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

KATHOLIEKE
UNIVERSITEIT
LEUVEN

WORKING PAPER SERIES
n°2006-01

THE ENFORCEMENT OF SPEEDING: SHOULD FINES BE HIGHER FOR REPEATED OFFENCES?

E. DELHAYE (ETE – CES, KULEUVEN)

January 2006

secretariat:
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.kuleuven.be/ete

THE ENFORCEMENT OF SPEEDING: SHOULD FINES BE HIGHER FOR REPEATED OFFENCES?

Eef Delhaye[1]
Center for Economic Studies – K.U.Leuven
Naamsestraat 69, 3000 Leuven - Belgium
Phone: +32 16326641 E-mail: eef.delhaye@econ.kuleuven.be

ABSTRACT

Speed limits are a well-known instrument to improve traffic safety. However, speed limits alone are not enough; there is need for enforcement of these limits. When one observes fine structures for speed offences one often finds two characteristics. First, the fine increases with the severity of the violation. Secondly, the fine depends on the speeders' offence history. We focus on this last point and confront two fine structures, both increasing with speed: a uniform fine and a differentiated fine, which depends on the offence history. Drivers differ in their propensity to have an accident and hence in their expected accident costs. Literature then prescribes that the fine for bad drivers should be higher than for good drivers. However, the government does not know the type of the driver. We develop a model where the number of previous convictions gives information on the type of the driver. We find that the optimal fine structure depends on the probability of detection and on the strength of the relationship between the type and having a record. We illustrate this by means of a numerical example.

[1] I would like to acknowledge the financial support of the Belgian Federal Science Policy research program – Indicators for sustainable development – contract CP/01/38 (Economic Analysis of Traffic Safety: Theory and Applications). I thank S. Rousseau for the useful comments and C. Billiet for the advice on the legal system.

1 INTRODUCTION

Since speed plays an important role in most accidents[1], speed limits are an important instrument for the government to improve road safety.

However, the imposition of speed limits alone is not enough; they have to be supplemented with enforcement[2]. Enforcement, typically, consists of two elements: the probability of detection and the magnitude of the fine. If the goal is to maximise social welfare, the probability of detection and the fine should[3] be such that

$$fine = \frac{\text{expected damage due to speeding}}{\text{probability of detection}} \tag{1}$$

The faster you drive, the higher the expected damage and hence, for a given probability of detection, the higher the fine should be. This coincides with reality since in all European countries the fine is increasing in the level of speeding[4].

In reality[5] we also see that the fines increase in the number of previous convictions. The goal of this paper is to find a rational for this observation. At first glance, it seems that the analysis of optimal fines for repeated offences would not differ from the analysis of a single offence. If the fine is set optimally with respect to the first offence, and the harm caused by the second offence is the same, there is no apparent reason to set the fine differently for a second offence[6]. There are, nonetheless, three reasons why it might be desirable to condition fines on the offence history[7].

Firstly, the use of the offence history may provide an additional incentive not to violate the law when detection not only leads to an immediate sanction, but also increases the sanction for future violations. Landsberger and Meilijson (1982) have been the first to analyze how prior offences should affect the expected fine. They have focused on the probability of detection rather than the level of punishment and have shown that given a fixed enforcement budget, a higher level of deterrence can be achieved by targeting potential violators based on past compliance rather than by treating everyone equal. This is feasible for environmental violations and tax evasion but in traffic it is difficult to control one particular party more than another. When the inspection frequency cannot be differentiated, it might be a logical idea,

---

[1] For an overview of the literature on speed and its relationship with traffic accidents we refer to Aarts ea. (forthcoming)
[2] The literature on optimal enforcement of regulation started with the seminal papers by Becker (1968) and Stigler (1970). Polinsky and Shavell (2000) provide a very comprehensive overview.
[3] Polinsky and Shavell (2000)
[4] European Commission (2004).
[5] European Commission (2004)
[6] Polinsky and Rubinfeld (1991)
[7] The first two are also stated in Polinsky and Shavell (2000)

which is also observed in reality, is to make the fines higher for repeated infractions. However, the literature on this is ambiguous. Harrington (1988) has found increasing fines for environmental violations, but he did not minimise the control costs for a given total pollution reduction. Firms with identical pollution cost functions end up polluting at different levels. If one takes these costs into account, Harford and Harrington (1991) have argued that a static solution, where all firms are treated alike, will often be superior to a state-dependent solution. Emons (2003), on the other hand, states that given that people's wealth is fixed, the optimal fining scheme is decreasing rather than increasing in the number of past violations.

Secondly, the offence history may provide information on the characteristics of individuals and the need to deter them. Polinsky and Rubinfeld (1991) could explain increasing fines by assuming that people receive an acceptable as well as an illicit gain from the criminal activity. In a traffic situation, the acceptable gain of speeding could be the gain in time; unacceptable could be the thrill that joy riders experience of driving too fast.

Thirdly, the traditional Becker result (1968) states that, with costly detection and costless fines, the fine should be set as high as possible. However, there are limits on the magnitude of the imposed sanctions. For example, the maximum amount that people can pay or the maximum amount that is politically and/or socially acceptable. If enforcement is imperfect, the Becker result leads to higher fines for repeated offenders if the upper limit is determined by the politically and/or socially acceptability and if people accept higher fines for repeated offenders. This makes that the expected fine increases, which on its turn increases compliance at no additional cost.

In this contribution we explore the second reason and state that a positive relationship between previous convictions and the probability of being involved in an accident may rationalize increasing fines. Drivers differ among others in their skills and risk taking behaviour. This implies that drivers differ in two aspects: Their propensity to have an accident and their ability to comply with the regulation. In other words, for the same level of speed, the probability of being involved in an accident is higher for a 'bad' driver than for a 'good' driver. Moreover, even if a bad driver decides that he wants to comply, there is a probability that he will speed 'by accident'. This makes that bad drivers have, for the same speed, higher expected accident costs, and given the structure of the optimal fine (equation (1)), should be fined more severely.

The government does not know who the bad drivers are, but previous accidents and speeding violations may act as a 'signal' for being a bad driver. The literature on the relationship between previous convictions and the probability of being involved in an accident typically finds a positive relationship. Gebers (1990) has stated that the number of previous traffic convictions (speeding, not stopping, no seatbelt) is one of the best single predictors of accident risk. Boyer et al. (1991) have found that the number of accidents is an increasing function of the number of previous offences. Stradling et al. (2000) argue that the kind of drivers recently caught for speeding are 59 per cent more likely to have also been recently involved in a car accident. Dagneault et al. (2002) focus on the relationship between previous convictions and the risk of subsequent accidents for drivers older than 65 years. They also find that convictions can predict the probability of an accident but state that prior accidents are a better predictor than prior convictions. Gebers and Peck (2003) again show that increased accident involvement is associated (among others) with increased prior traffic citation frequency and increased prior accident frequency. They state that traffic conviction frequency reflects risk-taking, social nonconformity and exposure.

The remainder of the paper is organized as follows: we first develop our model and calculate the private and socially optimal speed. Next, we calculate the speed limit. Then, we confront two fine structures, a uniform and a differentiated, and determine which structure performs best. We illustrate our model for interurban roads.

2 MODEL

We start with some notation. Next, we derive the socially and privately optimal level of speed and the optimal speed limit. Subsequently, we focus on the enforcement of this speed limit. As is common in the literature we assume that the speed limit and the fines are chosen independently. We derive the expressions for the uniform fine and the differentiated fines. Finally, we look at the influence of these fines on the chosen speed and calculate the welfare losses in order to compare the two systems.

2.1 Notation

For the individual driver the private cost of his trip $C(x)$ depends on the speed x. $C(x)$ consists of the resource cost, the fuel cost and the time cost. We assume that this cost function is convex, $C_{xx} \geq 0$. If speed increases, the private cost first decreases and then increases. Indeed if speed rises, the time needed to complete a certain trip decreases and hence the time costs decrease. This may also be interpreted more broadly. People may simply value fast driving positively, not for the time gain, but for the thrill and the excitement of it. On the other hand, the fuel costs increase if speed increases. For low to intermediate speeds, the gain in time dominates; for high speeds, the fuel costs dominate.

We consider unilateral accidents, this is, accidents in which only one party, the injurer, influences the probability of the accidents and the other party, the victim, bears all the losses. Think for example of an accident between a car driver and a cyclist[8]. In the remainder of the text we use 'car driver' for the injurer and 'cyclist' for the victim. We distinguish two types of drivers, good and bad ones, which differ in their ability to comply with the regulation and in their expected accident costs. The probability of an accident $p(x,\theta_i)$ depends on the level of speed, x and on the individual propensity to have an accident θ_i. People are either good, $\theta_i = g$, or bad drivers, $\theta_i = b$. For a given level of speed, the probability of being involved in an accident is higher for bad drivers than for good drivers, $p(\tilde{x},b) > p(\tilde{x},g)\ \forall\tilde{x}$. For a given type θ_i, the probability of an accident is increasing in the level of speed, $p_x(x,\theta_i) > 0$ ($p_{xx}(x,\theta_i) \geq 0$). If an accident happens, the victim incurs harm h. Drivers also differ in their ability to comply with regulation. A good driver who wants to comply will comply. We assume that bad drivers who want to comply can still speed by accident. If bad drivers unintentionally speed, they drive at speed $x_b^a = x^o + \varepsilon, \varepsilon > 0$, where x^o is the intended speed. The probability of speeding by accident is denoted by $q \in \{0,1\}$. We assume that all drivers think that they are good drivers[9]. Hence, bad drivers make decisions as if they are good drivers. For example, they do not take into account that they can speed by accident. There are γ good drivers and $(1-\gamma)$ bad drivers[10]. The government only knows this distribution but not the individual driver types. We further assume that drivers are risk neutral.

2.2 Private and Social Optimum

When the government does not intervene, the car driver only takes his private costs into account and increases his speed until

$$\min_x C(x) \Rightarrow C'(x) = 0 \qquad (2)$$

His private optimal level of speed $x^{private}$ is determined by the point where his marginal cost of increasing his speed by one km/hour does not provide a net benefit anymore.

[8] Of course in reality the cyclist also influences the probability of an accident and the driver can also have losses. Note that the qualitative results will not change if we include private accident losses into the private costs $C(x)$.
[9] This is not a very strong assumption. In general people overestimate their abilities. Svensson (1981) showed that 80% of the drivers think that they are above average drivers.
[10] γ is exogenously given with $0 < \gamma < 1$. We normalise the population to one.

The social optimum[11] on the other hand takes into account the expected accident costs and is determined by

$$\min_x C(x) + p(x,\theta_i)h \Rightarrow C'(x) = -p_x(x,\theta_i)h \tag{3}$$

The socially optimal level of speed $x^*_{\theta_i}$ is determined by the point where the marginal cost of lowering the speed equals the marginal social utility of lowering the speed, which equals the decrease in expected social accident costs. Without government intervention, car drivers do not take the full costs of driving into account and drive too fast. We show this in Figure 1. On the horizontal axis we represent the level of speed, on the vertical axis the costs in euro. The upward sloping curve represents the marginal private cost reductions of driving faster $C'(x)$. The downward sloping lines are the negative of the marginal accident cost for the good and the bad driver, $-p_x(x,\theta)h$. The private optimal level of speed is given by the intersection of the marginal cost with the horizontal axis. The socially optimal speed levels are given by the intersections of the marginal cost with the marginal accident costs. It is clear from this figure that $x^*_b < x^*_g < x^{private}$. The government can bring the private optimal speed closer to the socially optimal level by the use of liability rules, infrastructure, vehicle regulation or speed limits. In this paper we focus on the use of a speed limit[12].

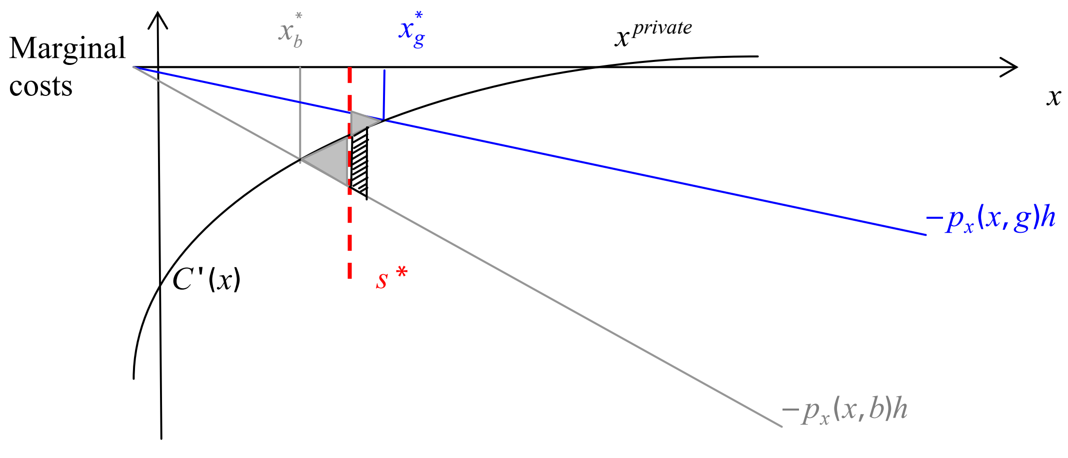


Figure 1 : Private and social optimal level of speed

[11] Note that we do not take into account the environmental and noise costs in determining the socially optimal speed. Rietveld ea (1998) calculate the socially optimal speed taking into account the private costs, the accident costs, the environmental costs, etc.
[12] We refer to Delhaye (2006) for the influence of regulation and/or liability on the speed.

2.3 Speed limit

The government influences the drivers' choice of speed by setting a speed limit. Because of the differences in accident propensity, it would be optimal to set a different speed limit for each type. However, the regulator lacks the information to do this and, for this reason, sets a uniform standard. This is also what we observe in the real world.

The speed limit is denoted by s. The regulator minimises the expected social costs, taking into account the distribution of drivers' types and the probability q with which bad drivers will speed unintentionally.

$$\begin{aligned}&\min_x C(x)+\gamma p(x,g)h+(1-\gamma)(1-q)\,p(x,b)h+(1-\gamma)qp(x+\varepsilon,b)h\\&\Rightarrow C'(x)=-\gamma p_x(x,g)h-(1-\gamma)(1-q)\,p_x(x,b)h-(1-\gamma)qp_x(x+\varepsilon,b)h\end{aligned} \tag{4}$$

This gives s^* the optimal uniform speed limit with $x_b^* \le s^* \le x_g^*$. s^* is lower than if bad drivers would be able to comply $(q=0)$. In Figure 1, s^* is represented by the dotted line. The uniform speed limit makes that bad drivers drive faster than optimal, while good drivers drive too slow. The grey areas in Figure 1 represent the welfare losses under perfect compliance compared to the social optimum. For the proportion q of bad drivers that do not comply, there is an additional welfare loss equal to the arched trapezium.

However, if there is no enforcement and given that $s^* < x^{private}$, no driver will have an incentive to comply and they will all drive at their private optimal speed. Therefore we need to discuss enforcement.

2.4 Enforcement

The government uses a fine $\varphi(x)$ and a probability of detection δ to enforce the speed limit. In this paper we assume that the probability of detection is given and fixed. Even though the probability of detection does not depend on the level of speed, the fine does.

We consider two cases. In the first case, the government sets a uniform fine. In the second case, the information imbedded in the offence history is used. This makes the fine dependent on the offence history.

(a) Uniform fine

A uniform fine only depends on the level of speed and not on the drivers' type. The fine is equal to zero if people do not speed and larger than zero if people speed. This is

$$\varphi(x) \text{ with } \begin{cases} \varphi(x) = 0 \text{ for } x \le s \\ \varphi(x) > 0 \text{ for } x > s \end{cases} \tag{5}$$

The government determines the optimal fine by setting the private cost of driving at a chosen speed $x > s$ equal to the expected social cost of driving at speed $x > s$.

$$\begin{aligned} & C(x) + \delta\varphi(x) = C(x) + \mathrm{E}\left[p(x,\theta_i)h\right] \\ & \Rightarrow \delta\varphi(x) = \gamma p(x,g)h + (1-\gamma)\left(1-q\right)p(x,b)h + (1-\gamma)qp(x+\varepsilon,b)h \\ & \Rightarrow \varphi^*(x) = \frac{\gamma p(x,g)h + (1-\gamma)\left(1-q\right)p(x,b)h + (1-\gamma)qp(x+\varepsilon,b)h}{\delta} \end{aligned} \tag{6}$$

The fine thus equals the expected social cost of speeding, corrected for the probability of detection. Given this fine, the driver can choose whether to speed or not. He will not speed if the cost of speeding, taking into account the expected fine, is larger than the cost of driving at the speed limit. Hence if he does not speed, he will drive at the speed limit and $\varphi(x) = 0$. He will not drive slower than the speed limit because $s^* < x^{private}$. If he speeds, the problem for the driver becomes, using (6),

$$\min_x C(x) + \delta\varphi(x) \Rightarrow C'(x) = -\delta\varphi^{*\prime}(x) \tag{7}$$

This fine makes that the driver wants[13] to drive at the speed limit s*. However, q percent of the bad drivers will speed by accident and drive at speed $x_b^a = s^* + \varepsilon, \varepsilon > 0$. Given that all drivers think that they are good drivers, they will not take this into account when choosing their level of speed.

We show this in Figure 2. The 'fat line' gives the negative first derivative of the expected fine. People choose the speed where the first derivative of the private costs, which is the marginal benefit of speed, equals the marginal accident cost, which is the expected fine. This happens at s^*. Hence good drivers drive slower than socially optimal and bad drivers drive faster. q percent of the bad drivers will drive at speed $x_b^a > s^*$. The social welfare loss for a good driver $\left(WL_g\right)$ equals the black triangle in Figure 2. They have to drive at a speed where the marginal benefit of increasing ones' speed – the private cost- is higher than the marginal costs – the accident costs. The grey triangle represents the social welfare loss for a bad driver who complies $\left(WL_b\right)$. They drive at a speed where the marginal benefit of speed is lower than the marginal costs. The welfare loss for a bad driver who fails to comply equals the grey

[13] Insert (6) in (7) and compare with (4)

triangle, (WL_b), plus the hatched trapezium, (WL_b^a). Total social welfare loss of a uniform fine (WL_{uf}) then equals

$$\boxed{\begin{aligned} WL_{uf} &= \gamma WL_g + (1-\gamma)(1-q)WL_b + (1-\gamma)q\left(WL_b + WL_b^a\right) \\ &= \gamma WL_g + (1-\gamma)WL_b + (1-\gamma)qWL_b^a \end{aligned}} \tag{8}$$

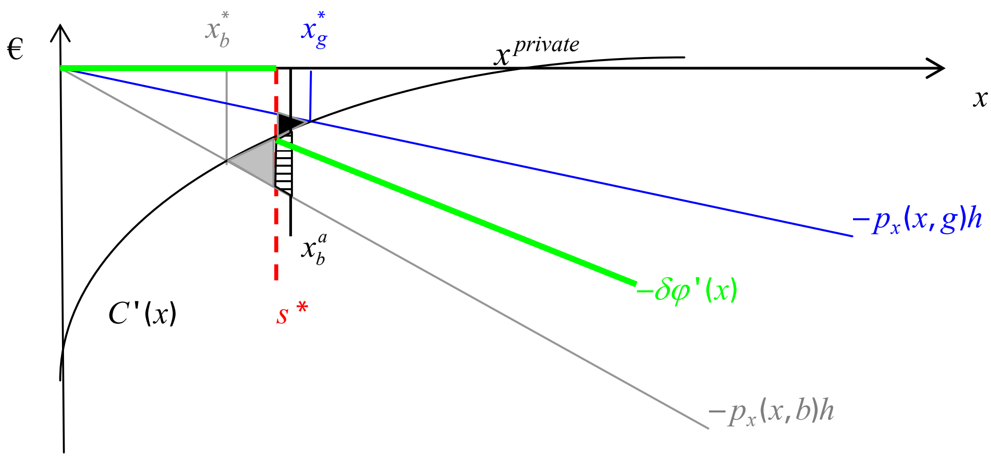


Figure 2: Uniform fine

(b) Fine depends on offence history

The government does not know who the good and the bad drivers are. However it does know that there is a positive relationship between the number of previous convictions and the probability of an accident. Therefore, the drivers are divided into two groups: a group with no record and a group with a record. A driver gets a record if he caused an accident and/or if he is caught speeding. Both groups will consist of good and bad drivers. This is an important difference with the uniform case. Denote Π_{nr}^g as the proportion of good drivers without a record, Π_r^g the proportion of good drivers with a record, Π_{nr}^b the proportion of bad drivers without a record and Π_r^b the proportion of bad drivers with a record. Note that $\Pi_{nr}^g + \Pi_r^g = 1$ and $\Pi_{nr}^b + \Pi_r^b = 1$. We calculate these proportions in equilibrium using Markov chains later in this paper.

The government then sets a fine $\varphi(x,k)$, which depends firstly on the level of speed x and secondly on the history k of the driver.

$$\varphi(x,k) \text{ with } \begin{cases} \varphi(x,k) = 0 \text{ for } x \le s \\ \varphi(x,k) > 0 \text{ for } x > s \end{cases} \tag{9}$$

where k equals 0 if the driver has no criminal record and equals 1 if the driver has a criminal record.

We assume that the government set fines in the following way. If the driver has no record, the regulator assumes that he is a good driver and equates the private costs with the social costs for a good driver. This means that

$$\begin{aligned} &C(x) + \delta\varphi(x,0) = C(x) + p(x,g)h \\ &\Rightarrow \varphi^\circ(x,0) = \frac{p(x,g)h}{\delta} \end{aligned} \tag{10}$$

If the driver has a record, the government assumes that he is a bad driver and the fine equals

$$\begin{aligned} &C(x) + \delta\varphi(x,1) = C(x) + p(x,b)h \\ &\Rightarrow \varphi^\circ(x,1) = \frac{p(x,b)h}{\delta} \end{aligned} \tag{11}$$

We do not assume that the regulator sets the fines socially optimal. Comparing (11), (10) and (6) yields immediately that $\varphi^\circ(x,1) \ge \varphi^*(x) \ge \varphi^\circ(x,0)$. How will this structure influence the speed choice of the drivers and hence the welfare losses? People again choose whether to speed or not. If they choose not to speed, they drive at the speed limit since $s^* < x^{private}$ and they will not pay a fine. Remember that bad drivers can speed unintentionally with probability q. If they do speed[14], they pay a fine, which depends on their criminal record. There are four cases we need to consider: good drivers with and without a record and bad drivers with and without a record. We first discuss, with the help of Figure 3, the case for drivers without a record and then turn, using Figure 4, to the case where drivers have a record. Both figures have the same structure as Figure 1. For $x \le s^*$, $\varphi(x,k)$ equals zero and coincides with the horizontal axis. For $x > s^*$, $\varphi(x,0)$ is given by the fat line in Figure 3 and coincides with the marginal accident cost for the good drivers. $\varphi(x,1)$ coincides with the marginal accident cost for the bad drivers and is represented by a fat line in Figure 4.

1) Good drivers with no record.

When good drivers speed their problem is represented by

$$\begin{aligned} &\min_x C(x) + \delta\varphi(x,0) \Rightarrow C'(x) = -\delta\varphi_x(x,0) \text{ (using (9))} \\ &\qquad \Rightarrow C'(x) = -p_x(x,g)h \end{aligned} \tag{12}$$

[14] You cannot comply by accident.

Note that (12) is the same as (3) and that good drivers with no record speed $\left(x_g^* > s^*\right)$ and choose the socially optimal level of speed. Hence there are no welfare losses for this group.

2) Bad drivers with no record

Bad drivers with no record face the same problem as in (12) and hence chose speed $x_g^* > x_b^*$. The welfare loss $\left(WL_b^{nr}\right)$ of this equals the grey triangle. However, a proportion q of them will drive faster unintentionally. The additional welfare loss $\left(WL_b^{nra}\right)$ of this subgroup is represented by the black trapezium.

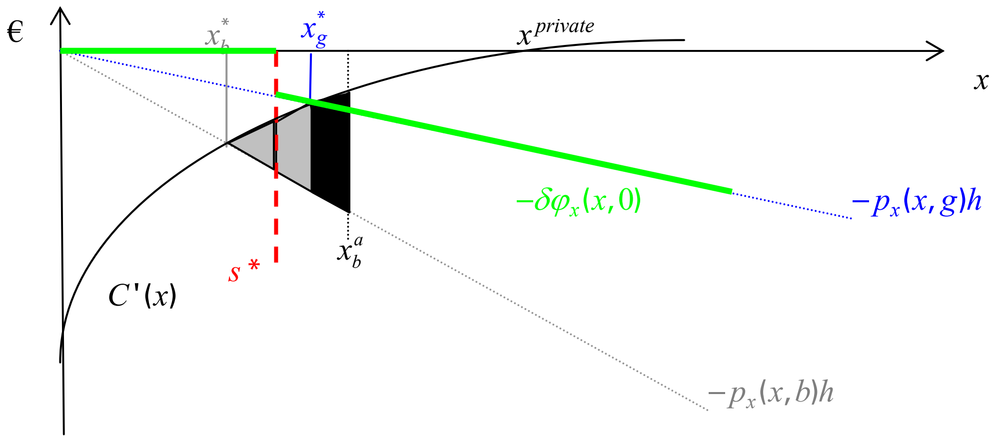


Figure 3: Differentiated fine for drivers without a record

3) Good drivers with a record

When good drivers with a record speed, they minimize the following problem

$$\min_x C(x) + \delta\varphi(x,1) \Rightarrow C'(x) = -\delta\varphi_x(x,1) \text{ (using (10))} \\ \Rightarrow C'(x) = -p_x(x,b)h \qquad (13)$$

The solution to this problem is speed x_b^* at which point the expected fine is zero. Hence they will drive faster than x_b^*, and choose to drive at the maximum speed limit. The welfare loss for this group $\left(WL_g^r\right)$ equals the black triangle in Figure 4.

4) Bad drivers with a record

Bad drivers with a previous record also face problem (13); hence they try to comply. A proportion $(1-q)$ of bad drivers drive at the maximum speed level and their welfare losses

$\left(WL_b^r\right)$ are denoted by the grey triangle. The other q percent of bad drivers speed unintentionally and their welfare losses equal the grey triangle, $\left(WL_b^r\right)$ and the small hatched trapezium, $\left(WL_b^{ra}\right)$.

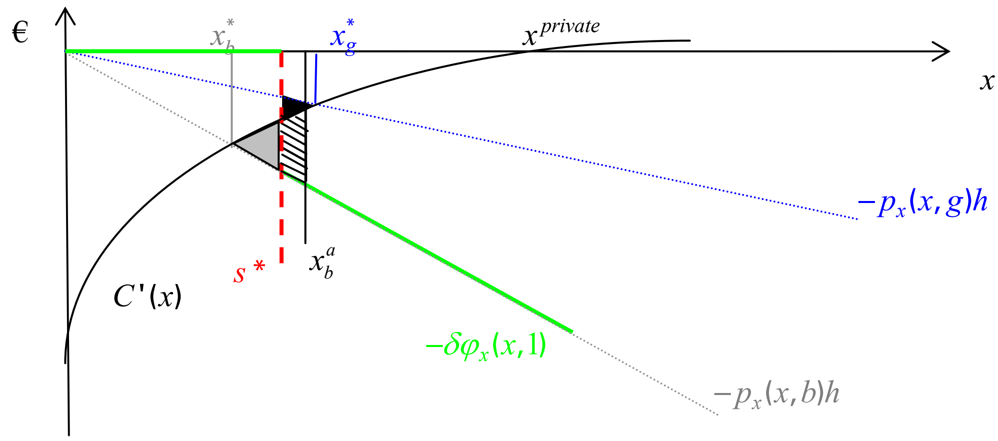


Figure 4: Differentiated fine for drivers with a record

Total welfare losses for a differentiated fine $\left(WL_{df}\right)$ then equal

$$\boxed{WL_{df} = \gamma\Pi_g^{nr}0 + \Pi_b^{nr}(1-\gamma)\left(WL_b^{nr} + qWL_b^{nra}\right) + \gamma\Pi_g^{r}WL_g^{r} + (1-\gamma)\Pi_b^{r}\left(WL_b^{r} + qWL_b^{ra}\right)} \tag{14}$$

(c) Comparison of welfare losses.

Which structure of fines should the regulator choose? He should compare the welfare losses under a uniform fine, given by (8) with the losses under a differentiated fine, given by (14). The differentiated fine is better if the welfare losses are lower than under a uniform fine, this is, if

$$\begin{aligned}
&0 + (1-\gamma)\Pi_b^{nr}\left(WL_b^{nr} + qWL_b^{nra}\right) + \gamma\Pi_g^{r}\underbrace{WL_g^{r}}_{=WL_g} + (1-\gamma)\Pi_b^{r}\left(\underbrace{WL_b^{r} + qWL_b^{ra}}_{=WL_b + qWL_b^{a}}\right) \\
&< \gamma WL_g + (1-\gamma)\left(WL_b + qWL_b^{a}\right) \\
&\Rightarrow (1-\gamma)\Pi_b^{nr}\left(WL_b^{nr} + qWL_b^{nra}\right) < \gamma\left(1-\Pi_g^{r}\right)WL_g + (1-\gamma)\left(1-\Pi_b^{r}\right)\left(WL_b + qWL_b^{a}\right) \\
&\Rightarrow (1-\gamma)\Pi_b^{nr}\left(WL_b^{nr} - WL_b + q\left(WL_b^{nra} - WL_b^{a}\right)\right) < \gamma\Pi_g^{nr}WL_g
\end{aligned} \tag{15}$$

We cannot say that one structure will always dominate the other. In order to be able to compare the welfare losses, we have to calculate $\Pi_{\theta_i}^{r}$ and $\Pi_{\theta_i}^{nr}$. If for example Π_{b}^{nr} is very low and Π_{g}^{nr} is very high, this is that the past violations are a good predictor of the drivers' type, it is more likely that (15) will hold. We can calculate $\Pi_{\theta_i}^{r}$ and $\Pi_{\theta_i}^{nr}$ in equilibrium if we know the movements from the drivers in and out the two groups. We argue that good drivers with no records will speed and moved to the 'record group' for two reasons: they are caught with probability δ or they cause an accident with probability $p\left(x_g^*,g\right)$. Good drivers with a record will comply and move with an exogenous probability u back to the 'no record group' if they do not have an accident. This reflects the fact that, if the driver is not caught and he did not cause an accident, after a period of time his record is cleared. Bad drivers with no record will also speed and have the same probability δ of being caught and transferred to the 'record group'. The probability that they have an accident, $p\left(x_g^*,b\right) > p\left(x_g^*,g\right)$ is higher. Hence the probability that a 'bad driver without a record' receives a record is higher than the probability that a 'good driver without a record' moves to the 'record group'. If bad drivers have a record, they will try to comply. However with probability q they will speed unintentionally and with probability δ they are caught. Moreover, they will also stay in the 'record group' if they have an accident. Hence their probability of moving to the 'no record group' is lowered to $u - q\delta - p\left(s^*,b\right)$. We summarise these movements in the transition matrices represented in Table 1.

Table 1 : Transition matrices

Good drivers			Bad drivers		
	No record	Record		No record	Record
No record	$1-\delta-p\left(x_g^*,g\right)$	$\delta+p\left(x_g^*,g\right)$	No record	$1-\delta-p\left(x_g^*,b\right)$	$\delta+p\left(x_g^*,b\right)$
Record	$u-p\left(s^*,g\right)$	$1-u+p\left(s^*,g\right)$	Record	$u-q\delta-p\left(s^*,b\right)$	$1-u+\delta q+p\left(s^*,b\right)$

The long run equilibrium, or steady state, probability Π_j may be found[15] by solving the following set of linear equations: (with t_{kj} the kj th element of the transition matrix)

[15] Winston W.L. (1994).

$$\Pi_j = \sum_{k=1}^{k=s} \Pi_k t_{kj} \quad (j = 1,2,...s;\ omit\ one\ of\ these\ equations)$$
$$\Pi_1 + \Pi_2 + .. + \Pi_s = 1 \tag{16}$$

Using this information, we can calculate the steady state equilibrium and find that

$$\Pi_g^{nr} = \frac{u - p(s^*, g)}{\delta + u + p(x_g^*, g) - p(s^*, g)}, \qquad \Pi_g^{r} = \frac{\delta + p(x_g^*, g)}{\delta + u + p(x_g^*, g) - p(s^*, g)}$$
$$\Pi_b^{nr} = \frac{u - q\delta - p(s^*, b)}{\delta - q\delta + u + p(x_g^*, b) - p(s^*, b)}, \qquad \Pi_b^{r} = \frac{\delta + p(x_g^*, b)}{\delta - q\delta + u + p(x_g^*, b) - p(s^*, b)} \tag{17}$$

In general $\Pi_g^{nr} > \Pi_b^{nr}$ and $\Pi_g^r < \Pi_b^r$, so proportional to the population, it is most likely that there are more good drivers than bad drivers in the 'no record group' and that there are more bad than good drivers in the 'record group'.

The best structure is the one with the lowest welfare losses. Hence we prefer a uniform fine if $WL_u < WL_{df}$ and vice versa. At a first sight it is impossible to see which structure will perform the best. It depends mainly on the level of $\gamma, \Pi_{\theta_i}^{nr}, \Pi_{\theta_i}^{r}$. However, for one, although unrealistic, case the situation is clear-cut. If $\delta = q = u = 1$, then $\Pi_g^{nr} = \Pi_g^r = 1/2$ and $\Pi_b^{nr} = 0, \Pi_b^r = 1$. This is, the bad group coincides perfectly with the record group and the good drivers are evenly distributed into the two groups. In this case, the differentiated fine outperforms the uniform fine for any γ. The welfare losses for the bad drivers are the same under both fine systems, but under the differentiated fine, half of the good drivers will drive at their socially optimal speed.

In reality, δ, q and u will not take such extreme values. Which structure performs best, switches for a certain values for δ, q and u. This is shown in the illustration, which is discussed in the next paragraph.

3 NUMERICAL EXAMPLE

We apply this model to interurban roads since unilateral accidents between cars and cyclists are most likely on this type of roads. The current speed limit in Belgium on interurban roads is either 70 or 90 km/h. We first calculate the private and socially optimal level of speed and the optimal uniform speed limit. We then compute the fines and compare them with the current fine structure. We end this section by determining the welfare losses to determine which fine structure performs best. The private cost for a driver is assumed to equal the sum of the resource costs, the time costs and the fuel costs. The resource cost consists of the purchase cost, the insurance cost, maintenance,… We assume that this cost is independent of speed and equals 0.2355 €/km (De Borger and Proost 1997). The fuel cost depends on the fuel type, the price and the consumption. All elements needed to calculate the fuel costs are represented in Table 2.

Table 2 : Fuel costs

Fuel type	*Fuel price (€/l)*	*Consumption (l/km)*	*% share*
Diesel	0.811	$0.13778 - 0.00242x + 0.000016x^2$	40.6
Gasoline	1.068	$0.0396 + 0.00064x$	59.4

Ministry of Economic Affairs (2001), MEET project (1998), IEA (2002), Ministry of Traffic and Infrastructure (2000)

The time cost equals the value of time divided by the level of speed. For the value of time, we make a weighted average of the value of time of commuters, business and others. We obtain a value of time of 6.3917 €/h[16]. The sum of the resource cost, the weighted fuel cost and the time cost make that we can express the private costs as

$$C(x) = 0.30599 + \frac{6.3917}{x} - 0.3919 \cdot 10^{-3} x + 0.536 \cdot 10^{-5} x^2 \tag{18}$$

The private optimum for drivers then equals (min C(x)) 98 km/h

In order to derive the expected accident cost $\left(p\left(x,\theta_i\right)h\right)$ we first consider the present accident risk $\left(accrisk\left(a\right)\right)$, given a current speed of 80 km/h[17], and correct this for changes in speed[18]. We then multiply this risk with the value for the harm done (h(a)). We focus on accidents with slightly injured, heavy injured and deaths. Hence we do not take into account accidents with only material damage. The expected accident costs for a good driver can then be expressed as .

$$p(x, g)h = \sum_{a=acctype} accrisk(a) * \left(\frac{x}{\text{current speed}} \right)^{m(a)} h(a) \tag{19}$$

with m(slight injury)=2, m(heavy injured=3), m(fatal)=4

[16] Own calculation based on Gunn ea (1997) and Huber and Toint (2002).

[17] We assume that the speed limit equals 90 km/h on half of the interurban roads and 70 km/h on the other half.

[18] Elvik (2000) gives a formula for calculating the effect of a change in speed on the number of accidents:

$$\frac{\#acc\left(a\right)\ after}{\#acc\left(a\right)\ before} = \left(\frac{mean\ speed\ after}{mean\ speed\ before}\right)^m$$

We assume that the accident risk for bad drivers is 1.59 times the accident costs for good drivers, this is, $p(x,b)h = 1.59 p(x,g)h$ (Stradling ea (2000)). Table 3 gives the current accident risk and the cost of an accident.

Table 3 : Accident risk and accident cost.

Accident type	*Cost accident (€)*	*Accident risk*
Light	26.273	$7.92*10^{-7}$
Serious	965.131	$1.27*10^{-7}$
Fatal	2.197.540	$0.25*10^{-7}$

Own calculations based on De Brabander (2005), NIS(2005)

Taking these accident costs into account yields the socially optimal speeds of $x_g^* = 71$ km/h and $x_b^* = 64$ km/h.

Given this information and assuming that 20% of the population are bad drivers we first calculate the socially optimal uniform speed limit and find that $s^* = 68$ km/h[19]. Next we calculate the uniform and the differentiated fines for each speed faster than the speed limit, assuming a probability of detection of 0.9% per trip and an average trip of 13 km. In order to compare these with the speed fine structure in Belgium we average these fines over the same classes as the current structure. Table 4 shows the results.

Table 4 : Comparison with the existing structure

	Present structure	Results		
Speeding	Average immediate collection (€)	Uniform fine (€)	Differentiated fine (€)	
			Fine no record	Fine if record
< 10 km/h	50	50	44	71
10-40 km/h	128	89	79	125
+ 40 km/h	court	255	226	360

Source: wegcode.be, KB 30 September 2005, own calculations.

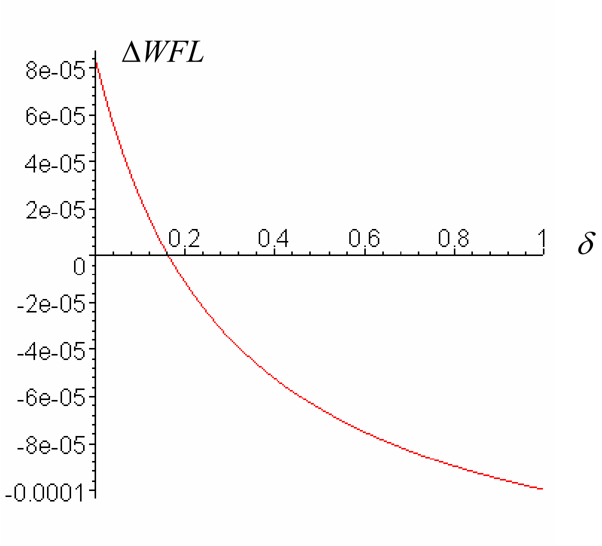
If we assume[20] a probability of detection of 0.9%, the calculated fines for small offences equal the existing ones. For larger offences, the current fines increase more steeply in the level of violation than the calculated fines.

[19] Note that if no one speeds by accident, $q = 0$, the optimal speed limit would equal 69 km/h.

[20] There is no data available for Belgium on what the actual probability could be.

In order to compare these two fining systems, we need to calculate the welfare losses. We let the probability of detection, δ free. We first assume that 80 % of the drivers are good drivers ($\gamma = 0.8$), that the probability that bad drivers speed unintentionally equal 40% ($q = 0.4$) and that the probability to return to the 'no record group' equals 30% ($u = 0.3$). The last figure means, for example, that you move to the 'record group' after three years if you were not caught or did not have an accident during these three years. Given this information we calculated $\Pi^{r}_{\theta_i}, \Pi^{nr}_{\theta_i}$ and the difference in social welfare, ΔWFL (welfare losses uniform fine minus welfare losses differentiated fine). The result is given in Figure 5.

Figure 5 : Difference in welfare losses if $\gamma = 0.8$, $q = 0.4$, $u = 0.3$

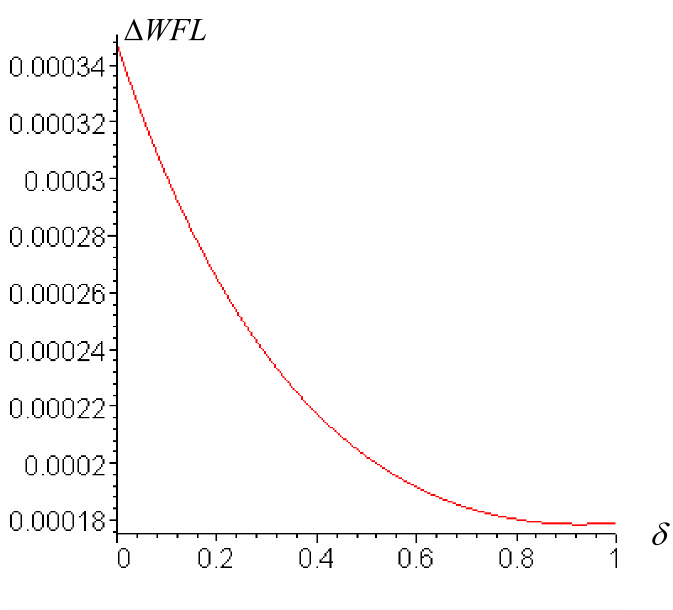


We see that for $\delta < 0.16$ the differentiated fine performs better than the uniform fine. If $\delta > 0.16$ the uniform fine performs better. It is hard to know the real probability of detection in Belgium, but it will most likely be lower than 16% per trip[21]. In this case we should prefer a differentiated fine. The optimal structure switches for a certain probability of detection. If δ increases, the uniform fine performs better. The reason for this is that if the probability of detection increases, the proportion of good drivers with a record also rises. Moreover, the probability of clearing the record is only $u = 0.3$. Hence, once a good driver has a record it keeps that record for a long time. If on the other hand the probability of clearing the record rises to 60 per cent $(u = 0.6)$, the differentiated fine performs better as long as the probability of detection is lower than 0.36. Hence, for a given q, the probability of detection under which the differentiated fine performs better increases in the probability of clearing the record. If

[21] We can obtain such a high probability of detection for certain areas by the use of automated speed control. However, it would be infeasible to obtain on a large area such as Belgium as a whole.

$\gamma = 0.8,\ q = 1,\ u = 1$, the differentiated fine always outperforms the uniform fine. We see this in Figure 6. The main reason for this is that with $q = 1$, all bad drivers unintentionally speed and the probability that they belong to the 'record group' increases.

Figure 6 : Difference in welfare losses if $\gamma = 0.8, q = 1, u = 1$



This numerical example shows that for reasonable probabilities of detection, the differentiated fine should be preferred[22]. Only if no bad driver speeds unintentionally $(q = 0)$ and the probability to return to the 'no record group' is very low $(u = 0.1)$, the uniform fine is always preferred. The reason for this is that in this case the correlation between the type and having a record or not is not very good. Having a record is not a good signal anymore for the drivers' type.

4 CONCLUSION

When one analyses fine structures for speed offences, one often finds two characteristics. Firstly, the level of the fine is increasing in the severity of the violation. Secondly, fines increase with the offence history. The first result is common in the standard literature. For the second result, there is much more controversy. Increasing fines in the offence history are often found in the real world, but are still a theoretical puzzle.

[22] If $q = 0.1, u = 0.6$ we prefer the differentiated fine if $\delta < 0.2$. Even if no bad driver speeds by accident, If $q = 0, u = 0.3$ we prefer the differentiated fine if $\delta < 0.08$.

We focus on the structure of the fines and on repeated offences. We confront two fine systems: a uniform fine and a fine dependent on the offence history. Our rationale for having offence dependent fines is the following. People differ in their ability to follow the rules and in their propensity to cause an accident. This is, there are good and bad drivers and bad drivers can speed unintentionally even if they want to comply. Moreover, the expected accident cost for bad drivers is higher than for good drivers. Standard theory then prescribes that bad drivers should be fined more severely than good drivers. However, the government does not know who is a good and who is a bad driver. The literature shows that there is a relationship between the probability of being involved in an accident and the number of previous offences.

We do not look for the optimal structure, but merely compare two systems. A uniform fine makes that good drivers are fined too harshly and bad drivers not enough. However, the differentiated fine system also does not work perfectly because there is no perfect correlation between the type and the group. There are bad drivers in the 'no record group' and good drivers in the 'record group'. The choice between these two systems depends on how good the relationship between the type of the driver and the record of the driver is.

We make a numerical illustration, which looks at two things. First, we calculate the optimal values for the speeding fines and compare these with the existing fines in Belgium. We find that the current fine structure increases faster than our calculated fines. We also find that for the current fines to be optimal, the probability of detection should be around 0.9% per trip. Further, we also study the critical values for the probability of detection, which determine the choice between the two fine structures. The analysis shows that for reasonable values for the probability of detection a differentiated fine should be preferred.

REFERENCES

Aarts, L.T. , Van Schagen, I. (forthcoming), Driving speed and the risk of road crashes: a review*, Accident Analysis and Prevention*

Becker (1968), Crime and Punishment: an Economic Approach, *Journal of Political Economy* 76, 169-217

Boyer,M.; Dionne, G.; Vanasse, C. (1991), Infractions au code de la sécurité routière, infractions au code criminel et gestion optimale de la securité routière, *L'Actualité économique, Revue d'analyse économique,* Vol. 67 (3), 279-305

Daigneault G, Joly P, Frigon JY (2002), Previous convictions or accidents and the risk of subsequent accidents of older drivers, *Accident Analysis and Prevention*, Vol 34(2), 257-261

De Borger, B., Proost, S., (1997), Mobiliteit: de juiste prijs, *Garant*, Leuven-Apeldoorn, 312 p

De Brabander, B. (2005), Investeringen in verkeersveiligheid in Vlaanderen. Een handleiding voor kosten-batenanalyse, *LannooCampus*, Tielt, 183 p

Delhaye, E. (2006), Traffic Safety: regulation, liability and pricing, *Transportation Research A,* Vol 40(3), 206-226

Elvik, R., Admundsen, A.H., (2000), Improving Road Safety in Sweden, An Analysis of the Potential for improving Safety, the Cost-Effectiveness and Cost-Benefit Ratio's of Road Safety Measures, *Report 490/2000* Norwegian Centre for Transport Research, Oslo, 201 p.

Emons, W., (2003) A note on the optimal punishment for repeat offenders, *International review of law and economics, 23,* p 253-259

European Commission (2004), Comparative study of road traffic rules and corresponding enforcement actions in the Member States of the European Union, Final report, Annex 2, http://europa.eu.int/comm/transport/road/publications/trafficrules/reports/annex_02/topic_tables/annex_2_topic_tables_05_11_speed_limits_en.pdf

Gebers, M.A. (1990), Traffic Conviction- and Accident-Record Facts, *California Department of Motor Vehicles*, Report No. 127, Sacramento, CA

Gebers, M.A; Peck, R.C. (2003), Using traffic conviction correlates to identify high accident-risk drivers, *Accident Analysis and Prevention*, Vol. 35, 903-912

Gunn et al. (1997), Value of Dutch Travel Time Savings in 1997, *8th WCTR Proceedings,* Vol. 3, p 513-526

Harrington, W. (1988), Enforcement leverage when penalties are restricted, *Journal of Public Economics,* 37, p. 29-53

Harford J.D.; Harrington, W. (1991), A reconsideration of enforcement leverage when penalties are restricted, *Journal of Public Economics,* 45, p. 391-395

Hubert, J.P., Toint, P.(2002), La mobilité quotidienne des Belges, *Presses Universitaires de Namur,* 352 p.

International Energy Agency, (2002), Energy prices & taxes, quarterly statistics, third quarter, France, 484 p.

Landsberger, M.; Meilijson, I (1982), Incentive generating state dependent penalty system, The case of income tax evasion, *Journal of Public Economics,* 19, p. 333-352

MEET project, (1998), Average Hot emission Factors for passenger cars and light duty trucks, Task 1.2/ Deliverable 7, LAT report No 9811, Aristotle University Thessaloniki, Thessaloniki 112 p.

Ministerie van Economische Zaken, Bestuur Energie, Afdeling Petroleum, (2001), Dagelijkse prijsberekeningen aardolieproducten, http://mineco.fgov.be/energy/energy prices nl 002.htm

Ministerie van Verkeer en Infrastructuur (2000), Verkeer en Vervoer in België: Statistiek, 29^{e} uitgave, Brussel, 123 p.

N.I.S. (2005), Het Mobiliteitsportaal – Verkeersongevallen en afgelegde afstanden, http://statbel.fgov.be/port/mob_nl.asp#A01
Polinsky, A.M.; Rubinfeld, D.L. (1991), A model of optimal fines for repeat offenders, *Journal of Public Economics,* 46, p. 291-306
Polinsky, A.; Shavell, S. (2000), The Economic Theory of Public Enforcement of Law, *Journal of Economic Literature,* Vol. 38, p 45-76.
Rietveld, P.; van Binsbergen, A.; Schoemaker, T.; Peeters, P. (1998), *Optimal Speed Limits for Various Types of Roads: A Social Cost-Benefit Analysis for the Netherlands,* Published in Roson, R. ; Small, K.A. (eds), Environment and Transport in Economic modelling, 2006-225
Schwab, N., Soguel, N., (1995), Le prix de la souffrance et du chagrin, une evaluation contingente appliqué aux accidents de la route, *Institut de recherches économique et regionales*, Neuchâtel, 165 p.
Stigler, G.J. (1970), The optimum enforcement of laws, *Journal of Political Economy*, 78, p. 526-536
Stradling, S.; Meadows, M.; Beatty, S. (2000), *Characteristics of Speeding, Violating and Thrill-seeking Drivers,* International Conference on Traffic and Transport Psychology, Bern, September 2000
Svensson, O. (1981), Are we all less risky and more skilful than our fellow drivers? *Acta Psychologica*, 47, 143-148
Winston, W.L. (1994), Operations Research: Applications and Algorithms, third edition, Duxbury Press, California, 1318 p.
www.wegcode.be

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.

ETE WORKING PAPER SERIES 2006

N°2006-01 Delhaye E. (2006), The Enforcement Of Speeding: Should Fines Be Higher For Repeated Offences?

ETE WORKING PAPER SERIES 2005

N°2005-10 Rousseau S., Billiet C. (2005), How to determine fining behaviour in court? Game theoretical and empirical analysis

N°2005-09 Dunkerley F., de Palma A. and Proost S. (2005), Asymmetric Duopoly in Space – what policies work?

N°2005-08 Rousseau S. (2005), The use of warnings when intended and measured emissions differ

N°2005-07 Proost S., Van der Loo S., de Palma A., Lindsey R. (2005), A cost-benefit analysis of tunnel investment and tolling alternatives in Antwerp

N°2005-06 de Palma A., Lindsey R. and Proost S. (2005), Research challenges in modelling urban road pricing: an overview

N°2005-05 Moons E., Rousseau S. (2005), Policy design and the optimal location of forests in Flanders

N°2005-04 Mayeres I., Proost S. (2005), Towards better transport pricing and taxation in Belgium

N°2005-03 Proost S., Sen A. (2005), URBAN Transport pricing reform with TWO levels of government

N°2005-02 Moons E., Saveyn B., Proost S., Hermy M. (2005), Optimal location of new forests in a suburban area

N°2005-01 Pepermans G., Willems B. (2005), The potential impact of cross-ownership in transmission: An application to the Belgian electricity market