FACULTY OF ECONOMICS AND
APPLIED ECONOMIC SCIENCES
CENTER FOR ECONOMIC STUDIES
ENERGY, TRANSPORT & ENVIRONMENT

KATHOLIEKE
UNIVERSITEIT
LEUVEN

WORKING PAPER SERIES
n°2001-10

When consumers can decide not to pay a tax: enforcing and pricing urban on-street parking space

Edward Calthrop
(K.U.Leuven-CES)

February 2001

contact:
Isabelle Benoit
KULeuven-CES
Naamsestraat 69, B-3000 Leuven (Belgium)
tel: +32 (0) 16 32.66.33
fax: +32 (0) 16 32.69.10
e-mail: Isabelle.Benoit@econ.kuleuven.ac.be
http://www.econ.kuleuven.ac.be/ew/academic/energmil

When consumers can decide not to pay a tax: enforcing and pricing urban on-street parking space*

Edward Calthrop
Centre for Economic Studies, K.U.Leuven.

February 2001

Abstract

Governments may be hindered in setting taxes on markets in which the consumer can choose to consume the good but not pay the tax. An example is urban on-street parking. If government attempts to ration demand to supply via a peak-load fee, but fails to invest in costly enforcement, drivers park but do not pay the meter fee. This paper examines optimal enforcement levels and meter fee rates for on-street parking. It is shown that, when enforcement is sufficiently costly, peak-load pricing is not desirable. In addition, some positive amount of illegal parking remains in the optimum. Finally, the model is used to explore the behaviour of local government when, as was the case in the U.K., it does not receive the revenues from fine payments. It is shown that this might lead local government to set meter fees and enforcement levels that are too low - something that has been widely observed in the U.K.

1 Introduction

To consume gasoline, a driver has virtually no choice but to pay the full consumer price, including any tax placed on the sale by government. But not all markets are equally amenable to the levying of taxes. Take the case of urban on-street parking market. Government can place a tax on on-street parking, but, in the absence of costly enforcement, drivers may choose to use the space without paying. Another example is that of household waste. In many European cities, urban regulators require that households place their waste in special taxed bags. But a household can decide to dump waste rather than pay the tax. One final example. On many types of buses, it is difficult for passengers to board without paying the driver. In contrast, at urban rail termini (often dating from the 19th

*Email:Edward.Calthrop@econ.kuleuven.ac.be I would like to thank Stef Proost for providing extensive comments. Usual disclaimers apply.

century) passengers can usually exit the station relatively easily. Rail staff tend to board trains and check payment in transit. But this makes non-payment of fares relatively easy.

These types of markets are characterised by the need for the government to set two variables: the consumer price and the level of costly enforcement. This paper examines this issue, and makes three separate contributions. Firstly, the paper highlights potential trade-offs involved in setting different combinations of user fees and costly enforcement levels. A simple static partial model is used to develop expressions for the optimal level of meter fees and enforcement levels. The model used is similar to those developed in the quite large literature on enforcement issues. The literature stemmed from the seminal paper by Becker [2], and reviews can be found in, amongst others, Polinsky and Shavell [12] and Heyes [8]. However, those papers typically consider the setting of either enforcement levels alone, or combinations of enforcement and fine levels. This paper, in contrast, deals with the simultaneous setting of taxes (or consumer prices) and enforcement levels. In addition, this paper highlights potential inefficiencies resulting from separation between the layer of government responsible for setting enforcement levels, and that receiving the fine revenue. The issue of fiscal federalism has seldom been discussed in the enforcement literature.

Secondly, the model is applied to the urban parking market. Although other markets could have been chosen, the parking market seems particular apt for several reasons. The development of a better understanding of the desirability of intervention is something of clear practical relevance. Indeed, there has been considerable debate about the correct level of enforcement within the applied transport engineering literature. The consensus appears to be that, at least in the case of London, enforcement levels and meter fees were too low during the 1970s and 1980s[1]. Enforcement has been deregulated since the 1990s and concerns have been raised that enforcement levels are now too high[2]. The question of the correct level of enforcement and meter fees is something that is explicitly addressed in this paper. In addition, the paper contribution in the transportation economics literature on urban parking. William Vickrey [13], was the first to apply the idea of peak-load pricing to urban parking markets. Arnott and Rowse [1] argue for parking fees to equal marginal external cost, defined as the addition to average search time required by other drivers resulting from the decision to park for an additional unit of time. Finally, Calthrop and Proost [6] argue the case for meter-fees rather than time restrictions to be used in regulating on-street space. In all three papers, the need to raise fees stems from the short-run fixed supply of parking space. All three papers assume perfect costless enforcement of regulations. This paper extends that literature by integrating costly enforcement into a peak-load pricing model. Moreover,

[1] For instance, Kimber [] reports that 48% of all meter parkers and 78% of all yellow line parkers were committing an offence. See also Elliot and Wright [].

[2] The Daily Telegraph, *Taking a firm yellow line on London's roads*, 31st August 1996, reports that the number of parking tickets issued has more than doubled since the introduction of a new private enforcement scheme in London. They go on to discuss accusations that the local authority schemes are profit-driven and excessive.

this model collapses into a simple peak-load pricing model if enforcement is assumed to be costless.

The third contribution of the paper is a small numerical model calibrated to data from London. The model can be used as a starting point to develop more detailed policy tools. It also aids basic intuition into the model as certain results are not in closed-solution form.

Section 2 introduces the basic model of on-street parking, while section 3 characterises optimal enforcement and meter rates. Section 4 highlights the fiscal federalism issue and Section 5 concludes. Proofs and sensitivity tests are contained in the Annexes.

2 A model of on-street parking

This section develops the analytical and numerical model of urban on-street parking.

2.1 The analytical model

Consider a fixed number n of risk-neutral consumers[3] that wish to use a fixed number of urban parking spaces during the peak period. Each driver chooses how long to park for, and whether to pay at the meter or not. If a driver chooses not to pay, he or she risks incurring a fine. Drivers that do not pay at the meter are henceforth termed as behaving 'illegally'.

Parking meters charge a per time unit fee equal to m. Two types of costs are incurred if a driver parks illegally. The first cost is given by the expected fine per unit of time parked, equal to ϕF, where ϕ denotes the per time unit probability of being caught for illegal parking and F gives the fixed penalty fine[4]. The probability of being caught depends on the level of enforcement, which in the case of on-street parking, is usually performed by traffic wardens.

Secondly, each driver pays an individual 'non-compliance' cost from each time unit parked illegally[5 6]. This is given by a random variable c, from a known continuous and differentiable cumulative probability distribution, $G[c]$ with support $[0,\infty)$. The associated probability density function is given by

[3] Each consumer is assumed to have a quasi-linear utility function with respect to parking time.

[4] As pointed out by Becker [2], if enforcement is costly, any desired expected fine level is most efficiently reached by setting as high a fine level as possible and as low a probability of inspection level as possible. Several authors have investigated conditions under which this result breaks down, including the presence of wealth constraints, risk-aversion or the probability of erroneous monitoring. See the review of this issue in Polinsky and Shavell [12].

[5] The term non-compliance cost is introduced in this context by Elliot and Wright [7], who argue that this is an important cost component in illegal parking.

[6] This approach can be seen as a short-cut to formalling modelling heterogeneous consumer preference towards risk. I conjecture that such an approach would give similar results to that adopted here.

$g[c]$[7]. A driver therefore chooses to park illegally if $\phi F + c < m$ and hence with probability $G[m - \phi F]$. If the meter fee is set below the expected fine, it is assumed that there is full compliance i.e. $G[.] = 0$.

$n(1 - G[m - \phi F])$ drivers park legally. Each receives a consumer surplus from parking for q units of time, S^L, given by:

$$S^L = \int_0^{q^L} (\alpha - \beta q - m) dq$$

The remaining drivers choose not to pay at the meter. For any value of the non-compliance cost, c, consumer surplus from illegal parking, S^I, is given by:

$$S^I = \int_0^{q^I} (\alpha - \beta q - \phi F - c) dq$$

Each driver parks until the marginal benefit of an additional unit of time parked equals the marginal cost. In the case of a legally parked driver, this is given by q^L such that:

$$\frac{dS^L}{dq^L} = \alpha - \beta q^L - m = 0$$

which gives:

$$q^L(m) = \frac{\alpha - m}{\beta} \tag{1}$$

Alternatively, an illegal driver with a non-compliance cost, c, expects to park for a time q^I such that:

$$q^I(\phi; c) = \frac{\alpha - \phi F - c}{\beta} \tag{2}$$

[7] They are several possible interpretations for this variable. Firstly, as given, it can be seen as a psychological cost from illegal behaviour. Secondly, it can be interpreted as an upward bias in the expectation of the expected fine. Polak and Axhausen [11], given a range of the chance of detection for illegal parking based on a survey in Birmingham, U.K. Estimates varied from under 10% to 100%. Thirdly, with a slight change in the model structure, we could interpret the variable as an additional cost, perhaps a time cost from having to deal with the payment of the fine. The value of this cost varies through the population. Jebson [9] reports that over 50% of respondents to her survey said that time delay involved , if caught, discouraged illegal parking more than cost.

Note that the implies that illegally parked drivers outstay the legal[8]. Total expected demand per person, $D(m, \phi)$, is therefore a function of both the meter fee and the level of enforcement of payment:

$$D(m, \phi) = (1 - G[m - \phi F])\, q^L(m) + \int_0^{m-\phi F} q^I(\phi; c) g[c] dc \qquad (3)$$

Marginally increasing the meter fee induces some (probability mass of) drivers to switch from legally to illegal parking. Demand for parking time from these switchers remains unaltered, as $q^L(m) = q^I(\phi; m - \phi F)$. Hence the change in total demand 3 from a marginal increase in meter fee is given by:

$$\frac{\partial D(m, \phi)}{\partial m} = \frac{-1}{\beta} [1 - G[m - \phi F]] < 0 \qquad (4)$$

If $m < \phi F$, $G[\cdot] = 0$, there is full compliance, and expression 4 gives the marginal demand response as $-1/\beta$. In general, however, expression 4 shows that allowing for non-compliant behaviour results in a fall in demand which is not larger than the full-compliance case.

Differentiating demand 3 with respect to the expected fine level, ϕF, gives:

$$\frac{\partial D(m, \phi)}{\partial \phi F} = \frac{-1}{\beta} G[m - \phi F] < 0 \qquad (5)$$

Increasing the level of the expected fine induces some illegally parked drivers to pay at the meter. Just as in the case above, however, these marginal drivers length of stay is unaltered by the rise in expected fine. Only those drivers that remain parking illegally respond to the higher expected fine by reducing their length of stay.

The supply of parking hours per peak period per person is given by Z. A peak-load price $\widehat{m}$ is assumed to exist such that per person demand , D, equals supply, Z. Sustituting expressions 2 and 1 into 3, the peak-load price can be given by the following implicit equation:

$$\widehat{m} - \int_0^{\widehat{m}-\phi F} (\widehat{m} - \phi F - c) g\,[c]\, dc = \alpha - \beta Z \qquad (6)$$

The right-hand side gives the price at which demand would be rationed to supply in the case of perfect compliance. Equation 6 shows that the peak-load price allowing for non-compliant behaviour is not less than the price assuming

[8] Jebson [9] asked drivers how long they would park for under various types of parking control. The results show that for all form of control, drivers who parked illegally provided an average time which was higher than that of the group who parked legally.

compliant behaviour. The integral term on the left hand side of the expression is non-negative, and hence $\widehat{m}(\phi F) \geq \alpha - \beta Z$.

Notice that if $\phi F \geq \alpha - \beta Z$, $\widehat{m} = \alpha - \beta Z$. If the level of the expected fine is relatively high, all demand can be rationed to meet supply at the meter price equal to $\alpha - \beta Z$. The cut-off level of inspection probability is defined by $\overline{\phi} \equiv \frac{\alpha - \beta Z}{F}$, which, to keep the problem interesting, is assumed to be strictly less than one. If the level of enforcement is such that the inspection probability is equal to, or higher than $\overline{\phi}$, demand can be rationed to supply with all drivers choosing to park legally. However, if enforcement are such that the inspection probability is below $\overline{\phi}$, it is clear from equation (6) that $\widehat{m} > \phi F$ and demand can only be rationed to supply with some percentage of drivers choosing to park illegally.

To ease later exposition, this is stated in the form of a lemma.

Lemma 1 *If the level of enforcement is such that $\phi \geq \overline{\phi}$, the 'peak-load' meter fee (required to ration demand to available supply) is given by $\widehat{m}(\phi F) = \alpha - \beta Z \leq \phi F$ and hence all drivers pay at the meter. Otherwise, if $\phi < \overline{\phi}$, $\widehat{m}(\phi) > \alpha - \beta Z > \phi F$ and with some positive probability, $G[.]$, drivers park illegally.*

When $\phi < \overline{\phi}$, marginally increasing the level of the expected fine reduces the peak-load price. Using implicit function theorem, equation 6 shows that:

$$\frac{\partial \widehat{m}}{\partial \phi F} = -\left(\frac{G[\widehat{m} - \phi F]}{1 - G[\widehat{m} - \phi F]}\right) \leq 0 \tag{7}$$

Increasing the level of the expected fine reduces the peak-load meter fee by the ratio of illegal to legal parkers. The larger the level of non-compliant behaviour, the greater the reduction in the peak-load price resulting from a marginal increase in the level of expected fine. This is also obvious from expressions 4 and 5 above - marginal changes in price variables do not induce changes in demand from those consumers that switch from legal to illegal behaviour or vice versa.

The probability of finding a vacant space is assumed to be given by a random-rationing rule[9]:

$$\rho(m, \phi) = \begin{cases} \frac{Z}{D(m,\phi)} & \text{if} \quad m \leq \widehat{m} \\ 1 & \text{otherwise} \end{cases}$$

To make the problem interesting, capacity is assumed to be scarce: i.e. $\rho(0, \phi) < 1$. Expected social welfare per person is given by:

[9] This seems a reasonable assumption in the case of on-street parking. See Calthrop and Proost [6] for a more detailed justification. However, use of a competing reasonable rule - rationing to those with the lowest willingness-to-pay - would not alter the substance of the conclusions of this paper.

$$SW(m,\phi) = \rho\overline{W} - C(\phi; F, nZ) \tag{8}$$

where $C(\cdot)$ gives the cost per person of achieving any level of inspection probability per time unit across a fixed supply of urban spaces, nZ, given a fixed fine F and $\overline{W}$ gives the benefit to a driver conditional on getting a parking spot, and is given by:

$$\overline{W} = \left[(1 - G[m - \phi F])W^L + \int_0^{m-\phi F} W^I(c) g[c] dc \right]$$

where:

$$W^L(m) = \int_0^{q^L(m)} (\alpha - \beta q) dq$$

and:

$$W^I(m,\phi,c) = \int_0^{q^I(m,\phi)} (\alpha - \beta q - c) dq$$

Fine revenues and meter fee payments are returned lump-sum to the population. The government's problem is to maximise social welfare 8 with respect to two instruments: the per time unit meter fee, m and the inspection probability, ϕ. The social welfare function is continuous, and with a compact action set, $(\widetilde{m} \leq m \leq 0; 1 \leq \phi \leq 0)$ optima are guaranteed by Weierstrass Theorem.

2.2 The numerical model

A small numerical model is used to help illustrate the ideas of the paper. Parameter values are shown in Table 1. Two different assumptions are made about the distribution of the variable c. In one formulation, I use an exponential function, thus capturing that a large percentage of drivers park illegally once the meter fee is marginally higher than the expected fine. In an alternative formulation, I use a uniform distribution. In either case, unless otherwise stated, the mean value of the c is identical for the two distributions.

Table 1 - parameter values

parameter	level
α	20
β	4
μ_c	10
z	2.5
γ	2

The choice of values for α and β correspond to those chosen in Calthrop and Proost [**?**], which were loosely calibrated to data for central London. The values for the mean value of the non-compliance cost distribution, μ_c, and the exponent in the cost function are essentially arbitrarily chosen. There are both the subject of sensitivity testing below.

The cost function per person of the inspection probability plays an important role in the numerical model. I assume that this cost function is given by:

$$C(\phi; nZ, F) = h(nZ) * (\phi F)^\gamma \tag{9}$$

In the central case, γ is assumed to equal 2. This gives the ratio of marginal cost to average cost of inspection. There is some evidence for decreasing returns to scale in enforcement activities: employing additional wardens tends to be less and less effective, as it is difficult to co-ordinate their activities. The parameter h is allowed to vary from 0.05 to 0.3 in the base case computations. The range is based on data reported in Brown [3][10].

3 The social optimum

The maximisation problem presented in equation 8 needs to be solved with respect to the two instruments available to government: the per time unit meter fee, m and the per time unit inspection probability, ϕ. To aid insight, it is useful to split the problem into two stages: first, maximise welfare with respect to the meter fee for any given enforcement level; and, secondly, optimise the inspection probability. In particular, the solution to the first stage problem corresponds to the situation faced by local urban authorities in the U.K. prior to the 1991 legislation. Enforcement levels were set by a regional (not local) police authority. Each local urban authority faced the problem of maximising welfare for a given level of enforcement.

3.1 The optimal meter fee

Assume that the local urban authority can maximise welfare with respect to a meter fee for any given level of enforcement. The problem to solve is to maximise social welfare, given in equation 8 with respect to the meter fee. Three lemmas help simplify the search for the optimal meter fee.

Lemma 2 establishes that it is never optimal for the meter fee to be set at a level strictly higher than the peak-load level. There is no rationale for reducing

[10] Brown reports that the expected fine per illegal act is £1.13 in Brighton (Table 28). The total annual cost of enforcement is given in Table 23. It is not clear which of the costs are fixed and which are variable: converting to a daily basis, I use a range of £740-1612, and assign 75% to the peak period. Table 18 reports 10,539 parking acts per day, of which I assume one-half occur in the peak period. These values can be used to estimate a value for h. For example, suppose that the cost per peak-period parking act is £1000*0.75/5000 = £0.15. Equation [] gives that: $\mathbf{0.15} = h(\mathbf{1.13})^2$, which gives $h = \mathbf{0.12}$. Using the range of cost information, gives a range of the parameter h from $\mathbf{0.08}$ to $\mathbf{0.18}$. In the numerical computations, I allow for a slightly broader range of values of h : $\mathbf{0.05}$ to $\mathbf{0.3}$.

demand below supply in the model. Doing so would only reduce social welfare. Hence, $m^* \leq \widehat{m}(\phi)$.

Lemma 2 *The optimal meter fee for any given level of enforcement, m^* is less than or equal to the level required to ration demand to available supply, $\widehat{m}(\phi)$.*

Proof. See Annex 1 ■

Lemma 3 establishes that for a sufficiently high inspection probability level $\phi \geq \overline{\phi}$, the optimal meter fee is just the peak-load fee which in turn is less than the expected fine from illegally parking.

Lemma 3 *If $\phi \geq \overline{\phi}$, the optimal meter fee, m^*, is given by $m^* = \alpha - \beta Z = \widehat{m}(\phi) < \phi F$. All drivers park legally.*

Proof. See Annex 1 ■

The final lemma establishes that for relatively low enforcement levels, it is optimal to raise the meter fee to at least the level of the expected fine. This is also intuitive. Enforcement levels are relatively low. If the meter fee is lower than the expected fine, there is full compliance and all drivers pay at the meter. However, excess demand remains, and rationing benefits arise from increasing the meter fee. This induces drivers to park for a shorter period and thus increases the collective probability of finding a vacant spot. These marginal benefits remain until the meter fee equals the level of the expected fine.

Lemma 4 *If $\phi < \overline{\phi}$, the optimal meter fee, m^*, is equal to, or greater than, the expected fine: $m^* \geq \phi F$.*

Proof. See Annex 1 ■

Hence the remaining maximisation problem can be written as:

$$\underset{\phi F \leq m \leq \widehat{m}(\phi)}{Max} \quad SW(m;\phi)$$

Assuming an interior solution, Annex 1 derives the first-order condition:

$$\frac{(1 - G[\cdot])}{\beta D}\overline{W} = (1 - G[\cdot])\frac{m}{\beta} + g[\cdot]q^L(m - \phi F) \tag{10}$$

The left hand side term gives the expected benefit to a driver from an increased probability of being able to find a vacant spot. Increasing the meter fee reduces demand (from legal parkers) and increases the probability of a randomly arriving driver finding a vacant spot. The higher the compliance rate, $1 - G[\cdot]$, the larger the marginal benefit from raising the fee (for a fixed level of $\overline{W}$). When the meter fee is only marginally above the level of the expected fine, there is a high compliance rate. Increasing meter fees then has a large impact on total demand, as most drivers are parking legally. The increase in the probability of finding a vacant space is relatively large. In contrast, if the meter fee is relatively high in comparison to the level of the expected fine, many drivers park illegally. Thus a further increase in meter fee has only a small effect on total demand. The increase in probability of finding a vacant space is relatively small.

The right hand side consists of two cost terms. The first gives the marginal welfare cost to a legal parker from staying for a shorter period of time - recall that $dq^L/dm = -1/\beta$ and hence the loss in expected terms is $(1 - G[\cdot])\, m/\beta$. This marginal cost is outweighed by the marginal benefit of an increased probability of finding a vacant space at all meter fee level below the peak-load level. The second cost term on the right-hand side gives the loss of welfare to those drivers that switch from paying to not paying at the meter. For a single unit of time this is equivalent to the non-compliance cost of a driver that switches, which is given by $c = m - \phi F$. In expected terms, the loss from staying a full q^I units of time $(= q^L\ )$is given by $g[\cdot]q^L(m - \phi F)$. Assuming an interior solution, the optimal meter fee level is such that the marginal benefit from raising the fee, accruing to all drivers, exactly balances the marginal costs to legal parkers and induced 'switchers' to illegal parking.

It is clear from the formulation, however, that the optimal fee may be at an interior level, as given by the solution to equation 10, or it is at one of the two corner solutions. The numerical model is used to derive the optimal meter fee for any given enforcement level. Figure 1 shows the result for an exponential distribution of non-compliance costs - section 5 below shows an alternative assumption of a uniform distribution. Note that the optimal meter fee is denoted by (M-OPT) while the level required to ration demand to supply is given by (M-HAT).The fee and expected fine are in units of £ per hour.

For relatively low levels of enforcement, it is not optimal to set meter fees such that demand is rationed to supply - indeed it may not be possible to ration demand to supply at all. With low enforcement levels, setting higher meter fees leads to ever smaller benefits: if most drivers are parked illegally, raising meter fees has little impact on aggregate demand. Low meter fees were therefore a rational response to the fixed low enforcement levels seen in many British urban areas in the 1970s and 1980s.

However, for relatively high enforcement levels, in the case of Figure 1 above the level of approximately £7 per hour, peak-load pricing remains desirable. As enforcement levels reach the level of $\overline{\phi}F$, in this example given at a level of £10 per hour, the optimal meter fee is also given by £10 per hour. At this fee level, demand is rationed to supply at a price in which all drivers choose to pay at the meter. If the expected fine is greater than this level, the optimal meter fee remains at the peak-load level of £10: this is just the result given in Lemma 3. For any level of expected fine below this level, however, notice that the optimal meter fee is strictly greater than the expected fine, and non-compliance rates are strictly positive.

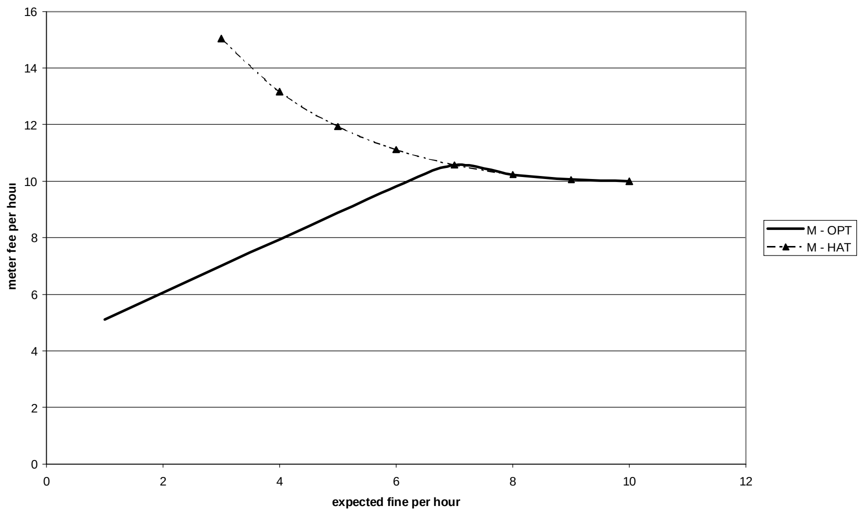

Figure 1: Optimal meter fee

3.2 The optimal enforcement level

Government can in principle alter both the level of inspection probability and the meter fee. The maximisation problem given in equation (8) can be solved by setting the probability of inspection level such that:

$$\frac{\partial}{\partial \phi}\left[\rho \overline{W}\right]|_{m^*} = C^{'}(\phi; nZ, F)$$

The marginal cost of raising the inspection probability should equal the increase in social welfare that follows from higher enforcement levels, evaluated at the optimal meter fee, derived above.

Figure 2 demonstrates the optimal enforcement level (dotted line) and meter fee for the numerical example, as a function of an enforcement cost parameter h. As would be expected, if enforcement is relatively inexpensive (low value of h), it is optimal to set a high inspection probability. As enforcement costs fall to zero, the optimal expected fine tends towards the level $\overline{\phi}F$, which in this example equals £10 per hour. This is the level at which, when meter fees match the expected fine, the probability of finding a space to rise to one, and all drivers choose to pay at the meter.

Two interesting results emerge from the numerical model. Firstly, for any strictly positive level of the cost parameter h, optimal meter fees are higher than the optimal expected fine. This is not surprising given the costly nature of setting positive inspection probabilities. Only if enforcement is costless does the

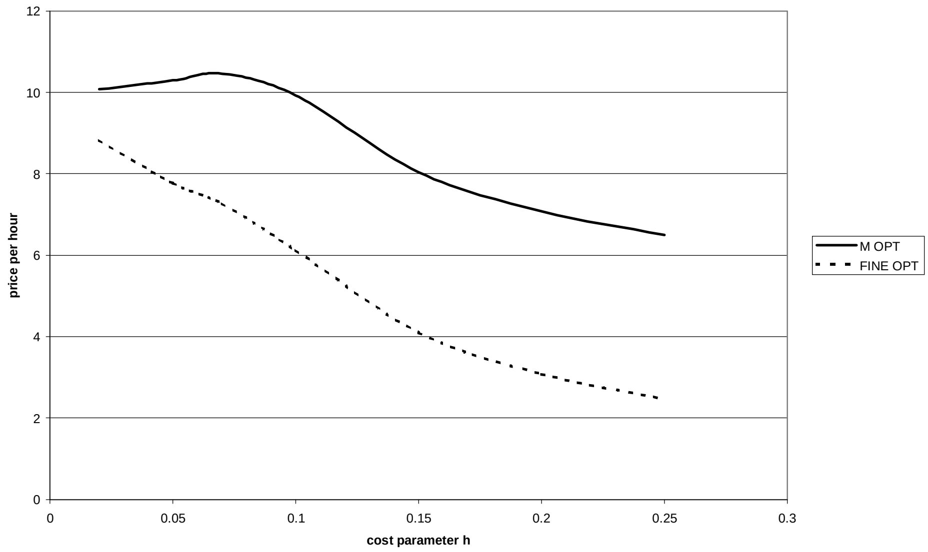

Figure 2: Optimal enforcement and meter fee levels

optimal meter fee coincide with the optimal enforcement level at the peak-load level. Secondly, if the cost of enforcement falls, perhaps due to new technology or better management, the optimal inspection probability increases. However, it is not always the case that the optimal meter fee rises. If costs are sufficiently small ($h < 0.07$), the policy of peak-load pricing requires reducing meter fees in response to higher enforcement levels. The data construction for the numerical model suggested a range of the value of h between 0.08 and 0.18. In this interval, Figure 2 suggests that any exogenous fall in enforcement costs should be met by higher inspection probabilities and higher meter fees.

4 The local government optimum

As discussed in the Introduction, in several countries, revenues from court-enforced fines accrue to the national treasury rather than the local jurisdiction. For example, in the U.K., prior to the introduction of the new act in 1991, several meter offences were liable to a fixed-penalty notice, which accrued directly to the national government. But the local jurisdiction decides upon the level of inspection. The following section of the paper examines the effect on local government behaviour resulting from the loss in fine revenues to central government. The level of the court fine for illegal parking,F, is taken as exogenously fixed[11]. Further, it is assumed that all consumers are inhabitants within the local jurisdiction.

4.1 The optimal local meter fee

The local agency rationally treats fine payments as a resource cost to the local community (rather than a transfer). Hence, social welfare is given by:

$$LSW(m,\phi) = \rho\overline{LW} - C(\phi; nZ, F) \tag{11}$$

where $\overline{LW}$ gives the net local benefit to a driver conditional on getting a parking spot, and is given by:

$$\overline{LW} = (1 - G[m - \phi F])W^L + \int_0^{m-\phi F} LW^I g\,[c]\,dc$$

where W^I is the same as given above, and the local welfare from parking illegally is given by:

$$LW^I(m,\phi) = \int_0^{q^I(m,\phi)} (\alpha - \beta q - \phi F - c)dq$$

As in the previous section, the implicit equation for the optimal fee, assuming an interior solution, balances the marginal benefits from raising fees with marginal costs (see equation A3. The loss of fine revenue from the community reduces local social welfare. The marginal benefit from a higher probability of finding a vacant space is therefore smaller than in the case for full social welfare. The loss of fine revenue also increases the local cost to raising meter fees. Raising meter fees induces some drivers to switch from parking legally to parking illegally. In doing so welfare is reduced per time unit parked by the non-compliance cost, c of those induced to switch, plus the loss of revenue to the local community, ϕF. Hence for any given enforcement level, the marginal benefits from raising fees is smaller while the marginal cost is higher than in the social optimum discussed above. Hence locally optimal fees are set at a lower level than in the social optimum. This result is presented in Proposition 1.

Proposition 1 *For any given level of expected fine, ϕF, a local agency sets a meter fee not greater than the socially optimal level. Further, for relatively low levels of enforcement, $\phi F < \overline{\phi} F$, a local agency sets a meter fee less than the socially optimal level.*

Proof. See Annex 1 ■

[11] The level of the fine is assumed to be set by central government. As in the previous section, it is assumed that for various reasons, altering the level of the fine is difficult. However, the model can be extended in a straightforward manner to allow for strategic behaviour on the part of central government in setting the level of the fine.

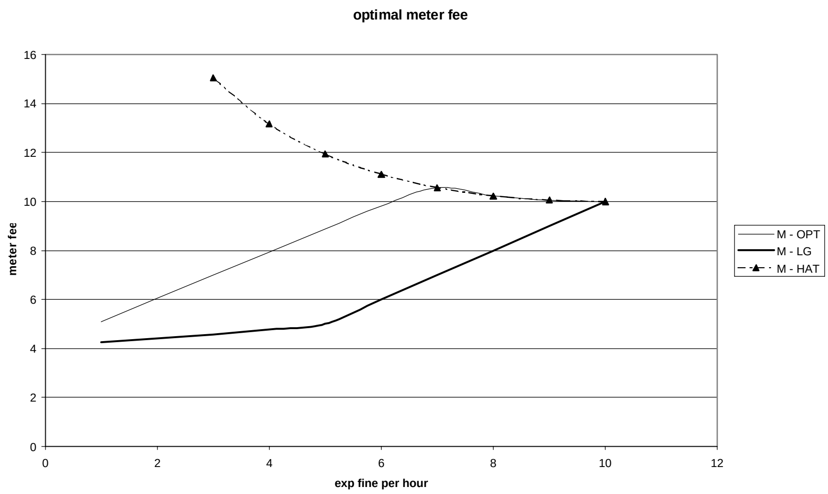

Figure 3: Optimal meter fee for local government

The result of the theorem is clearly seen in Figure 3. The locally optimal meter fee (M - LG) is set strictly below the level of the socially-optimal fee (now shown as a dotted line) for all levels of enforcement less than $\overline{\phi}F = £10$. For higher enforcement levels, the local government's problem is identical to that of the welfare optimiser: all drivers park legally up to and including the peak-load price. The optimal solution is therefore the same.

As discussed above, this figure demonstrates the position that most U.K. urban authorities faced prior to the introduction of the 1991 Act. Enforcement levels were set by the regional police force and not by the local urban authority. Fine revenues for most meter offences accrued to the national rather than local government. Theorem 1 therefore suggests that, a priori, we might expect a rational local government to set meter fees at a level below the socially optimal level. There was an incentive to use low meter fee rates to ensure revenues remained within the local community.

4.2 The locally-optimal enforcement level

The 1991 Act deregulates parking enforcement in the U.K. Power over setting enforcement levels is therefore transferred from the regional police force to the local urban government. This section derives the level of enforcement chosen by a local-social welfare maximising government.

It is clear that the local government faces something of a dilemma. If enforcement is relatively costly, it is unattractive to set high enforcement levels. An alternative means to reduce the flow of revenues to the central government is to set very low enforcement levels. Not catching offenders is one means of

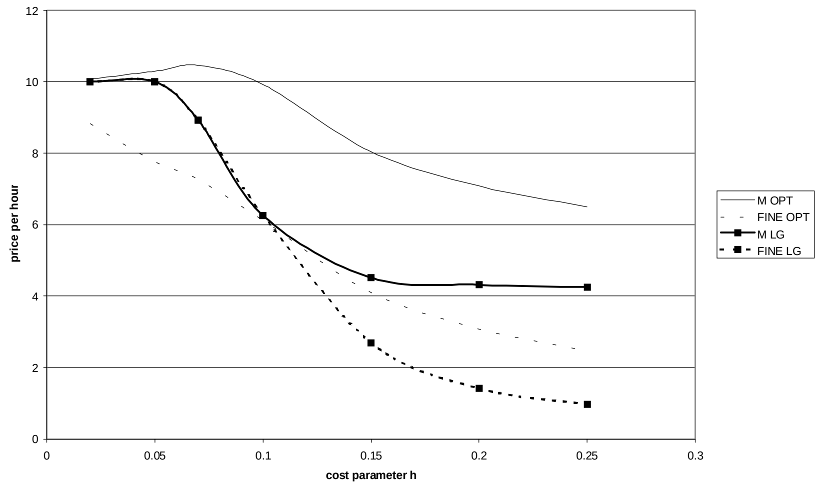

Figure 4: Optimal enforcement and meter fee levels - local government

preventing fine revenues flowing out of the local community. Coupled with low meter fees, this policy results in a badly-rationed parking market, but saves on enforcement costs. Conversely, if enforcement is relatively cheap, a local government may set excessively high enforcement levels. This induces drivers to choose to park legally, and is coupled with high meter fees and a well-rationed parking market.

Figure 4 shows the optimal enforcement level (in £ per hour) set by a local government in the numerical example. An exponential distribution of non-compliance costs is assumed. The dashed lines show optimal enforcement levels in the full social optimum (as in Figure 2 above) and in the local government optimum. The full lines show optimal meter fee levels, again for the full social optimum (as in Figure 1) and for the local government optimum (as in Figure 3).

Consider the results for optimal enforcement levels. As expected, for low costs of enforcement ($h<0.1$), local government over-invests in enforcement relative to the social optimum. Conversely, for high enforcement costs, local government under-invests. As given in Proposition 1, for any cost parameter value, local government sets lower meter fees than the social optimum.

The 1991 Act remedies the perverse incentives facing local government described in this section. It permits local government to levy an 'excess charge' from an offending driver, which is payable to the local community rather than the national treasury. This is also common practice in other European countries. However, should a large percentage of drivers choose not to pay the re-issued demand, but instead appear in court, the analysis of this section holds. The revenues from court fines accrue to central government.

5 Conclusion

On certain markets, it is relatively easy for a consumer to choose not to pay a tax but still consume the good. This paper has highlighted the example of on-street parking. In the absence of enforcement, drivers rationally choose to use the market without paying the fee. Government has to decide upon the appropriate level of costly enforcement and meter fee.

Three conclusions warrant comment. First, contrary to the transport economics literature that has assumed costless enforcement, peak-load pricing is shown not to be always desirable. If enforcement is sufficiently costly, the optimal meter fee and inspection probability are insufficient to ration demand to available supply. High enforcement costs reduce the optimal level of the expected fine. The lower the expected fine, the higher the level of the meter fee necessary to ration demand to available supply (equation 7). Figure 1 shows that, for instance, if the expected fine falls below approximately £7 per hour, it is not desirable to use the meter fee to ration demand entirely to available supply. Instead the rationing benefits have to be traded off against ever increasing welfare cost stemming from a declining tax base. Assuming a cost of enforcement parameter h equal to 0.2, Figure 2 shows that the optimal expected fine is only £3, and the optimal meter fee of £7 per hour fails to ration all demand to supply. The optimal probability of finding a vacant spot is 0.74.

The second conclusion is a corollary to the first. The optimal meter fee level is above the optimal expected fine. Hence those drivers with a low non-compliance cost choose to park illegally. Full compliance is not desirable. Again assuming a cost of enforcement parameter equal to 0.2, and applying optimal enforcment levels and meter fees, results in 0.33 percent of drivers choosing to park illegally. The magnitude of this result is, of course, sensitive to the assumption made about the distribution of non-compliance costs. Assuming a uniform rather than an exponential distribution results in an equivalent figure of 0.25. This can be compared with the estimate from Kimber [10] that 48% of parking meter users in early 1980s London committed an offence. It is thought that the use of private enforcement in London during the 1990s has markedly reduced the number of parking offences. This suggests the possibility of over-compliance. This issue is of incentives under private enforcement schemes is explored further in Calthrop [4].

The third conclusion applies when local government fails to receive fine revenues from illegal parking. This was the situation in the U.K. until recently. If this is the case, local government may set low enforcement levels. Not catching offenders is one way to prevent fine revenues being lost to the local community. In addition, local government may set meter fees that are too low: low meter fees induce drivers not to park illegally and thus reduces total fine revenue. This may help cast light on the perceived problem of low meter fees and enforcement witnessed in several U.K. cities during the 1970s and 80s. However, note that the result depends on the cost of enforcement. If enforcement costs are relatively low, local government may over-invest in enforcement activities. High expected fines encourage drivers to pay at the meter, and allow the community to reap some of the rationing benefits from higher meter fees.

The generality of these results are explored in Calthrop [5]. The paper examines marginal cost pricing in a market in which consumers can invest (at a cost) in avoiding paying for the consumption of goods. More general optimal enforcement and pricing rules are developed.

Some strong caveats are required when interpreting the model results to guide parking policy. Firstly, we have considered only a very particular type of illegal parking: the decision to not pay at the parking meter. A more convincing model might add an additional response of drivers faced with a low probability of finding a marked parking space: namely, to park at ad-hoc spots or areas specifically marked as banned. Parking is typically banned from areas in which parked vehicles would reduce visibility for other drivers and increase accident risk. This is the case, for instance, close to junctions. However, the framework developed in this paper can be extended to include a third dimension of driver choice of parking in a banned-area. This will presumably increase the benefits from a well-rationed parking market, in which only a few drivers will choose to not park in the permitted area. Optimal meter fees will probably rise above the case considered here.

Secondly, we adopt the random-rationing rule. Infact, drivers can exploit other margins to increase the probability of finding a vacant space. They can schedule arrivals for the earlier or later parts of the rush hour, or can perhaps acquire better information about parking availability. Moreover, the rule is only applicable to areas of shopping trips or leisure activities. Workplace parking is often reserved.

Thirdly, we assume identical demand curves for time spent parked in a city centre. Allowing for heterogeneity in demand characteristics will complicate the model, but is unlikely to alter the main conclusions. The basic model mechanism requires that if meter fees are in excess of the expected fine, some drivers choose to park legally. Without this aspect, optimal meter fees would just equal the level of the expected fine. This mechanism will also hold in a more complex model with greater consumer demand heterogeneity.

Finally, we ignore the off-street parking market. This is considered (in the case of costless enforcement) in Calthrop and Proost [6]. The enforcement problem exists for both time restrictions and meter fees, and thus does not affect the relative ranking of instruments derived in that paper. However, the optimal levels of instruments could be made a function of the cost of enforcement by integrating this model into that paper.

References

[1] Arnott, R. and Rowse, J., 1999, Modeling Parking, *Journal of Urban Economics*, 45(1), pp. 97-124.

[2] Becker, G.S., 1968, Crime and Punishment: An Economic Approach, *Journal of Political Economy*, 76, pp.169-217.

[3] Brown, M., 1991, *Car parking: the economics of policy enforcement*, Cranfield Press, UK.

[4] Calthrop, E., 2001a, *Privatising enforcement*, mimeo.

[5] Calthrop, E., 2001b, *On enforcing tax payments*, mimeo.

[6] Calthrop, E. and Proost, S., 2000, *Regulating urban parking: the case for meter fees versus time restrictions*, Centre for Economic Studies Discussion Paper, Public Economics, DPS 00.21, K.U.Leuven.

[7] Elliot, J.R. and Wright C.C., 1982, The Collapse of Parking Enforcement in Large Towns, *Traffic Engineering and Control*, June, pp. 304-310.

[8] Heyes, A., 2000, Implementing Environmental Regulation: Enforcement and Compliance, *Journal of Regulatory Economics*, 17:2, pp.107-129.

[9] Jebson, D.A., 1987, On-street parking in Central London: questionnaire survey of drivers, unpublished TRRL paper, Crowthorne, Berkshire.

[10] Kimber, R.M., 1984, *The effects of wheel-clamping in Central London*, Transport and Road Research Laboratory LR 1136.

[11] Polak, J.W. and Axhausen, K.W., 1989, The Birmingham CLAMP stated preference survey, second interim report to Birmingham City Council, TSU Ref 502.

[12] Polinsky, A.M. and Shavell, S., 2000, The Economic Theory of Public Enforcement of Law, *Journal of Economic Literature*, 38, pp.45-76.

[13] Vickrey, W., 1959, Statement to the Joint Committee on Washington DC Metropolitan Problems: Exhibit 53 - Economizing of Curb Parking Space - a suggestion for a new approach to parking meters, Hearings, US Congress Joint Committee on Metropolitan Washington Problems, reprinted in *Journal of Urban Economics*, 1994, vol 36,pp. 42-65.

6 Annex 1

This annex gives the proofs of the lemmas and propositions in the paper.

6.1 Proof of Lemma 2

The lemma is established by considering the alternative case: $m^* > \widehat{m}(\phi)$. The probability of getting a vacant spot is one, by assumption. Hence social welfare can be written as:

$$SW(m) = \int_0^{m-\phi F} W^I(c)g[c]dc + (1 - G[m - \phi F])W^L - C(\phi F) \qquad \text{(A1)}$$

It is direct that if $m \leq \phi F$, $G[\cdot] = 0$ and social welfare reduces to $W^L - C(\phi F)$. It is straightforward to show that with this social welfare function $\frac{dSW}{dm} < 0$.

It remains to show the result for the case that $m > \phi F$. Taking the derivative of A1 gives that:

$$\frac{dSW}{dm} = -\frac{m}{\beta}(1 - G[\cdot]) - g[\cdot]q^L(m)(m - \phi F) < 0$$

It is always welfare improving to reduce the meter fee, thus contradicting the assumption of an optimum. Q.E.D.

6.2 Proof of Lemma 3

By assumption, $\phi \geq \overline{\phi}$. The first part of the proof shows that if $m < \widehat{m}(\phi)$, $\frac{\partial SW}{\partial m} > 0$. The second shows that $m > \widehat{m}(\phi)$, $\frac{\partial SW}{\partial m} < 0$. Hence, $m^* = \widehat{m}(\phi)$.

Consider $m < \widehat{m}(\phi)$. The discussion of Lemma 1 establishes that $\widehat{m}(\phi) < \phi F$, and hence social welfare may be written as:

$$SW(m; \phi) = \rho W^L - C(\phi F) \tag{A2}$$

Taking the derivative of this expression, it is clear that $\frac{dSW}{dm} > 0$.

Now consider $m > \widehat{m}(\phi)$. It is shown in Lemma 2 above that for any value of $\phi, \frac{dSW}{dm} < 0$. This holds for the restriction range of ϕ considered here.Q.E.D.

6.3 Proof of Lemma (4)

Given that $\phi < \overline{\phi}$, I show that an optimal level of meter fee cannot be less than the level of the expected fine. If $m \leq \phi F$, $G[\cdot] = 0$. Social welfare is given by expression (A2). As in the first part of the proof for Lemma 3, it is straightforward to show that $\frac{dSW}{dm} > 0$. Q.E.D.

6.4 Deriving the first-order condition to meter fee

This section gives the derivation of equation 10. Taking the derivative of equation 8 gives:

$$\frac{dSW}{dm} = \rho' \overline{W} + \rho W'$$

Recalling equation 4, it is straightforward to show that $\rho' = (1 - G[\cdot])\, \rho / \beta D$. Setting the first order condition to zero and substituting for the derivative of the probability of finding a spot reveals:

$$\frac{(1-G[\cdot])\,\overline{W}}{\beta D}=\overline{W}'$$

Substituting the full expressions for W^L and W^I into W' and taking the derivative gives equation 10.

6.5 Proof of Proposition 1

The theorem states that the optimal locally-set meter fee is lower than or equal to the socially-optimal fee. The first order condition for an interior solution to problem 11 is given by:

$$\frac{1-G[\cdot]}{\beta D}\overline{LW}=(1-G)\frac{m}{\beta}+g[\cdot]q^L m \qquad \text{(A3)}$$

Let the solution to this equation be given by m_{LG}. This condition can be substituted into the first derivative of the full social welfare function. This gives:

$$\frac{1-G}{\beta d}(\overline{W}-\overline{LW})+g[\cdot]q^L m_{LG}\geq 0$$

This term the net social benefit from raising meter fees at the optimal level for the local community, m_{LG}. This is strictly positive (when $m_{LG}>\phi F$), thus indicating that social welfare is increased by raising the meter fee above the locally-optimal level. Only if $\phi F\geq\overline{\phi}F$, are the optimal social and local meter fees equal.Q.E.D.

7 Annex 2: sensitivity analysis

The model results presented above rest on two unknown parameters and one distribution. This section presents some results from altering the assumptions made for the base case above. Full sensitivity analysis results are available from the author.

7.1 A uniform-distribution of non-compliance cost

Figure 5 shows the full social welfare optimal meter fee and inspection probability under the assumption of a uniform distribution of non-compliance costs. The broken line indicates enforcement levels, while the solid line indicates meter fee levels. The optimal meter fee is denoted by MU-OPT, while the equivalent fee under an exponential distribution is given by ME-OPT. The use of the suffix U and E is also used to distinguish between the optimal enforcement levels. Note

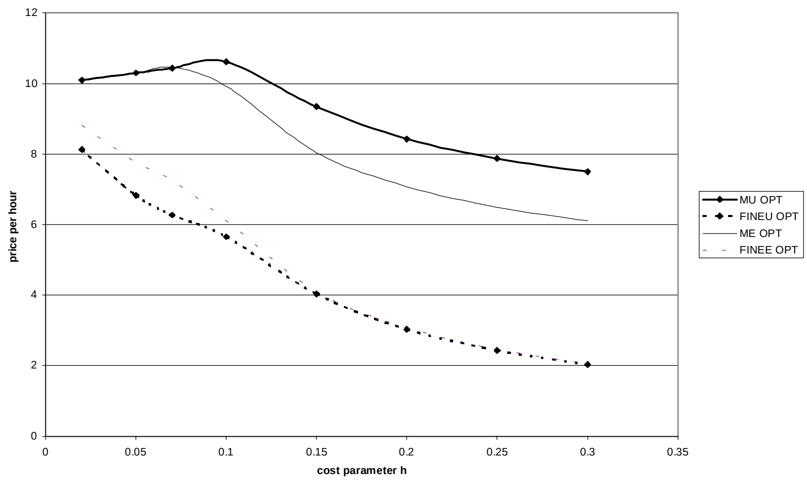

Figure 5: Uniform distribution of non-compliance cost

that under either assumption, the mean value of the distribution remains equal to 10.

Under an exponential assumption, a larger probability mass exists on small values of non-compliance cost: loosely this can be thought of as saying that a larger number of people switch to parking illegally when the meter fee is marginally raised above the level of the expected fine. The marginal welfare cost of inducing drivers to switch to parking illegally was discussed in equation 10. It follows that the marginal cost of raising fees is smaller under a uniform than an exponential distribution, as less probability mass rests on small non-compliance costs. Therefore, optimal meter fees are larger under a uniform distribution than an exponential, which is clearly seen in Figure 5.

At relatively high costs of enforcement, the optimal enforcement level is more or less equivalent under either assumption. At low cost, however, the uniform distribution results in lower enforcement levels. If people are less likely to park illegally, it is optimal to set lower levels of enforcement.

Results showing the impact of assuming a uniform distribution on the local government's problem are available on request from the author. The basic intuition shown here continues to hold.

7.2 Altering mean non-compliance cost

The mean-non compliance cost was given by £10 per hour in the analysis above. Raising the mean value for either the exponential or uniform distribution is equivalent to shifting the cumulative probability distribution to the right. The probability that a driver has a non-compliance cost less than or equal to $m - \phi F$

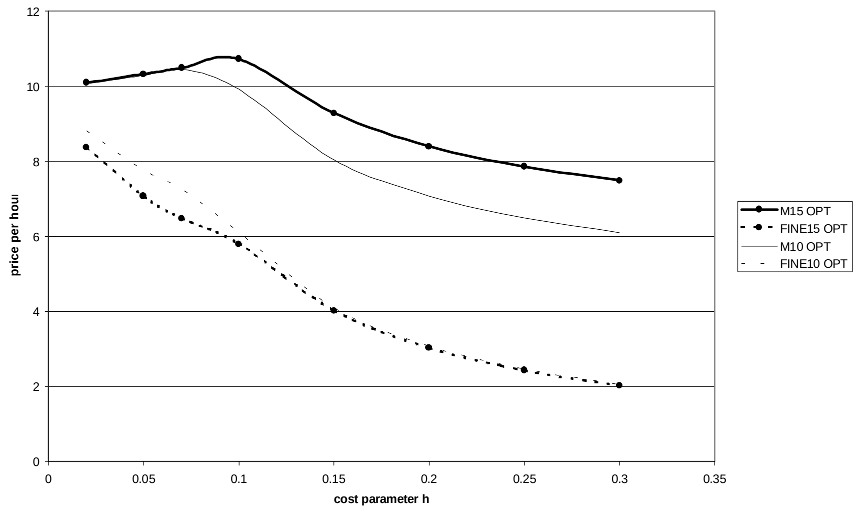

Figure 6: Increasing the mean non-compliance cost

falls. As with the discussion of the uniform distribution above, the reduction in the probability of parking illegally acts to reduce the marginal costs of increasing the meter fee in equation 10. Optimal meter fees rise. As in the section above, the reduced tendency to park illegally reduces the optimal level of costly enforcement.

Figure 6 demonstrates these effects. The mean non-compliance cost is raised from £10 to £15. An exponential distribution is assumed. The optimal meter fee weakly increases and the enforcement level weakly falls.

7.3 Altering the exponent in the cost function: γ.

For the cost function chosen, the parameter γ gives the ration between the marginal and average cost of setting a particular expected fine level. In the central case, I assume a value for γ equal to 2. This was chosen to reflect the difficulty in co-ordinating enforcement behaviour of wardens. In this section, I allow this parameter to vary.

Figure 7 presents the optimal enforcement level for three values of γ: 2, 1.5 and 1.

For any value of γ, the optimal enforcement level is inversely related to the cost parameter, h. However, the larger the value of γ, the larger the marginal cost of raising the expected fine, and the smaller the optimal level of enforcement.

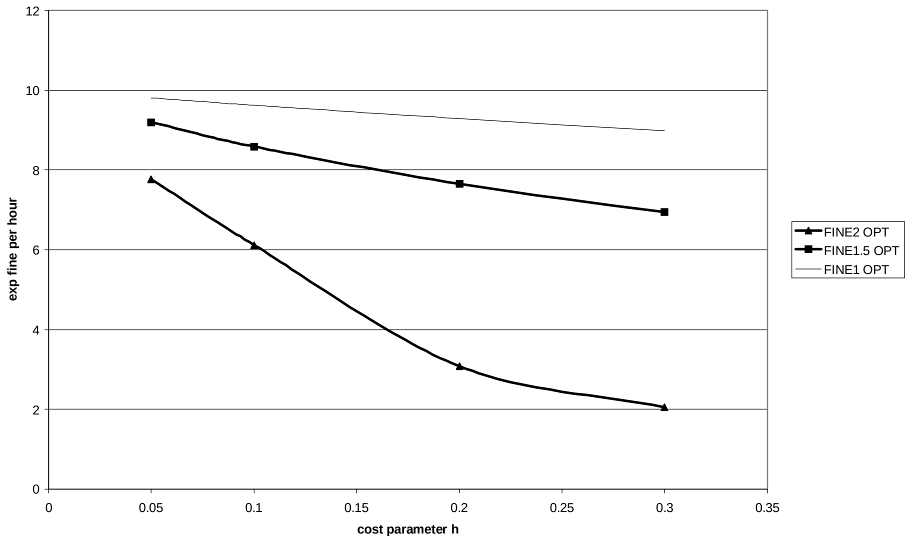

Figure 7: Altering cost function gamma

The Center for Economic Studies (CES) is the research division of the Department of Economics of the Katholieke Universiteit Leuven. The CES research department employs some 100 people. The division Energy, Transport & Environment (ETE) currently consists of about 15 full time researchers. The general aim of ETE is to apply state of the art economic theory to current policy issues at the Flemish, Belgian and European level. An important asset of ETE is its extensive portfolio of numerical partial and general equilibrium models for the assessment of transport, energy and environmental policies.

WORKING PAPER SERIES

n° 2001-10 Calthrop, E. (2001), When consumers can decide not to pay a tax: enforicing and pricing urban on-street parking space

n° 2001-09 Franckx, L. (2001), Ambient environmental inspections eliminate the need for marginal deterrence

n° 2001-08 Franckx, L. (2001), Optimal fines for environmental noncompliance under a decentralized enforcement policy

n° 2001-07 Franckx, L. (2001), Reputation effects in regulatory enforcement

n° 2001-06 Franckx, L. (2001), Ambient inspections in environmental enforcement: an extension

n° 2001-05 Eyckmans, J., and Cornillie, J. (2001), Supplementarity in the European carbon emission market

n° 2001-04 Franckx, L. (2001), Ambient environmental inspections followed by sequential firm inspections

n° 2001-03 Eyckmans J. (2001), On the farsighted stability of the Kyoto Protocol

n° 2001-02 Van Dender, K. (2001), Pricing transport networks with fixed residential location

n° 2001-01 Rousseau, S. and Proost, S. (2001), The relative efficiency of environmental policy instruments in a second-best setting with costly monitoring and enforcement (*also available as CES Discussion Paper 01.04*)

n° 2000-09 Proost, S., and Van Regemorter, D. (2000), How to achieve the Kyoto Target in Belgium — modelling methodology and some results

n° 2000-08 Eyckmans J. and Bertrand, C. (2000), Integrated assessment of carbon and sulphur emissions, simulations with the CLIMNEG model

n° 2000-07 Pepermans G., and Proost, S. (2000), Stranded costs in the electricity sector

n° 2000-06 Calthrop, E., and Proost, S. (2000), Regulating urban parking space: the choice between meter fees and time restrictions (*also available as CES Discussion Paper 00.21*)

n° 2000-05 Mayeres, I., and Proost, S. (2000), Should diesel cars in Europe be discouraged? (*also available as CES Discussion Paper 00.18*)

n° 2000-04 Willems, B. (2000), Cournot Competition in the Electricity Market with Transmission Constraints (*also available as CES Discussion Paper 00.24*)