demand functions, so we are able to give the range of welfare loss due to residential parking permits. The deadweight loss depends then on the number of residential parking permits per district. In the Netherlands, when paid parking is introduced, residents receive at least one permit.[22] As a result, the residential number of parking permits is usually close to the number of street places, so there are about 1,700 parking permits provided per shopping district.[23] 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. West Amsterdam (2012). In the current paper, we will assume that only 500 street parking places, so only 30% of the number of residential parking permits are occupied by residents at times when shoppers aim to park.

In addition, we assume that exactly 500 garage parking places are used by non-residents who viit the shops. The remaining 700 street parking places are assumed to be used by residents with permits (and used some part of the day) but the deadweight loss of these 700 permits is

[22] 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.

[23] Because the occupancy rate is essentially one in the evening/night, 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.

assumed to be negligible. In this way, we obtain (extremely) conservative estimates of the deadweight loss.

It is assumed that the combined willingness to pay of the 500 permit holders is equal to the combined supply costs ($A + C$ is equal to $B + C$ in Figure 4). This assumption is a reasonable approximation, because willingness to pay by the 500 residents with a permit as well as the supply costs of the *first* 500 street places will be low relative to the equilibrium price.[24]

Given these simplifying assumptions, the deadweight loss can be derived assuming first the absence of the parking permit policy, and then allow the inverse parking supply curve to shift to the left by 500 units. This shift is indicated in Figure 4 as a shift in the supply function from S to S'. This shift in supply affects the non-residents, who are assumed to be the high-demand consumers, indicated by the bold demand curve in Figure 4. In this figure, the deadweight loss is indicated with DWL. It is tedious but straightforward to show that given linear non-residents' demand and supply functions, the deadweight loss per day per shopping district is equal to:

$$DWL = \frac{1}{2} \cdot (V + Q_S) \cdot \beta \cdot A, \tag{3}$$

where $V$ denotes the number of non-residents ("visitors"), $Q_s$ denotes the undistorted number of parking places provided to non-residents in the absence of the provision of parking permits, $\beta$ equals the marginal effect of parking supply on parking prices (per day) and A equals the number of parking permits provided to residents. $Q_s$ is endogenously determined and depends, among

[24] 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.

others on the (unknown) price elasticity of demand. It can easily be shown that $Q_s$ is monotonically increasing in the (absolute) effect of price on parking demand with a minimum value of *V,* when parking demand is fully price elastic*,* and a maximum value of $V + A$, when parking demand is fully price inelastic. So, for example, when the demand for parking is fully price elastic, the deadweight loss per day per shopping district is equal to βAV.

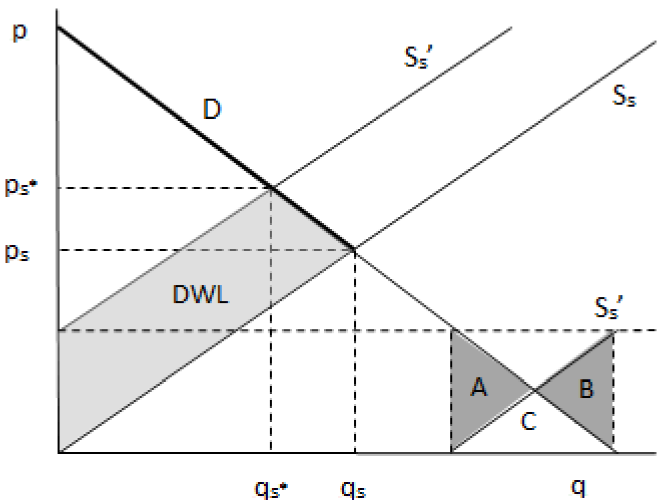



Figure 4. Welfare loss of residential parking permits.

Let us assume now that non-residents' parking demand is perfectly price elastic. When removing the residential parking policy (which provides 500 permits), parking prices do not fall, but demand for street parking by non-residents increases (by 500 parking places).[25] Given (3), the deadweight loss per parking place equals €1.28 per day, so €465 per year. When parking demand by non-residents is perfectly price inelastic, parking demand does not change, and the deadweight loss equals €621 per year. Because most non-residents (excluding commuters) park for a short duration, it is usually thought that the demand for parking is rather inelastic. A price

[25] 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).

elasticity of demand of -0.3 is sometimes suggested, see Litman (2012).[26] Given this value, the implied deadweight loss is €585 per year. 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 parking places is equal to the number of households with a car, and that in these shopping districts, only half of the households have a car (which is a conservative estimate), the deadweight loss is about €250 per household living in these districts, or €125 per capita. Nationwide, the deadweight loss will be €240 to 320 million per year according to our conservative estimate (assuming an annual loss of €465 to 621 per parking space, 1673 parking places per shopping district and 308 shopping districts).

We have also re-examined these results for other estimates of the inverse parking supply function. The deadweight loss results remain extremely robust. For example, when we assume that the marginal effect of parking supply on the price of parking is only €$2.4 \cdot 10^{-3}$ (rather than €$3.4 \cdot 10^{-3}$), which is the lowest point estimate of all our estimates, then the deadweight loss is still €429 per year.

We emphasise 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 non-residents) is larger than presumed, then the annual welfare loss per residential parking permit is much higher, because the deadweight 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 deadweight loss per parking permit is *at least* twice high.

[26] 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).

**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, so where there is also a demand for parking by non-residents, in particular shoppers. We derive the deadweight loss by estimating (inverse) parking supply functions. Our empirical results indicate that 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 deadweight loss of about €500 per parking permit, which is about 30% of the parking supply costs.

A parking permits policy provides advantages to local residents that are denied to non-residents. It is well known that residents have strong incentives to prevent *local* policies that are welfare improving (see, for example, Glaeser et al., 2005, or Cheshire and Hilber, 2008, in the context of building height regulation). 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 internalise 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.

## References


Arnott, R. (2006), Spatial competition between parking garages and downtown parking policy, *Transport Policy*, 13, 458-469.

Arnott, R. and J. Rowse (2009a), Downtown parking in auto city, *Regional Science and Urban Economics*, 39, 1-14.

Arnott, R. and J. Rowse (2009b), Curbside parking time limits, mimeo

Arnott, R., A. De Palma and R. Lindsey (1991), A temporal and spatial equilibrium analysis of commuter parking, *Journal of Public Economics*, 45, 301-335.

Arnott, R., and E. Inci (2006), An integrated model of downtown parking and traffic congestion, *Journal of Urban Economics* 60, 418-42.

Axhausen, K.W. and J.W. Polak (1991), Choice of parking: stated preference approach, *Transportation*, 18, 1, 59-81.

Calthrop, E. and S. Proost (2006), Regulating on-street parking*, Regional Science and Urban Economics,* 36 29-48.

CBS New York (2011), City council approves residential parking permit plan, November www.newyork.cbslocal.com

Cheshire, P.C. and C.A.L. Hilber (2008), Office space supply restrictions in Britain: the political economy of market revenge, *Economic Journal*, 118, F185-F221.

CROW (2008), Parkeercijfers - Basis voor Parkeernormering, EDE, the Netherlands.

Cutter, W.B. and S.F. Franco (2012), Do parking requirements significantly increase the area dedicated to parking? A test of the effect of parking requirements values in Los Angeles County, *Transportation Research A*, 46, 901–925

Feeney, B.P. (1989) , A review of the impact of parking policy measures on travel, *Transportation Planning and Technology, 13, 4, 229-244*

Gemeente Amsterdam (2000), *Parkeren is manoeuvreren* , Dienst Infrastructuur, Verkeer en Vervoer.

Glaeser, E.L., J. Gyourko and R.E. Saks (2005), Why is Manhattan so expensive? Regulation and the size in house prices, *Journal of Law and Economics*, 48, 2, 331-369.

Glazer, A. and E. Niskanen (1992), Parking fees and congestion, *Regional Science and Urban Economics*, 22, 123-132.

Hasker, K. and Inci, E (2011), Free parking for all in shopping malls, Sabanci University, Working Paper ID:SU_FASS_2010/0004.

Hensher, D.A. and J. King (2001), Parking demand and responsiveness to supply, pricing and location in the Sydney central business district. *Transportation Research A*, 35A, 177–196.

Holt, M.T. (2002), Inverse demand systems and choice of functional form, *European Economic Review*, 46, 117-142.

Kelly, J.A. and J.P. Clinch (2006), Influence of varied parking prices on parking occupancy levels by trip purpose. *Transport Policy*, 13, 487–495.

Kelly, J.A. and J.P. Clinch (2009), Temporal variance of revealed preference on-street parking price elasticity. *Transport Policy*, 16, 193–199.

Kensington and Chelsea (2012), www.rbkc.gov.uk.

Kim, J. (2012), Endogenous vehicle-type choices in a monocentric city , *Regional Science and Urban Economics*, 42, 749-760.

Kobus, M., E. Gutiérrez-i-Puigarnau, P. Rietveld and J.N. van Ommeren (2012), The on-street parking premium and car drivers' choice between street and garage parking, *Regional Science and Urban Economics, forthcoming*

Kunreuther, H. and P. R. Kleindorfer (1986), Sealed-bid auction mechanism for siting noxious facilities, *American Economic Review* , 76, 2, 295-299

Leichenko, R.M., Coulson, N.E., Listokin, D. (2001). Historic Preservation and Residential Property Values: An Analysis of Texas Cities. *Urban Studies 38(11): 1973-1987.*

Litman, T. (2012), *Understanding transport demands and elasticities*, Victoria Transport Policy Institute

Mingardo, G. and J. van Meerkerk (2012), Is parking supply related to turnover of shopping areas? The case of the Netherlands, *Journal of Retailing and Consumer Services*, 19(2), 195-201.

Shoup, D.C. (1999), The trouble with minimum parking requirements, *Transportation Research A*, 549-574.

Shoup, D.C. ( 2004), The ideal source of local public revenue, *Regional Science and Urban Economics,* 34, 6, 753-784

Shoup, D.C. (2005), *The High Cost of Free Parking*, Planners Press, Chicago.

Small, K.A. (1997), Economics and urban transport policy in the United States, *Regional Science and Urban Economics*, 27, 671-691.

Small, K.A. and E.T. Verhoef (2007), *The Economics of Urban Transportation*, Routledge. *Transportation Planning and Technology* 13(4), 229–244.

Statistics Netherlands (2008), Central Bureau of Statistics, the Hague.

Trajan (2009), Onderzoek Korte ritten en optimale grootte vergunningsgebieden.

Van Dijken (2002), *Parkeren in Nederland*, IOO, the Hague

Van Ommeren, J.N., D. Wentink and J. Dekkers (2011), The real price of parking policy, *Journal of Urban Economics*, *70, 25-31*

Van Ommeren, J.N and D. Wentink (2012), The (hidden) costs of employer parking policies*, International Economic Review*, *53,3, 965-977*

Van Ommeren, J.N., D. Wentink and P. Rietveld (2012), Empirical evidence on cruising for parking, *Transportation Research Part A, 46, 123-130*

Verhoef, E., P. Nijkamp, and P. Rietveld (1995), The economics of regulatory parking policies: the (im)possibilities of parking policies in traffic regulation, *Transportation Research Part A*, 29, 141-156.

Vickrey, W.S. (1954), The economizing of curb parking space, *Traffic Engineering*, 62-67, reprinted in *Journal of Urban Economics*, 1994, 36, 42-65.

Wheaton, W.C. (2004), Commuting, congestion, and employment dispersal in cities with *mixed* land use , *Journal of Urban Economics, 55, 3 , 417-438*

## APPENDIX

### 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.
* Significant at 5 per cent level, ** Significant at 1 per cent level.

## 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. * Significant at 5 per cent level, ** Significant at 1 per cent level.

## 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. * Significant at 5 per cent level, ** Significant at 1 per cent level.