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## Time-varying parking prices

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## ABSTRACT

According to welfare-maximising principles, the price of parking must vary per day given shifts in daily demand. We study the economic consequences of not doing so by estimating the employees' parking demand at an organisation that varies the price of parking by day of the week. We estimate the effect of the employees' parking price on demand using a difference-in-differences methodology. The deadweight loss of free parking due to overconsumption of parking is about 10% of the organisation's parking costs (excluding welfare costs due to increased travel externalities). Charging a fixed price per day induces a welfare loss of at least 4% of the organisation's parking costs.

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## 1. Introduction

It is rather well-known that parking is usually provided free to users (Shoup, 2005). There is however surprisingly little information to what extent not charging for parking creates welfare losses, although this is the central theme in the economics of parking literature (Vickrey, 1954; Roth, 1965; Arnott et al., 1991; Arnott and Inci, 2006, 2010; Anderson and De Palma, 2004; Kobus et al. 2013; Van Ommeren et al., 2011, 2012). One recent paper concluded that underpricing of parking for workers may create substantial welfare losses (Van Ommeren and Wentink, 2012). This loss is induced by non-optimal fringe benefit taxation, because the provision of parking is not taxed as income, whereas wages are taxed as income, which stimulates organisations to offer parking below its cost price, or even free, which increases the demand for parking. As far as we are aware only in Singapore, free employer-provided parking is taxed as income and, in line with theory, most employees pay for employer parking (ADB, 2010).

We continue on this theme by estimating the welfare loss of non-optimal pricing of parking of hospital workers in the Netherlands. Vickrey (1954) recommended to use *time-varying parking tariffs* to deal with variation in demand for parking.<sup>2</sup> This is in line with the more general principle that the price of a good must vary with time-shifts

in demand when changes in supply are costly.<sup>3</sup> It is unknown to what extent efficiency losses in the parking market are substantial when time-invariant parking tariffs are applied. Hence, we will estimate the deadweight loss of using a time-invariant parking tariff as well as the deadweight loss of free parking. In this way, we are able to understand the importance of applying time-of-day parking pricing compared to time-invariant pricing as well as compared to general underpricing of parking.

Hospitals operate on a 24-h a day basis, hence within-day parking variation in demand is related to the timing of nurses' and doctors' shifts (one peak between 7 and 8 am and another one between 2 and 3 pm), the arrival of administrative staff (at around 9 am) and of patients scheduled for treatment.<sup>4</sup> Parking demand on weekdays far exceeds the demand on weekends, but, as we will document later on, there also is quite some variation *between* weekdays, a characteristic which is ignored in the literature.

Now let us consider the case where the hospitals' weekly marginal resource cost of parking is given, which is plausible because hospitals are not able to vary the number of parking spaces within the week. Furthermore, consider the case where the demand for parking varies per day of the week (e.g. on Monday demand is higher than on Wednesday). Let us suppose that the hospital may freely choose the number of parking spaces (per week) as well as the parking price for each day. In line with principles already discussed almost 100 years ago by Pigou (1920), the *welfare-maximising* parking price to be paid by workers, i.e. the

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<sup>2</sup> Vickrey's (1954) vision is applied in many circumstances. For example, day and evening curbside parking fees are usually different.

<sup>3</sup> The classical example is the electricity industry where changes of supply within a day are expensive, so peak load pricing within the day (nights are cheaper) is common (Steiner, 1957).

<sup>4</sup> Visitors are a relatively small group who predominantly use parking spaces that are left vacant by workers/patients who have left earlier.

price that induces efficient use of parking space, must vary per day. To be more precise, it must vary such that for the *marginal* parking space, the sum of the (inverse) parking demand functions for each day of the week is equal to the weekly parking costs (Steiner, 1957).<sup>5</sup>

When shifts in demand between days of the week are substantial, there will be excess supply on some days of the week, which will be labelled as *slack days*. Given optimal parking pricing, the parking price is zero on slack days and positive on the remaining days—the peak days. Given identical demand functions on peak days, the optimal peak day parking price is equal to the weekly fixed costs divided by the number of peak days. We estimate the deadweight loss of not using the optimal parking price on slack and peak days.

For the welfare calculations it does not matter why organisations do not use optimal pricing. These reasons include for example the presence of distortionary fringe benefits taxation which reduces the incentives to charge for parking, and therefore also reduces the incentive to vary the price over the day of the week.<sup>6</sup> Another reason might be that it requires specialised parking equipment which induces a fixed cost, particularly for organisations that do not charge visitors. This reason is less likely to be applicable for hospitals – including the hospital we focus on – because hospitals use parking prices for patients (and visitors) to regulate demand for parking and to recover parking expenses.<sup>7</sup> Another reason is that it induces transaction costs (e.g. it requires the payroll administration to have data about parking usage) that only recently have fallen due to improvements in computer technology.

To determine the welfare loss of nonoptimal pricing of parking, we will estimate the price effect on parking demand for a single hospital that varies the parking pricing regime in several ways. In particular, it varied the parking price over the days of the week, after a period when it varied only with workers’ commuting distance. To vary price per day is rather unique – we are not aware of any other organisation employing this practice – and in line with economic theory to deal with variation in demand (Vickrey, 1954). Importantly, for the current paper, charging on a daily basis is useful as a quasi-natural experiment to identify the *causal* effect of pricing on workers’ parking demand.

In our welfare calculations, we will assume that parking demand is deterministic, but we will show that allowing for stochastic demand shocks does not fundamentally change the welfare calculations.<sup>8</sup> We will also discuss the possibility that the hospital adjust wages due to distortionary taxation, which complicates the welfare calculation. The case where parking is productive for the hospital, in the sense that workers use hospital parking for cars used for purposes (e.g. visit to patients at home), is discussed as well. Furthermore, we discuss the welfare consequences that underpricing of parking will increase travel demand

and therefore creates travel externalities as well as interactions with the parking market for patients.

The structure of the paper is the following: Section 2 describes the underlying assumptions of the welfare analysis. Section 3 contains the data description. Section 4 presents the empirical results. Section 5 discusses the deadweight loss of non-optimal pricing. The final section offers concluding remarks.

## 2. Theoretical foundations of the welfare calculations

### 2.1. Main assumptions

We assume a hospital which offers  $N$  parking spaces to one representative worker, where  $N \leq 1$ . So,  $N$  can be interpreted as the ratio of parking spaces to workers. We focus on a representative week. Each worker produces revenue  $R$  per week and obtains utility from income (wages minus payments for parking) and utility from parking at the hospital. For convenience, but this is not essential, we assume that their utility  $U$  is additive in income and utility from parking. The worker must receive (at least) the utility level that she could have received through alternative use of employment,  $U^*$ . The hospital consequently faces the following labour supply constraint:  $U = U^*$ .

The marginal cost of parking for one week is equal to  $c$ . The hospital is free to choose the supply of parking, but, conditional on that choice, supply is given for all days of the week.<sup>9</sup> The hospital is free to vary the parking price per day. We will denote total weekly revenue from parking per worker by  $S(N)$ .

Workers differ in the benefit from parking (e.g. some may walk to work, whereas others live far away). This implies that for a representative worker, we have a downward sloping inverse parking demand function, denoted by  $D(N)$ . When  $D(N) = 0$  for a value of  $N$ , then  $D(n) = 0$  for  $n > N$ .

Demand for parking differs between days of the week. We distinguish between  $n_p$  days of the week with high demand, which will be labelled *peak days*, and  $n_s$  days of the week with low demand which will be labelled *slack days*. The corresponding inverse parking demand functions on these days are denoted by  $D_s$  and  $D_p$ , respectively. Demand for parking is higher on peak days than on slack days, hence  $D_p(N) > D_s(N)$ .

The hospital will maximise profits by choosing a wage level  $W$  and parking quantity  $N$ . The following profit function is maximised

$$\text{profit} = R - W - cN + S(N), \tag{1}$$

given the constraint that

$$W - S(N) + n_s \int_0^N D_s(n)dn + n_p \int_0^N D_p(n)dn = U^*, \tag{2}$$

where the third and fourth terms on the left-hand side of the equation denote the worker benefits of parking on slack days and peak days, respectively. The solution to this maximisation problem can be written as:

$$n_p D_p(N^*) + n_s D_s(N^*) = c, \tag{3}$$

where  $N^*$  denotes the chosen quantity of parking. This solution is identical to the problem when the firm maximises *the welfare*

<sup>5</sup> The demand for parking is a derived demand, and this has some surprising consequences. For example, Hasker and Inci (2014) show that free parking may be optimal when a car driver visits a shopping mall and does not know with certainty whether the desired good is available.

<sup>6</sup> For example, hospitals charge workers a price for the use of parking that is much lower than their (long-run) marginal resource cost – the (annualised) expenses to increase the hospital’s parking with one unit – so parking for workers is implicitly subsidised (in line with the observation that workers pay a fraction of the cost paid by patients/visitors).

<sup>7</sup> Indeed it appears that a substantial proportion of hospitals charge workers for parking. This is true in the Netherlands (about one third), but also, for example, in the US (National Parking Association, 2009).

<sup>8</sup> In general, cruising for parking in the Netherlands is almost absent, particularly for workers. In general, cruising for parking is relevant when focusing on street parking, particularly when street parking is underpriced (Arnott and Inci, 2006). In the hospital we focus on, cruising for parking does not occur during the period of observation.

<sup>9</sup> Note that over a long period (e.g. of more than one year), parking supply is not fixed. For example, ground parking can be converted to multi-storey parking. In the US, construction costs of such a parking, excluding the cost of land or of any special foundations are about € 10,000 per space (Parking Consultants Ltd, 2010). According to the management of the hospital will focus on, the hospital chooses the parking quantity and adapts the parking price. For example, after the period analysed in this paper, the hospital has expanded parking capacity by building a garage further away from the hospital and has set the parking price for this garage such that demand equals supply on peak days.

function defined as the sum of profits and worker utility

$$n_s \int_0^N D_s(n)dn + n_p \int_0^N D_p(n)dn - cN + R. \tag{4}$$

We will assume now that on slack days, demand for parking is substantially less than on peak days (in line with our data). Hence, we will assume that given  $N^*$ , there will be excess supply on slack days, implying that  $D_s(N^*)=0$  so  $D_s(n)=0$  for  $n > N^*$ . In equilibrium, workers will equate their the marginal willingness to pay for parking to the price for parking, so on slack days parking prices will be set to zero by the hospital. From (3), it immediately follows that

$$n_p D_p(N^*) = c. \tag{5}$$

So, the hospital sets parking supply such that the sum of marginal benefit on peak days equals weekly marginal cost. So, the hospital chooses  $N^*$  and sets the parking price on peak days equal to  $c/n_p$ . On slack days, the optimal number of spaces occupied will be denoted by  $N_s^*$ . It follows that

$$D_s(N_s^*) = 0.$$

We will focus on a hospital which does not choose the optimal price and quantity. Note that under some circumstances, the hospital may also adjust parking prices and wages simultaneously. This will be analysed later on. The difference between the optimal price and the price set by the hospital will be labelled the ‘parking subsidy’, which may take positive as well as negative values. For example, when the price of parking is positive on slack days, then there will be a negative parking subsidy.

Given the definition of welfare function, see (4), it is straightforward to calculate the welfare loss. For example, when the number of parking spaces supplied will be equal to  $N$ , the welfare change is equal to

$$n_s \int_{N_s^*}^N D_s(n)dn + n_p \int_{N^*}^N D_p(n)dn - c[N - N^*]. \tag{6}$$

Note that if  $N$  exceeds  $N_s^*$ , then the first term is equal to 0, because  $D_s(n)=0$  for  $n > N_s^*$ . Let us suppose now the inverse parking demand functions  $D_s$  and  $D_p$  are (approximately) linear over the relevant range (in line with our data), implying that the demand functions for parking are linear functions of price. In the welfare analysis, for convenience, we will assume that the slopes are identical (this is not essential in the calculation, but is in line with our data). The absolute value of the marginal effect of price on parking demand is denoted by  $\varphi$ . See, Fig. 1, where we have given an example of this market for  $n_s = n_p = 1$ . In this figure,

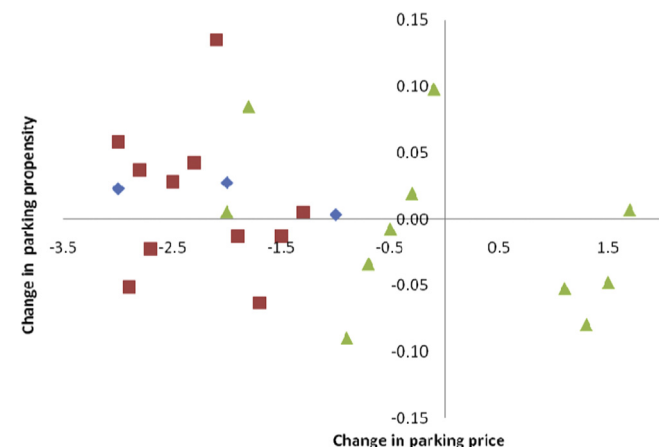


Fig. 1. Changes in parking price and parking propensity. Note: ▲ refers to strategy A; □ refers to strategy B; ◆ refers to strategy C.

the demand on both days are noted as  $D_s$  and  $D_p$ , whereas total demand per week is denoted as  $D_s + D_p$ . Clearly, when  $D_p=0$ , then  $D_s + D_p = D_s$ . In this figure, the slopes of  $D_s$  and  $D_p$  are both equal to  $-\varphi^{-1}$ , whereas the slope of  $D_s + D_p$  is equal to  $-2\varphi^{-1}$ , when  $D_s > 0$ , otherwise it is equal to  $-\varphi^{-1}$ . Note that in this figure  $D_s(N^*) + D_p(N^*) = D_p(N^*) = c$ , consistent with our assumption that  $D_s(N_s^*) = 0$ .

Given (6) and the level of the parking subsidy, the use of a linear parking demand (when the demand function is downward sloping) implies that the deadweight loss per day per worker is equal to  $0.5\varphi$  (parking subsidy)<sup>2</sup>. This calculation is usually called the ‘rule of half’ (e.g. Varian, 1992). Consequently, the (weekly) deadweight loss per worker is equal to  $0.5\varphi$  ( $n_s$ (parking subsidy on slack days)<sup>2</sup> +  $n_p$ (parking subsidy on peak days)<sup>2</sup>).

Let us suppose now that the firm asks the same price each day. Hence, the average cost price is equal to  $c/(n_s + n_p)$ . So, for example, in Fig. 1, the average cost price is equal to  $c/2$ . It is instructive to show that, conditional on that the firm asks the same price each day, this price minimises the deadweight loss, because minimising  $n_s(x_s - p)^2 + n_p(x_p - p)^2$ , where  $x$  denotes the cost of parking on a given (peak or slack) day and  $p$  denotes the price, generates as a solution  $p = (n_s x_s + n_p x_p) / (n_s + n_p) = c / (n_s + n_p)$ . For this reason, we will focus on several types of mispricing including free parking and average cost pricing. Given free parking, the parking subsidy is equal to 0 on slack days and equal to the optimal price on peak days. Hence, the welfare loss per week is equal to  $0.5\varphi n_p (c/n_p)^2$ . Given average cost pricing, the parking subsidy on peak days can be written as  $c/n_p - c/(n_p + n_s)$ , whereas on slack days it is equal to  $-c/(n_p + n_s)$ . Consequently, the weekly welfare loss is equal to  $0.5\varphi n_p (c/n_p - c/(n_p + n_s))^2 + 0.5\varphi n_s (c/(n_p + n_s))^2$ , which can be simplified to  $0.5\varphi c^2 n_s / ((n_p + n_s)n_p)$ . Again we refer to Fig. 1, where the deadweight loss is shown for average cost pricing as the sum of two standard welfare loss triangles. For other forms of mispricing, similar calculations can be done.

### 2.2. Distortionary fringe benefits taxation and changes in gross wages

In the above welfare calculations, we have ignored that when income is taxed, organisations may have an incentive not to charge for parking directly, but indirectly through reductions in gross wages.<sup>10</sup> We will discuss this case now following Katz and Mankiw (1985). We assume that the tax on income is optimal. So, wages are taxed at the optimal level of  $t$ , and the tax paid for receiving wages is equal to  $tW$ . The tax paid by the worker for the use of hospital parking is equal to  $t\theta$ , where  $\theta$  may take any positive value. So,  $\theta$  refers to the monetarised benefit of parking space that is included in taxable income. Here, we will first derive the optimal level of  $\theta$  from a welfare perspective.

When the hospital supplies parking for free, the profit is equal to  $R - W - cN$ . The firm will maximise profits by choosing wage levels and parking quantity conditional on the labour supply utility constraint, which takes into account that wages and benefits from parking are taxed

$$W - t[W + \theta[n_s \int_0^N D_s(n)dn + n_p \int_0^N D_p(n)dn]] + n_s \int_0^N D_s(n)dn + n_p \int_0^N D_p(n)dn = U^*. \tag{7}$$

<sup>10</sup> Subsidised or even free parking space is considered to be an important non-wage job characteristic for hospital workers as hospitals compete on the provision of parking to workers (Noether, 1988; Thomson, 1994) so it makes sense for a worker to consider parking as well as wages.

The necessary condition for profit maximisation is now that (for details, we refer to the Appendix of [Katz and Mankiw, 1985](#)):

$$n_p D_p(N) + n_s D_s(N) + t/[1 - t][n_p D_p(N) + n_s D_s(N) - \theta] = c. \tag{8}$$

The new term in this condition (compared to (3)) represents the tax saving from an additional unit of parking. The firm chooses the level of parking, so that marginal benefit to the worker plus the marginal tax saving equals the marginal cost.

According to (8), the level of  $\theta$  affects the number of parking places provided. If  $\theta$  is less than the marginal benefit of parking, for example when it is zero, then there is a positive tax saving by paying compensation in the form of parking rather than wages. The tax system is only neutral if  $\theta$  is equal to the marginal benefit of parking. Because the marginal benefit of parking is equal to the marginal cost of parking, then this implies that the optimal level of  $\theta = c$ . This has a straightforward interpretation: welfare is maximised when the benefit of parking is taxed as additional income using the costs to the hospital as a measure of additional income.

Let us now consider the case where  $t=0.5$  and  $\theta$  is 0, which is representative for the Netherlands. So the marginal income tax rate is 0.50 and the benefits from parking are not taxed. In this case, the first-order condition equals

$$n_p D_p(N) + n_s D_s(N) = c/2, \tag{9}$$

implying that the firm will supply parking such that the marginal benefit of parking is equal to half of the marginal cost of parking. So, the firm will implicitly charge workers for exactly 50% of the full parking price by offering parking fringe benefit for free. Because worker utility is a given, this allows the firm to reduce the gross wage (which immediately follows from (7)).

We have seen that the deadweight loss is exactly proportional to the square of the parking subsidy. Hence, the tax-induced welfare loss is then one quarter of the loss induced by free parking where gross wages are not adjusted. This case is relevant, also for the hospital we focus on which does not explicitly differentiate gross wages based on the use of parking. It is possible however that this hospital offers lower gross wages to all workers compared to other organisations which do not offer any parking.

### 2.3. Parking as an input in the production function

It is assumed that parking is not an input in the production function ([Katz and Mankiw, 1985](#)), which is a reasonable assumption in the case of hospitals, because hardly any hospital worker works offsite. It is however straightforward to allow for this complication in the model. In this case, there will be another term on the left-hand side of (8) equal to the marginal benefit of parking to the firm.

### 2.4. Parking and its effect on car travel

In the welfare function, we have ignored welfare effects of the hospital's policy on welfare through its effect on car use and therefore congestion when congestion is not optimally taxed. It is straightforward to allow for this in the theoretical model, explicitly modelling the relationship between car parking at the hospital, car use and non-taxed travel externalities. In our welfare calculations, we will take this into account by some back on the envelope calculations.

### 2.5. Stochastic demand

We have assumed above that demand is deterministic, so we exclude stochastic variation in demand in the welfare calculation. This can be justified because for the hospital we focus on, variation in parking demand within the day of the week is limited.

Nevertheless, it is useful to discuss the consequences of excluding stochastic variation in our welfare calculation. So let us assume that the demand function also has a *observed stochastic* component which is *additive* to the deterministic component. We believe this assumption is not too restrictive. The stochastic component is completely random and is, for example, due to the weather (which can be observed). In the empirical analysis, we will fully control for the stochastic component by means of *day* fixed effects. So, we will measure the effect of price on the deterministic demand component, controlling for the stochastic component.

Hospital workers have very strict patterns of going to work and they usually (but not always) make use of the same travel mode, so the stochastic component in demand is small relative to the deterministic component. In our empirical analysis, the standard deviation in daily parking is a factor 5 to 10 times smaller than the mean daily parking number. It is therefore reasonable to assume that supply has been chosen by the hospital such that there is *always* excess supply on *slack days*. Hence, stochastic variation in demand has only effect on the chosen parking supply through stochastic variation on *peak days*.<sup>11</sup>

Let us assume now that on peak days, there is a given probability,  $\Omega$ , that the willingness to pay for parking is increased by  $\lambda$ , whereas on other peak days, it is decreased by  $\lambda^*$ . So, the welfare function to be maximised looks like

$$n_s \int_0^N D_s(n)dn + n_p [1 - \Omega] \int_0^N [D_p(n) - \lambda^*]dn + n_p \Omega \int_0^N [D_p(n) + \lambda]dn - cN. \tag{10}$$

Let us assume that given optimal parking supply, there is excess supply on slack days and that the organisation adjust the price depending on the (observed) level of demand on peak days.<sup>12</sup> The first-order condition which determines the optimal parking supply can then be written as:

$$n_p D_p(N^*) + n_p \Omega \lambda - n_p [1 - \Omega] \lambda^* = c. \tag{11}$$

Importantly, one expects that the last two terms of the left-hand side are small relative to  $c$  (the standard deviation in daily parking is a factor 5 to 10 times smaller than the mean daily parking number), so we will ignore this complication in the analysis later on. Note furthermore that if  $\Omega \lambda = (1 - \Omega) \lambda^*$ , then the welfare calculation is even exact.

### 2.6. Interaction with other parking markets

We have been silent about the possible interaction with other parking markets. In our empirical application, we do not have information about parking demand by patients. In principle, patients and workers may use the same parking spaces. So, the welfare effects of distortionary pricing of parking for workers and patients may differ when parking demand by workers and patients is negatively related to each other per day of the week. For example, if there are more workers on Tuesday, but less patients on Tuesday, then it makes sense to analyse both markets simultaneously. However, the patients' presence *positively* covaries with the workers' presence, because fluctuations in overall demand for hospital parking by workers and patients are the result of the same within-week employment fluctuations. In this case, each parking space is either used by a patient or by a worker.

<sup>11</sup> This assumption seems to hold for the hospital (at least for the period after April 2008), because its management has chosen a pricing structure such that demand just equals supply on *peak days*.

<sup>12</sup> When the hospital cannot change the price on a daily basis (which seems reasonable), then there is an additional welfare loss. This additional loss will be present with and without the levels of pricing discussed in the current paper.

Hence, the interaction between patients' and workers' parking market can be ignored, as the patient and a worker markets function independently.

### 3. The data

We focus on a middle-sized *not-for-profit* private hospital in The Hague, called Bronovo, which is in a neighbourhood with residential parking permit only, so workers who commute by car (have to) rely on employer-provided parking. The annual marginal parking costs for the hospital are about €1200.<sup>13</sup> The data used in the empirical analysis combines information from the hospital's daily parking lot use, daily working hours schedules for a period of one and half years (1 April 2007–9 October 2008) and the personnel file at the end of the period (this file includes workers who have left). We focus on working days, so we exclude weekends (during weekends workers park for free, so we do not have any variation in the weekend price of parking). We do not have micro level information about transport mode (except when the worker uses the parking). For the estimation procedure, we do not need this information. We have aggregate information about an earlier period which indicates that the large majority of those who do not travel by car come by bicycle. We do not have information about car pooling, which is rare in the Netherlands.

Before April 2007, a period for which we do not have data, workers parked for free, whereas patients and visitors paid €1.50 *per hour*. As a result, patients and visitors who arrived later during the day were not able to park on certain days. As a result, to avoid excess demand, starting from 1 April 2007, paid parking for workers was introduced and a register system was installed which provides us with data on parking by workers. After a while, the management of the hospital realised that there was excess supply, particularly on Wednesdays and Fridays). So, one year later, 1 April 2008, the parking fee for workers was reduced on Mondays, Tuesdays and Thursdays (the peak demand days), and parking became free on Wednesdays and Fridays (the slack demand days), so time-varying parking prices were introduced. After this date, there is essentially no excess supply *at peak moments* but there is also no excess demand according to the management of the hospital. We will distinguish between a period before and a period after 1 April 2008.

We observe the *exact* times of the workers' presence and parking use. Depending on the shift, a worker may work during the day or at night. Only daytime workers, who normally enter between 7 and 9 am and exit between 4 and 5 pm, are subject to variation in the parking price. Night workers park for free.

The number of daytime workers present on the hospital's premises varies over the days of the week as shown in Table 1. For example, before 1 April 2008, there are, on average, 286 daytime workers present on Fridays and 361 on Tuesdays. These numbers underestimate total employment because they exclude nightshift workers who are on the premises during a part of the day. Total employment varies – on average – from a minimum of about 349 persons on Fridays to a maximum of about 419 persons on Tuesdays.

The variation in (total) employment induces a variation in the demand for (total) parking space over the week. As can be seen

from Table 1, Monday, Tuesday and Thursday are peak days, while Wednesday and Friday are slack days. For example, after 1 April 2008, on Tuesdays, parking demand is on average 232, about 40 places higher than on Fridays (so, by about 20%).<sup>14</sup>

We emphasise the standard deviations of the number of cars in the parking (and of employees at the hospital) are rather low (compared to the average), so the variation in parking demand within specific periods is low, which justifies our approach to ignore cruising for parking. The deviations become even much smaller when we exclude 15 of days where there was an extremely low number of cars in the parking (e.g. Christmas, Easter). For example, the standard deviations of the total number of cars parked before 1 April 2008 drop then to about 27.

The number of daytime workers present on the hospital's premises varies over the days of the week as shown in Table 1. For example, before 1 April 2008, there are, on average, 287 daytime workers present on Fridays and 361 on Tuesdays. These numbers underestimate peak employment because they exclude nightshift workers who are on the premises during a part of the day. Peak employment varies – on average – from a minimum of about 352 persons on Fridays to a maximum of about 421 persons on Tuesdays.

The variation in (peak) employment induces a variation in the demand for (peak) parking space over the week. As can be seen from Table 1, Monday, Tuesday and Thursday are peak days, while Wednesday and Friday are slack days. For example, after 1 April 2008, on Tuesdays, parking demand is on average 275, about 40 places higher than on Fridays (so, by about 17%).<sup>15</sup>

The hospital provides 676 parking spaces, of which 120 are reserved for workers, 220 for both workers and patients/visitors, 316 for patients/visitors and 20 for people with a physical handicap, so there are maximally 340 parking spaces available to workers, a number which exceeds the workers' *average* peak demand.<sup>16</sup> The current parking capacity consists of a combination of asphalted land and single-storey underground parking. Expansion of parking capacity is only possible by building new parking structures.

To be more specific, before 1 April 2008, the daily parking price depended on the employee's commuting distance and was a combination of a parking fee and a foregone bonus for not parking. Workers received a bonus of €0.20 per kilometre for not parking (up to a maximum €2). In addition, workers had to pay €1.10, €1, or €0.80 for parking when the commute was less than 10, 10 to 20 or more than 20 km, respectively. So, the effective parking price varied from €1.10 to €2.80.<sup>17</sup> After 1 April 2008, the price also varied per day of the week: on peak days (Mondays, Tuesdays, and Thursdays), workers within 5, from 5 to 10, or further than 10 km from the hospital, paid €3, €2, or €1, respectively. On the other days, parking was free.

The change in parking policy on 1 April 2008 resulted, *on average*, into a price increase of one euro for workers within the 5 km radius, a negligible change for workers between 5 and 10 km and a price decrease of €1.80 for workers further than 10 km from the hospital. The change in policy induced a *decrease* in the average parking price paid of about €1.20 on peak days and €2.65 on slack days.<sup>18</sup> The *reduction* in the average price, although rather small compared to the overall cost of driving to work (gasoline, wear and tear) suggests that demand for parking will increase, which

<sup>13</sup> We have calculated this cost using different approaches that generate about the same value. The hospital is located in a residential area with paid street parking at the same price of € 1.50 per hour. Over the period considered, the parking price for patients and visitors on weekdays was €1.50 per hour up to a maximum of €7.00 per day. The marginal parking space will however have an occupancy rate which is (much) lower than one. This suggests that the weekly fixed costs are *maximally* €35. The costs of adding space using a multi-story parking lot are estimated to be about €20 to €30 per week (based on recent building costs at other hospitals), although. We use €24 per week.

<sup>14</sup> These figures exclude parking used by 50 medical doctors who park for free and who are not included in the administrative data available to us.

<sup>15</sup> These figures exclude parking used by 50 medical doctors who park for free and who are not included in the administrative data available to us.

<sup>16</sup> Staff may use other parking places but then they pay the same price as other users.

<sup>17</sup> For example, a worker at 4 km who parked the car would forego a bonus equal to €0.80 and pay a parking fee of €1.10, so the effective parking price is €1.90.

<sup>18</sup> About 9% of car parkers have a commuting distance of less than 5 km, whereas 61% have a distance that exceeds 10 km.

**Table 1**  
Average number of workers, parking places occupied and parking price.

	Before 1 April 2008				Parking price	After 1 April 2008				
	Workers present		Parking places occupied			Workers present		Parking places occupied		
	Daytime	Total	Daytime	Total		Daytime	Total	Daytime	Total	Parking price
Monday	336 (33)	404 (36)	227 (50)	257 (43)	2.65	336 (26)	404 (28)	219 (23)	260 (24)	1.5
Tuesday	361 (26)	419 (29)	237 (70)	264 (68)	2.66	351 (26)	416 (27)	232 (23)	274 (24)	1.49
Wednesday	319 (20)	383 (22)	202 (54)	234 (51)	2.65	314 (20)	377 (22)	206 (15)	248 (17)	0
Thursday	341 (27)	402 (32)	226 (47)	253 (45)	2.66	330 (28)	397 (30)	217 (18)	258 (19)	1.48
Friday	286 (25)	349 (29)	194 (45)	225 (36)	2.66	285 (27)	350 (26)	193 (23)	232 (22)	0

Note: Parking by 50 medical doctors is excluded. "Daytime" refers to daytime workers only. "Total" denotes the total number on a day. Standard deviations in parentheses.

is suggested by the aggregate data that suggest a (small) increase in peak parking use, although the aggregate number of workers present decreased, particularly on slack days (see Table 1). For example, on Wednesdays, during peak hours, the parking propensity of workers present increased from 0.607 (233/384) to 0.653 (247/378), suggesting that a €2.65 drop in the parking price increases the parking propensity by 0.046. We will see that our micro-econometric investigation generates similar results.

In our analysis, we exclude observations for workers who always or never park during the period of observation (as the effect of the parking price is not identified for this sample of workers). Our sample amounts then to 132,292 employment days by 784 workers over 384 workdays. The average daily parking probability of these workers is 60%. The average workers' commuting distance (determined by the hospital and not self-reported) is 16 km. Their average age is 37 years; 56% work full-time and 93% have a permanent contract.

The combination of (i) a change in pricing regime on 1 April 2008, (ii) differences in parking prices between peak and slack days (after 1 April 2008) and (iii) a price that varies with the workers' commuting distance results in 25 (within-worker) differences in the level of the parking price. We use a difference-in-differences methodology to estimate the effect of the parking price on demand that exploits these differences. We have categorised these 25 differences in three types of 'strategies', which makes it possible to identify the effect of the change in parking price in different ways.

The first strategy, A, exploits (within-worker) price variation between peak days before and after April 2008. The second strategy, B, exploits the same type of variation, but on slack days. The third strategy, C, exploits (within-worker) price variation between different days of the week after 1 April 2008. We emphasise that these three strategies are mutually exclusive, so they rely on different sources of variation in the data. Fig. 1 shows the relationship between changes in the price and in the average parking propensity. It is clearly negative for all three identification strategies Fig. 2.

## 4. Empirical analysis

### 4.1. Main results

The essence of the paper lies in the estimation of the daily demand function. Our dependent variable is whether a (dayshift) worker makes use of hospital parking on a given day of employment. We use the three identification strategies described above. We also combine these strategies to obtain more precise estimates. We estimate linear probability models that include *worker-specific*

and *day-specific fixed effects*.<sup>19</sup> In this way, we avoid bias in estimates related to time-invariant unobserved worker heterogeneity (e.g. workers' preferences for car use; household income) as well as unobserved day heterogeneity. For example, for many Dutch hospital workers, biking is the main alternative to driving, which can be a rather unpleasant experience in bad weather, so parking demand is sensitive to weather.

Given both types of fixed effects, the effects of variables that vary both across workers and day of employment can be identified. We are able to identify the effects of the daily parking price, working hours at the hospital, number of work activities (i.e. tending patients, and pharmacy) and whether the worker also worked off the hospital premises (e.g. visiting patients at home). Descriptive statistics for these variables are presented in the Appendix. They show for example that most hospital workers (78%) work exactly 8 h on a day and almost all workers (97%) do not leave the hospital's premises.

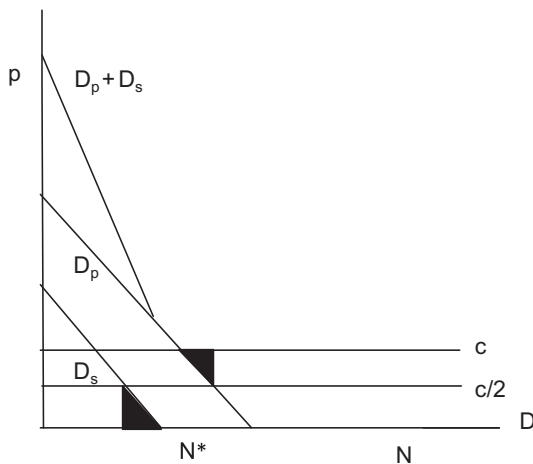
The empirical results are presented in Table 2. Our main result is that for each strategy the parking price (measured in Euros per day) has a (statistically significant) negative effect on the probability to park of approximately  $-0.015$ .<sup>20</sup> These results are in line with studies such as Willson and Shoup (1990) and Willson (1992), which also analyse the effects of employer-paid parking.

The estimated effects are (almost) identical for each identification strategy, which increases confidence in the estimation procedure. These results also imply that the slope of the demand function does not vary between peak and slack days. This makes sense as the large majority of workers work on both days, so differences in aggregate demand between days are mainly due to differences in number of workers present and is not due to differences between characteristics of workers. Combining the strategies, the estimated effect of an increase of one euro per day for parking at the hospital is  $-0.015$  with a standard error of 0.002.

The results for the control variables make sense. Workers with off-site work activities have a higher probability to park. The number of hours at work has a positive effect on the probability to park, which is consistent with the diminishing marginal benefit of

<sup>19</sup> We estimate linear probability models, rather than discrete choice models, because of the large number of worker and day fixed effects. Both models provide consistent estimates of the coefficients of interest, see, for example, Maddala (1983), Angrist and Pischke (2009).

<sup>20</sup> In economics, it is common to report price elasticities. As commuters usually face zero monetary parking costs, reporting of price elasticities for commuters is less useful, because given a linear specification the implied price elasticity of demand is zero for a price close to zero and (approximately) proportional to the level of the price. The (implied) elasticity is  $-0.025$  at a price of 1 euro,  $-0.08$  at a price of 3 euro, and in the order of  $-0.2$  given a price of 8 euro per day.



**Fig. 2.** Demand function where  $n_s = n_p = 1$ . Note that the slopes of  $D_s$  and  $D_p$  are both equal to  $-\varphi^{-1}$ ; the slope of  $D_s + D_p$  is equal to  $-2\varphi^{-1}$ , when  $D_s > 0$ , otherwise it is equal to  $-\varphi^{-1}$ .

**Table 2**  
Linear probability estimates of parking probability.

	Strategy A	Strategy B	Strategy C	All strategies
Price (in € per day)	-0.014*** (0.003)	-0.014* (0.008)	-0.016*** (0.006)	-0.015*** (0.002)
Activity off-site	0.050*** (0.014)	0.011 (0.020)	0.109*** (0.022)	0.038*** (0.012)
Working hours				
Three	-0.207*** (0.010)	-0.266*** (0.014)	-0.247*** (0.016)	-0.227*** (0.008)
Four	-0.040*** (0.010)	-0.076*** (0.011)	-0.080*** (0.013)	-0.060*** (0.007)
Five	-0.050*** (0.010)	-0.014 (0.019)	-0.032** (0.016)	-0.048*** (0.008)
Six	-0.004 (0.010)	-0.011 (0.014)	-0.009 (0.015)	-0.008 (0.009)
Seven	-0.200*** (0.008)	-0.261*** (0.009)	-0.313*** (0.010)	-0.224*** (0.006)
Nine or more	0.021*** (0.006)	0.017 (0.009)	0.276*** (0.010)	0.020*** (0.005)
Activities				
One	0.035 (0.029)	0.126*** (0.048)	0.030 (0.039)	0.062** (0.025)
Two	0.018 (0.025)	0.133*** (0.043)	0.049 (0.032)	0.054** (0.021)
Worker fixed effects	Yes	Yes	Yes	Yes
Day fixed effects	Yes	Yes	Yes	Yes
No. of observations	82,789	49,503	39,141	132,292
No. of workers	784	784	631	784

Note: standard errors in parentheses. The three strategies are explained in the main text.

\*\*\* Significant at the 1% level.

\*\* Significant at the 5% level.

leisure time, so on days that workers are scheduled to work only few hours, the use of slower modes such as bicycle/public transport becomes more attractive. Since we use worker and day fixed effects, we believe these effects can be interpreted as causal. Interestingly, this is the first study that is able to demonstrate the causal effect of daily variation in labour supply on daily variation of car parking (and therefore on car use). One well-known characteristic of the linear probability model is that it does not constrain the probabilities to the 0 to 1 interval. In our applications, only 8% of the predicted probability to park falls outside this interval.

## 4.2. Sensitivity analyses

We have done a range of sensitivity analyses. First, we have re-estimated the model without day fixed effects, but with year, month and day-of-the-week fixed effects. This generates almost identical results. Second, we have estimated a conditional logit model instead of a linear probability model. For computational reasons, we restricted the analysis to strategy C (which uses less observations and slightly less fixed effects) as it takes even for this strategy several days to estimate a conditional logit model. We found almost identical results. We have also estimated conditional logit models without day fixed effects, but with year, month and day-of-the-week fixed effects.

Because of the limited number of fixed effects, we can use this approach for all strategies as well as the combined strategy. Now we find substantially larger effects (except for strategy B which provides almost identical estimates), but with larger standard errors. For example, the overall effect is now  $-0.029$  with a standard error of 0.004. Hence, our estimates reported above are conservative, and will underestimate the welfare losses of mispricing.<sup>21</sup> Interestingly, for this model, the marginal effect of price is constant over its range (at the 10, 25th, 50, 75 and 90 percentiles), justifying linear probability model.

We have examined alternative specifications using the combined strategy. For example, we have estimated models adding the square of parking price. Although its coefficient is (just) statistically significant, the marginal effects are  $-0.010$ ,  $-0.014$ , and  $-0.013$  when the price is one, two or three euros, respectively, so the marginal effect is essentially constant over the relevant range. We have also interacted the price with three distance dummies (up to 10 km, 10 to 20 km, and more than 20 km). The effect of price is then  $-0.007$ ,  $-0.016$  and  $-0.017$ , respectively. This result is likely due to the fact that up to 10 km, the average price change is small ( $+\text{€}0.25$  per day), whereas from 10 km, the average price change is large ( $-\text{€}1.80$  per day).

We have also re-estimated the models for specific subsamples. For example, we have excluded workers hired after certain dates (e.g. 1 February 2008) and workers who have left the hospital before certain dates (e.g. 1 June 2008), but the results remain the same.

One interesting feature of the linear probability model (e.g. compared to the conditional logit model) is that worker (and day) fixed effects are identified. The worker fixed effects are consistently estimated in our application because the time dimension of the panel is large (Wooldridge, 2002), which offers the possibility to apply a two-stage estimation procedure. We use the worker fixed effects obtained from the estimates presented in Table 2 in a second stage, by regressing them on time-invariant worker characteristics (age, wage, part-time job, temporary job, log of commuting distance).<sup>22</sup> This suggests that the probability to park increases strongly with distance and is slightly higher for part-time and temporary workers (we do not interpret these effects as causal due to the endogenous nature of distance). Importantly, the  $R^2$  of the second stage regression is rather low (0.16) implying that most of the time-invariant worker heterogeneity in car parking is unexplained. This suggests that the use of worker fixed effect to obtain consistent results for estimates such as reported in Table 2 is essential. This is confirmed by re-estimating the linear probability model without worker fixed effects (but with the time-invariant worker characteristics mentioned above). We now find that price has a positive (rather than a negative) effect on parking, which is clearly a spurious result due to a lack of relevant time-invariant control variables.

<sup>21</sup> See Angrist and Pischke (2009) who argue that it is prudent to choose the linear estimate from a range of reasonable specifications, particularly when it provides the smallest effect size.

<sup>22</sup> Strictly speaking, not all of these characteristics are time-invariant, but they are almost always invariant in our application.

## 5. Deadweight loss

To estimate the deadweight loss of non-optimal pricing, we use a marginal resource cost of €24 per week (about €1200 per year). For the hospital, we observe three peak days. We assume that these three peak days have identical demand functions (in line with our findings). So, the optimal price is €8 on these days. As mentioned above, the difference between the actual and the optimal price is the ‘parking subsidy’. When the hospital offers parking for free (as is the case for about two thirds of Dutch hospitals) and adapts parking supply accordingly to avoid excess demand for parking on peak days, the parking subsidy is €8 on peak days (and €0 on slack days). The annual deadweight loss amounts then to €74.88 per worker present ( $52 \times 0.5 \times 0.015 \times 3 \times 8^2$ ), which is equivalent to €126 per parking place, about 10.5% of the annual resource cost (see Table 3).<sup>23</sup>

We emphasise that we assume that supply can be adapted (a long-run assumption), and that the marginal costs remain constant. However, our calculations are conditional on the location of the hospital. So, one may argue that our calculations are short run, because it is likely that at other locations the marginal cost of parking differs from the marginal resource cost of the current location.

The above calculation may be criticised because in our data do not observe parking prices as high as €8 per day, so we are effectively using out-of-the-sample marginal effects. We cannot address this issue. However, there are reasons to believe that this is less essential than it seems, because a hypothetical increase in the parking price to €8 is not extremely large compared to the average overall transport price of car use in our data.

Assuming a monetary expense of €0.20 per kilometre, the daily travel expense, excluding parking, is on average about €6, so including parking equal to €8.50 (before the introduction of paid parking). Given a €8 parking price, the overall price of commuting by car increases to €14 on average, about 65% higher than before. This is not an extreme increase in the average price of going to work by car. Nevertheless, we emphasise that the welfare calculations should be interpreted as indicative only. Note further that assuming a linear relationship between the probability of parking and parking is likely a reasonable assumption, because even given a large hypothetical increase in parking price, the change in parking probability is only 0.015.

We have above ignored the effect on car travel (see Section 2.4). Given the assumption that workers who do not park at the hospital premises do not travel with their own car, then the average increase in external commuting costs due to the increase in congestion induced by free parking is on peak days about €0.30 per worker (given an average one-way commuting distance of 16 km and an external costs of €0.08 per kilometre, these costs can be calculated as  $0.015 \times 8 \times 32 \times 0.08$ ).<sup>24</sup> So, the annual loss due to increased congestion is about €47 per worker ( $3 \times 52 \times 0.30$ ), more than half of the private deadweight loss.

We now focus on the case that the hospital would use a fixed price per day (the same price on all days of the week), which holds for about one third of the Dutch hospitals. The deadweight loss of

**Table 3**

Welfare loss due to distortionary pricing (relative to parking expenditure).

	Free parking	Mean costs pricing (€4.80 per day)	Fixed price €1.50 per day	€1.50 On peak days free on slack days
Welfare loss	10.50	4.21	7.20	6.95

Note: welfare loss as percentage of hospital parking expenditure.

non-optimal pricing depends on the level of the price. We use the fixed price that minimises the deadweight loss. As shown above, this price equals the mean daily cost (€4.80 in our data). Given the assumption of zero cross-price effects from day to day, the total loss is then the sum of the losses on peak days (due to excess demand) and the losses on slack days (due to excess supply).<sup>25</sup> Recall that the effect of parking price on demand is the same on slack and peak days (see Table 2). The annual loss is then €30 per worker ( $52 \times 0.5 \times 0.015 \times (3 \times 3.20^2 + 2 \times 4.80^2)$ ), so €50.55 per parking space. Thus, the minimum loss of using a fixed price is 4.21% of the resource costs (see Table 3). This is a substantial loss, but less than half of the loss when parking is free.

Dutch hospitals that use a fixed price usually charge a parking price of €1.00 or €1.50 per day. Using the latter for the current hospital, the corresponding annual loss is €86.39 per parking space ( $52 \times 0.5 \times 0.015 \times (3 \times 6.50^2 + 2 \times 1.50^2)$ ), so 7.20% of the resource cost. Although a welfare improvement compared to free parking, this loss is much higher than using a price which reflects mean costs (of €4.80). Reducing the price on slack days does not have much effect on welfare. For example, when the hospital charges workers €1.50 per day on peak days and zero on slack days, then the annual loss is about €84.7 ( $52 \times 0.5 \times 0.015 \times (3 \times 6.50^2)$ ), so 6.95% of the resource cost, which is only slightly less than the loss of charging a fixed price of €1.50 (see Table 3). This is a relevant result: the zero price on slack days decreases workers' overall parking expenditure by almost 40%, which makes a policy that introduces paid parking for workers much more acceptable to workers and their representatives.<sup>26</sup>

As discussed in Section 2.2, a share of the above-mentioned welfare loss is likely induced by a distortionary tax regime, which prevails in all countries we are aware of (except Singapore). The presence of a positive income tax rate together with a fiscal regime that does not consider free parking as a benefit in kind induce firms to offer free parking and to increase parking supply. The marginal income tax for Dutch workers (with annual earnings in excess of €20,000) is about 50%. Optimal fringe benefits taxation, viz. a tax that maximises welfare in the economy, implies that the difference between the firms' cost of providing a benefit and the price paid by the worker for this benefit must be taxed as income (so, the worker pays for the full price of the benefit out of net wages).

To determine the distortionary effect of current tax policies regarding parking, it is important to realise that firms may reduce gross wages for employees who park for free (see Katz and Mankiw, 1985). Given the assumption that firms will reduce gross wages, workers who make use of free parking will pay for about 50% of the parking costs through a decrease in gross wages equal to the parking costs (as the marginal income tax rate is about 0.50). The deadweight loss is, given the assumptions on the

<sup>23</sup> Note that for this calculation we do not have to assume that cross-price effects are zero from day to day, because on slack days the optimal price is equal to the price asked by the hospital, so on slack days the market is not distorted. To calculate the loss per parking place, we divide the loss per worker by the average parking propensity, which is 0.60. Our loss estimate is roughly half of the estimate of a recent Dutch office market study which uses a completely different methodology and where firms are allowed to relocate (Van Ommeren and Wentink, 2012).

<sup>24</sup> In the Netherlands, it is usually argued that fuel taxation internalises environmental externalities (except congestion), so we ignore these. Note that €0.08 is a very rough estimate, but in line with other studies (Small and Verhoef, 2007).

<sup>25</sup> This assumption seems reasonable in the current context as for most workers the days on which they work are given.

<sup>26</sup> Our estimates cannot be generalised to the whole hospital sector, but they are suggestive of the order of magnitude. Given 140,000 parking places for hospital workers, assuming that the parking place costs €1200 per year and that two-thirds of hospitals do not charge workers for parking, the annual loss for the Dutch hospital sector is in the order of €16 million.



demand and supply functions, exactly proportional to the square of the parking subsidy (see Section 2.2). Hence, the tax-induced welfare loss is then 'only' one quarter of the loss induced by free parking, thus €31 per parking space, 2.6% of resource costs. However, firms usually do not differentiate wages based on workers' parking use, including the hospital we focus on, so the tax-induced deadweight loss must be substantially higher.

## 6. Conclusion

We study the consequences of non-optimal pricing of parking by estimating the employees' demand for parking. We identified the price effect on parking demand using an innovative difference-in-differences methodology for an organisation which rather uniquely varies the price of parking per day of the week. The loss generated by free parking for workers is about 10% of the organisation's parking costs. This excludes any welfare costs due to an increase of travel externalities. By using peak pricing on high demand days, this loss can be minimised. By using a fixed price per day, the loss is still at least 4% of the organisation's cost. This is of particular interest to economists, as already in 1954, Vickrey recommended to use time-varying parking tariffs to deal with variation in demand.

It is plausible that a (substantial) proportion of this loss arises from a distortionary tax rule that does not tax free employer-paid parking as a fringe benefit in kind. Free parking for hospital workers is frequently proposed in the UK press as a useful mandatory government policy. Our results (in line with intuition) suggest that this is not such a good idea from a welfare perspective.

## Appendix. Descriptives

See Table A1

**Table A1**  
Descriptive statistics.

Variable	Mean	Standard deviation
Parking price (€)	2.070	1.024
Activity off-site	0.032	0.176
Daily working hours		
Three or less	0.017	0.129
Four	0.036	0.186
Five	0.033	0.179
Six	0.026	0.160
Seven	0.042	0.200
Eight	0.777	0.416
Nine or more	0.069	0.253
Number of activities		
One	0.957	0.202
Two	0.040	0.197
Three	0.003	0.049
No. of observations	132,292	

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